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CHAPTER 13

The way ahead

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ABSTRACT

The purpose of this chapter is to attempt to make an assessment on what may lie ahead as regards sustainable shipping. The focus of the chapter is the April 2018 decision of the International Maritime Organization (2018) on the formulation of an Initial Strategy to reduce maritime green house gas (GHG) emissions. In that context, an assessment of the prospects for alternative fuels, which figure centrally in the Initial Strategy, is also included.

LIST OF ACRONYMS AND ABBREVIATIONS

AER	Annual Efficiency Ratio
BAU	Business As Usual
BIMCO	Baltic and International Maritime Council
BRI	Belt and Road Initiative
CBDR-RC	Common But Differentiated Responsibilities and Respective Capabilities
CH_4	Methane
CO_2	Carbon Dioxide
ECSA	European Community Shipowners Associations
EEDI	Energy Efficiency Design Index
EESH	Energy Efficiciency per Service Hour
EGR	Exhaust Gas Recirculation
EPA	Environmental Protection Agency (US)
ESPO	European Seaports Organisation
ETS	Emissions Trading System
EU	European Union
DCS	Data Collection System
FORS	Fuel Oil Reduction Strategy
GHG	Green House Gas
GWP	Global Warming Potential
HFO	Heavy Fuel Oil
IAPH	International Association of Ports and Harbors

IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
ICS	International Chamber of Shipping
ISPI	Individual Ship Performance Indicator
ITCP	Integrated Technical Cooperation Programme
kwh	kilowatt hour
LBSI	Lean Burn Spark Ignition
LDC	Least Developed Country
LNG	Liquefied Natural Gas
LPDF	Low Pressure Dual Fuel
MDO	Marine Diesel Oil
MEPC	Marine Environment Protection Committee
MGO	Marine Gas Oil
MBM	Market Based Measure
NG	Natural Gas
NH_3	Ammonia
NO_x	Nitrogen Oxide
NGO	Non Governmental Organization
OECD	Organisation for Economic Cooperation and Development
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
SEEMP	Ship Energy Efficiency Management Plan
SECA	Sulphur Emissions Control Area
SCR	Single Catalytic Reduction
SDG	Sustainable Development Goal
SO_x	Sulphur Oxide
SSS	Short Sea Shipping

1. Introduction

The purpose of this chapter is to attempt to make an assessment on what may lie ahead as regards sustainable shipping. As without any doubt the single most important recent event that may impact international shipping in the years ahead has been the April 2018 decision of the International Maritime Organization (IMO) at the 72nd session of the Marine Environment Protection Committee (MEPC 72) to adopt an Initial Strategy to reduce maritime green house gas (GHG) emissions (IMO, 2018), the exclusive focus of this chapter will be the above decision. This is said realizing that other aspects of sustainable shipping, for instance ship recycling, oil pollution, ballast water, logistical measures, sulphur, green ports, and others, are also important. However, we feel that the treatment of these subjects in the previous chapters of the book is adequate and nothing more on these subjects needs to be added in the book. By contrast, not much has been said thus far in this book on the April 2018 IMO/MEPC 72 decision, therefore we feel that some comments are definitely necessary to that effect.

The rest of this chapter is organized as follows. Section 2 highlights some of the main elements of the IMO/MEPC 72 decision. Section 3 discusses the issue of alternative (low carbon or zero carbon) fuels, very much central within the IMO Initial Strategy. Commentary on the way ahead is provided in Section 4. The IMO/MEPC 72 decision is presented in its entirety as an Appendix to the chapter.

The treatment of alternative fuels in this chapter rather than elsewhere in the book stems mainly from two reasons: (a) such fuels figure prominently within the IMO Initial Strategy, and (b) such fuels can conceivably represent the future in shipping, provided of course they will prove technically and economically viable. Our own assessment on this score is that, as things stand, the road ahead is a long one.

2. The April 2018 IMO decision

The IMO Initial Strategy to reduce maritime GHG emissions is in the form of *Resolution MEPC.304(72)*, and includes, among others, the following elements: (a) the vision, (b) the levels of ambition, (c) the guiding principles, (d) a list of short-term, medium-term and long term candidate measures with a timeline, and (e) miscellaneous other elements, such as follow up actions and others.

We briefly highlight some of these elements below.

2.1 Vision

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.

2.2 Levels of ambition

The Initial Strategy identifies levels of ambition for the international shipping sector noting that technological innovation and the global introduction of alternative fuels and/or energy sources for international shipping will be integral to achieve the overall ambition. Reviews should take into account updated emission estimates, emissions reduction options for international shipping, and the reports of the Intergovernmental Panel on Climate Change (IPCC). Levels of ambition directing the Initial Strategy are as follows:

1) ***carbon intensity of the ship to decline through implementation of further phases of the energy efficiency design index (EEDI) for new ships***

to review with the aim to strengthen the energy efficiency design requirements for ships with the percentage improvement for each phase to be determined for each ship type, as appropriate;

2) ***carbon intensity of international shipping to decline***

to reduce CO_2 emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008; and

3) GHG emissions from international shipping to peak and decline

to peak GHG emissions from international shipping as soon as possible and to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008 whilst pursuing efforts towards phasing them out as called for in the Vision as a point on a pathway of CO_2 emissions reduction consistent with the Paris Agreement temperature goals.

2.3 Guiding principles

The principles guiding the Initial Strategy include:

a) the need to be cognizant of the principles enshrined in instruments already developed, such as:

  - the principle of non-discrimination and the principle of no more favourable treatment, enshrined in MARPOL and other IMO conventions; and

  - the principle of common but differentiated responsibilities and respective capabilities, in the light of different national circumstances, enshrined in UNFCCC, its Kyoto Protocol and the Paris Agreement;

b) the requirement for all ships to give full and complete effect, regardless of flag, to implementing mandatory measures to ensure the effective implementation of this strategy;

c) the need to consider the impacts of measures on States, including developing countries, in particular, on LDCs and SIDS as noted by MEPC 68 (MEPC 68/21, paragraphs 4.18 to 4.19) and their specific emerging needs, as recognized in the Organization’s Strategic Plan (resolution A.1110(30));

and

d) the need for evidence-based decision-making balanced with the precautionary approach as set out in resolution MEPC.67(37).

2.4 List of candidate measures

2.4.1 Short-term measures (finalized and agreed by the Committee between 2018 and 2023)[1]

- further improvement of the existing energy efficiency framework with a focus on EEDI and SEEMP, taking into account the outcome of the review of EEDI

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[1] The Initial Strategy is subject to revision based on fuel oil consumption data collected during 2019-2021 and does not prejudge any specific further measures that may be implemented in Phase 3 of the three-step approach.

regulations;

- develop technical and operational energy efficiency measures for both new and existing ships, including consideration of indicators in line with the three-step approach that can be utilized to indicate and enhance the energy efficiency performance of shipping, e.g. Annual Efficiency Ratio (AER), Energy Efficiency per Service Hour (EESH), Individual Ship Performance Indicator (ISPI) and Fuel Oil Reduction Strategy (FORS);

- establishment of an Existing Fleet Improvement Programme;

- consider and analyse the use of speed optimization and speed reduction as a measure, taking into account safety issues, distance travelled, distortion of the market or trade and that such measure does not impact on shipping's capability to serve remote geographic areas;

- consider and analyse measures to address emissions of methane and further enhance measures to address emissions of Volatile Organic Compounds;

- encourage the development and update of national action plans to develop policies and strategies to address GHG emissions from international shipping in accordance with guidelines to be developed by the Organization, taking into account the need to avoid regional or unilateral measures;

- continue and enhance technical cooperation and capacity-building activities under the ITCP;

- consider and analyse measures to encourage port developments and activities globally to facilitate reduction of GHG emissions from shipping, including provision of ship and shoreside/onshore power supply from renewable sources, infrastructure to support supply of alternative low-carbon and zero-carbon fuels, and to further optimize the logistic chain and its planning, including ports;

- initiate research and development activities addressing marine propulsion, alternative low-carbon and zero-carbon fuels, and innovative technologies to further enhance the energy efficiency of ships and establish an International Maritime Research Board to coordinate and oversee these R&D efforts;

- incentives for first movers to develop and take up new technologies;

- develop robust lifecycle GHG/carbon intensity guidelines for all types of fuels, in order to prepare for an implementation programme for effective uptake of alternative low-carbon and zero-carbon fuels;

- actively promote the work of the Organization to the international community, in particular, to highlight that the Organization, since the 1990s, has developed and adopted technical and operational measures that have consistently provided a reduction of air emissions from ships, and that measures could support the Sustainable Development Goals, including SDG 13 on Climate Change; and

- undertake additional GHG emission studies and consider other studies to inform policy decisions, including the updating of Marginal Abatement Cost Curves and alternative low-carbon and zero-carbon fuels.

2.4.2 Medium-term measures (finalized and agreed by the Committee between 2023 and 2030)

- implementation programme for the effective uptake of alternative low-carbon and zero-carbon fuels, including update of national actions plans to specifically consider such fuels;

- operational energy efficiency measures for both new and existing ships including indicators in line with three-step approach that can be utilized to indicate and enhance the energy efficiency performance of ships;

- new/innovative emission reduction mechanism(s), possibly including
- Market-based Measures (MBMs), to incentivize GHG emission reduction;

- further continue and enhance technical cooperation and capacity-building activities such as under the ITCP; and

- development of a feedback mechanism to enable lessons learned on implementation of measures to be collated and shared through a possible information exchange on best practice.

2.4.3 Long-term measures (finalized and agreed by the Committee beyond 2030)

- pursue the development and provision of zero-carbon or fossil-free fuels to enable the shipping sector to assess and consider decarbonization in the second half of the century; and

- encourage and facilitate the general adoption of other possible new/innovative emission reduction mechanism(s).

2.5 Follow-up actions

These are listed in Table 1.

Table 1: Key stages for the adoption of a Revised IMO GHG Strategy in 2023 as set out in the Roadmap

Spring 2018 (MEPC 72)	Adoption of the Initial Strategy including, inter alia, a list of candidate short-, mid- and long-term further measures with possible timelines, to be revised as appropriate as additional information becomes available
January 2019	Start of Phase 1: Data collection (Ships to collect data)
Spring 2019	Initiation of Fourth IMO GHG Study using data from 2012-2018
Summer 2020	Data from 2019 to be reported to IMO
Autumn 2020 (MEPC 76)	Start of Phase 2: data analysis (no later than autumn 2020) Publication of Fourth IMO GHG Study for consideration by MEPC 76
Spring 2021 (MEPC 77)	Secretariat report summarizing the 2019 data pursuant to regulation 22A.10 Initiation of work on adjustments on Initial IMO Strategy, based on Data Collection System (DCS) data
Summer 2021	Data for 2020 to be reported to IMO
Spring 2022 (MEPC 78)	Phase 3: Decision step Secretariat report summarizing the 2020 data pursuant to regulation 22A.10
Summer 2022	Data for 2021 to be reported to IMO
Spring 2023 (MEPC 80)	Secretariat report summarizing the 2021 data pursuant to regulation 22A.10 Adoption of Revised IMO Strategy, including short-, mid- and long-term further measure(s), as required, with implementation schedules

We note again that this section is not encyclopaedic; the complete IMO/MEPC 72 decision is included as an Appendix to this chapter.

3. Alternative fuels: looking at the crystal ball

3.1 Preamble

It is very clear from the Initial Strategy that alternative (low-carbon and zero-carbon) fuels are centrally placed within the IMO decision document. Reference to such fuels is made in (a) the “level of ambition” section, (b) four instances in the set of short-term measures, (c) one instance in the set of medium-term measures, and (d) one instance in the set of long term measures. If anything, this reflects the fact that the development and eventual use of such fuels is a matter of high priority for the maritime industry, particularly if the targets set in the IMO Initial Strategy stand any reasonable chance to be reached. Put another way, if fossil fuels continue to be used in a "business as usual" (BAU) fashion, the chances of reaching the GHG reduction targets look slim. In that sense, it is reasonable to expect that low-carbon and zero-carbon fuels might provide the necessary "quantum leap" that might give the quest for decarbonization enough momentum to reach the stated targets. The obligatory question of course is whether the above expectation has a reasonable chance to be realized.

It is fair to say that the subject of alternative fuels is vast, with many studies and projects examining the subject from various twists and angles, and also with specific real-life demonstration projects whose purpose has been to test such fuels in actual ships under specific scenarios in terms of technical and economic viability. See for instance, among others, the work of DNV GL (2018) in the area. For recent surveys on the decarbonization possibilities of such fuels and other technologies and measures, see Bouman et al. (2017) and OECD (2018), among others.

It is also fair to say that, for all such work, and even though an upbeat picture is typically being painted by, among others, various players who have a stake (commercial or other) in such technologies, much uncertainty and divided opinion still prevails on the subject. As a result, the future of such fuels is very much uncertain. This section is an attempt to highlight some of the issues that exist in this area, with the hope that these issues eventually find a way to be addressed. This section is purposely brief, as an exhaustive analysis of various alternative fuels would require much more than one chapter in a book, or even a book by itself.

To that effect, this section will concentrate on the GHG effect of several proposed alternative fuels for marine use as well as on practical aspects of application. Most of these alternative fuels are alleged as being "clean burning". This may be true, in part, if one focuses on the emissions affecting human health (SO_x, NO_x and Particulate Matter-PM). However, a rather rosy picture has been painted for these fuels also as regards their GHG footprint, something that several recent studies are strongly challenging. It turns out the Lifecycle footprint of nearly all proposed alternative fuels is quite poor and, in most cases, worse than current conventional liquid fuels (Marine Gas Oil- MGO, Marine Diesel Oil- MDO, or de-sulphurized fuel oil). As such, their branding as "transitional" or "bridge" fuels towards decarbonization is seriously questioned.

In the following, a more extensive discussion is devoted to Natural Gas, since most of the other proposed alternative fuels are in many ways by-products of, or originate from, Natural Gas, something which may not be widely known. For a more detailed study, the reader may consult the references herein.

3.2 Natural Gas (NG) and Liquefied Natural Gas (LNG)

Natural Gas (NG) after extraction needs to be treated, through a fractionation process, to remove impurities (CO_2, water, sulphur, etc.), as well as propane and butane (those being 1-4 % of the extracted gas) which are used separately. The purified gas (pure methane and ethane) is then cooled in stages to -162 C where it becomes liquid (LNG).

During the cooling process excess nitrogen is also removed. The liquefaction reduces the volume of natural gas by a factor of 600, allowing it to be stored in insulated tanks or transported by ship or tanker trucks. LNG is regasified at the destination by heating and transported as gas via pipelines to consumers. When used as fuel of ships (other than LNG carrier ships) it is bunkered as liquid from tanker trucks or barges and stored as liquid onboard. Obviously, purification and liquefaction requires large amounts of energy. The CO_2 intensity of liquefaction alone is 0.2 – 0.4 kg CO_2 released for every kg LNG produced (Jaramillo et al., 2005).

NG is about 90% methane (CH_4) and LNG is about 95% CH_4. CH_4 is a GHG much worse than CO_2 in terms of effect on global warming. The Global Warming Potential (GWP) of CH_4 is not constant, but depends on the time horizon contemplated. Thus, for a time horizon of 5, 10, 20 and 100 years, CH_4 is respectively 116, 110, 86 and 34 times worse than CO_2 (Myhre et al (2013), Howarth (2014), Allen (2014)). It is clear that a time horizon of 100 years, being the lifetime of CO_2 in the atmosphere, is not very relevant in the climate change discussion, given the urgency of the situation. In that sense, more and more scientists are calling for the US Environmental Protection Agency (EPA), academia and regulators to stop using the (misleading) 100 year time horizon in GHG studies. In fact Myhre et al (2013) state that *"There is no scientific argument for selecting 100 years compared with other choices. The choice of time horizon is a value judgment because it depends on the relative weight assigned to effects at different times".*

The above is an important point because using the proper GWP factor of 86 (instead of 25) immediately reverses all claims of LNG having a better GHG footprint than conventional liquid fuels. We refer to the GHG effect when LNG/ CH_4 escapes unburned to the atmosphere.

Indeed, when NG or LNG is burned in a ship's engine, it produces about 20 – 25% less CO_2 than a conventional liquid fuel (HFO, MDO or MGO), due to its lower carbon content. However, this assumes perfect combustion, which exists only in chemistry text books. In real life a quantity of NG remains unburned and is emitted to the atmosphere together with the combustion exhausts. This escape, also known as methane slip, occurs in sufficient amounts in the vast majority of marine engines (4-stroke and 2-stroke dual fuel or Otto cycle -spark plug- engines). For all these engines, the methane slip -even according to the engine manufacturers' stated numbers- renders them immediately worse than conventional liquid fuel engines, even when a mild GWP factor of 25 is used (Corbett et al. (2015), EU (2016)). For some latest type high pressure combustion engines, methane slip is stated to be very small, but this refers more to the engine laboratory shop-test conditions and not necessarily to measured values in actual ship operation. In any case, multiplying even very small quantities of methane slip by 86, brings these state-of-the-art engines also at par to existing conventional ones, as is also discussed below.

The vast majority of gas engines on ships operate using the Otto cycle (as opposed to the Diesel cycle). Such engines have a published methane leak rate of 3–6 gr CH_4/kwh corresponding to a fuel loss of 2-3%. Actual measurements invariably show a larger fuel leak rate (e.g. 6-8 gr/kwh in optimal operation and much higher multiples at low loads) (Corbett et al., 2015). These are LPDF (Low Pressure Dual Fuel) engines with pilot fuel and Lean Burn Spark Ignition (LBSI) engines. SINTEF (2017) has measured the methane leak of these engines at 6.9 gr/ kwh and 4.1 gr/ kwh respectively with much higher valves reported throughout the literature especially for LBSI engines. At these methane slip levels, either published by engine makers or independently measured, the GHG footprint of combustion is quite higher than conventional marine diesel engines, even using a 100-year GWP of 25. When a GWP of 86 is used, the GHG performance of NG combustion in marine engines becomes substantially worse than diesel or heavy fuel combustion. Furthermore, there is a limiting trade-off in that, if the engines are operated at a lower air to fuel ratio to reduce methane slip, then NO_x emissions increase exceeding Tier III limits. Already, exhaust after–treatment options are being discussed among regulators, involving methane oxidation / capture devices at the stack.

The latest type newly introduced gas engines (High Pressure Dual Fuel- HPDF) are promoted as zero slip (0.2% of consumption) by their makers (e.g. the ME-GI DF engine by Man B&W) although independent references (Corbett et al., 2015) give 0.7 gr/kwh as more common (i.e. 0.4% of consumption). Although this is definitely a big improvement over the Otto cycle engines, we should remember that even just a 1 gr/kwh methane slip represents 86 gr/kwh of equivalent CO_2, and thus any GHG benefit over standard diesel engines is mostly lost. In addition, the NO_x reduction benefit of these engines is diminished, requiring a selective catalytic reactor (SCR) or exhaust gas recirculation (EGR) to comply with NO_x regulations.

The above discussion concerns only the LNG methane slip during combustion at the engine, which is only one of the areas of methane slip, perhaps the most minor one. Nevertheless we felt it had to be addressed in some detail since it is usually under-evaluated, especially when the (inappropriate) GWP of 25 is being used to assess the Greenhouse effect of natural gas. To the leaks at combustion we must add the methane leaks before the engine (pumps, piping), at the ship's LNG storage tanks (boil off) and during bunkering, which are found to be very substantial (Corbett et al., 2015). With regard to the size of LNG tanks needed onboard, these are 3-4 times larger than those of conventional liquid fuels (DNV GL, 2015), which may impact either the cargo carrying capacity or the cruising range of the ship. Equipping a ship for LNG use as fuel increases its new building cost by about 30%.

Lastly, with regard to LNG's Particulate Matter (PM) emissions, there have been concerns expressed that, although its combustion produces less PM than conventional fuels, it does produce ultra-fine PM which cannot be addressed (EU, 2016). Ultrafine particles penetrate the respiratory system and are transported to other parts of the body via the blood. They also may play a role in atmospheric processes, dictating the amount and lifetime of clouds, which can influence the climate.

Of course, for a fuel such as LNG, its *lifecycle* methane slip should be considered. That involves possible leaks during transportation to consumer and, most of all, leaks during its extraction from the ground, which all currently are either ignored or severely understated from a proper Global Warming assessment. These leaks invariably occur and they can be considerable.

The bulk of recent (post 2013) scientific literature indicates that LNG's lifecycle Global Warming effect is much worse than that of conventional liquid fuels (diesel, heavy fuel oil) and may even be worse than that of coal. Many experts agree that if methane slip from the whole LNG lifecycle (extraction to combustion) exceeds 3%, then LNG becomes worse than coal in terms of Global Warming effect. And, unfortunately, detailed and undisputed measurements in the US show an overall average escape to the atmosphere of 3.6 – 7.9% natural gas at the extraction fields (Utah basin as high as 11% and Los Angeles basin at 17%) (Howarth, 2014). Arguably the US shale gas extraction process results in more CH_4 escape than conventional gas fields, which are estimated at 4% leaks (Howarth, 2014). However, in other countries the leaks downstream (i.e. during liquefaction, transportation and pipe distribution) are recorded higher. It should be mentioned that gas producers claim that extraction leaks remain generally at 1-2%, a figure, however, that has been discredited time and again by researchers' actual measurements.

To the above measurements of average 5.8% USA extraction fields leaks (and 4% estimated worldwide), the leaks from the distribution pipes to consumers should be added, a pipe network that in most cities is aged. Although such estimates for Lifecycle NG methane leak vary greatly, a realistic figure seems to be 5-7% of the total NG production. Current NG production (2017) is about 3 billion tonnes (3,670 billion cubic meters) (BP, 2018). Even assuming just a 4% lifecycle leak, instead of 5-7%, multiplied by a GWP of 86 results in over 10 billion tonnes of CO_2 equivalent yearly, which is currently unaccounted for or largely underestimated. We remind that the total man-made CO_2, which we are trying desperately to reduce, is estimated at 36 billion tonnes per year, of which international shipping produces about 0.8 billion (IMO, 2014). Considering the above, LNG as ship fuel should be viewed only as a SO_x and also -for non High Pressure Dual Fuel Gas Injection (HPDF GI) type engines- a NO_x compliant fuel. Following from the above, its GHG footprint does not allow it to be considered either as a transitional or a short-term solution. It clearly is more disadvantageous in terms of GWP than conventional liquid fuels.

CH_4 currently contributes 40% of the heat trapping effect of all human-produced GHGs in the atmosphere (AES, 2018) as calculated by using the 100-year GWP. However, at the 20-year forward timescale, total global emissions of methane are equivalent to over 80% of global CO_2 emissions. Furthermore, while CO_2 in the atmosphere has increased by 35% in the last 300 years, methane has increased by more than 150% since 1750. (Oliver and Oliver, 2018). All this suggests that CH_4 represents a more serious problem for the planet than CO_2 and, instead of LNG being promoted as a transitional fuel, efforts should be exerted to at least contain CH_4 leaks to the atmosphere.

3.3 Liquefied Petroleum Gas (LPG)

Liquefied Petroleum Gas (LPG) is any mixture of propane and butane in liquid form. Propane and butane are the first light distillates during crude oil refining by an amount of about 4%. It is also contained in the NG fields in amounts of 1-5% and thus it is collected as a by product of NG extraction. LPG combustion results in no SO_x and about 15% less CO_2 than fuel oil. However its GWP is three to four times that of CO_2 when LPG-slip occurs (DNV, 2018). For two stroke marine engines, NO_x Tier III requirements are not met thus EGR or SCR equipment is needed. Liquid Propane (boiling point – 42C) and butane (boiling point 0 to -10C) are relatively easy to store and transport in pressurized or semi-refrigerated containers. Overall, however, its GHG reduction potential is modest while LPG's availability is limited to play a major role as shipping fuel, being practically a by-product of LNG extraction or oil refining.

3.4 Hydrogen

About 95% of the world's hydrogen production comes from reforming fossil fuels, mostly NG (Milne at al. (2006), Collodi (2010)). Obviously then the GHG issues described in the previous section on NG and LNG are also applicable to hydrogen, not including the CO_2 emissions in producing it from NG. The most common method to produce hydrogen is by steam CH_4 reforming whereby steam under high pressure, and in the presence of a catalyst, produces hydrogen and carbon monoxide and, with further "water-gas shift reaction", CO_2 and more hydrogen are produced. One tonne of hydrogen produced in this process releases 9 - 12 tonnes of CO_2 (Collodi, 2010).

Hydrogen when burned emits no CO_2, no SO_x and small amounts of NO_x. Thus, it is potentially a viable alternative fuel, provided the CO_2 intensity of its production could be addressed and provided that several technological and safety hurdles could be overcome. The CO_2 intensity of hydrogen production could be reduced by capturing and storing the released CO_2. Nevertheless, its origin, being mostly CH_4, results in the potent GHG effects related to methane's lifecycle (methane slip, etc). Clearly the carbon footprint of hydrogen produced from NG is higher than that of HFO or MDO (DNV GL, 2018).

An alternative way to produce hydrogen is from water electrolysis. Only about 4% of the world's hydrogen production uses that method. However, even this hydrogen cannot be considered as "green", since electrolysis requires large amounts of electricity which usually comes from the grid. Only if this electricity originates from renewable sources (solar, wind, hydro) or even nuclear, could the hydrogen produced be considered carbon-free. About 55 kwh are required to produce 1 kg of hydrogen at an assumed efficiency of more than 60% [2,3]. One kwh of electricity, when produced from a coal burning power plant, generates about one kg of CO_2 [4]. The US average is about 0.69 kg of CO_2 per kwh (DNV GL, 2015), while China and Russia produce most of their electricity from coal and most other countries from diesel oil. At an assumed worldwide average of 0.80 kg CO_2 per kwh, 55 kwh to produce 1 kg of hydrogen from electrolysis will emit 44 kg of CO_2.

As things stand, the technology required to enable use of hydrogen as a marine fuel is still under development. Hydrogen is not an easy fuel to handle, transport and store. The boiling point of liquid hydrogen is -253 C (DNV GL, 2018) thus super insulated (cryogenic) pressure vessels are needed for storage. Depending on the pressure, the size of the tanks needs to be 10-15 times larger than those of conventional liquid fuels (DNV GL, 2015). Also safety issues due to the volatility of hydrogen need to be resolved.

To sum up, and even though burning hydrogen would result in zero GHG emissions, as things stand a number of very serious issues need to be resolved in order to make it a viable zero carbon fuel.

3.5 Methanol

Today methanol is mostly produced from NG, in a process similar to the production of hydrogen (see section above). Thus the aforementioned GHG issues (methane slip of NG at extraction and transportation, etc.) are also applicable here, including the large carbon intensity of steam CH_4 reforming. Methanol is only employed as a transportation fuel on a significant basis for cars in China, where it is inexpensive by being produced cheaply from coal but with a highly negative GHG impact (IMO, 2016). Methanol is easier to handle than hydrogen, being liquid at atmospheric pressure, thus the renewed interest into its possibility as marine fuel. However it is toxic and has a low flash point of only 12 C and, as such, several safety barriers must be employed.

Although methanol produces negligible SO_x emissions, its NO_x emissions, although reduced, are not down to Tier III levels. However, the well-to-propeller GHG emissions of NG-derived methanol are higher than liquid fuels (HFO, MDO) (IMO, 2016) and a lot higher when the proper GWP of 86 (20-year time frame) is used. For methanol to offer any substantial GHG reductions, it has to be produced from biomass using renewable energy (wind/solar), something that for the time being is not realistic.

3.6 Ammonia

Ammonia (NH_3) is produced from hydrogen by adding nitrogen. Nitrogen is obtained from the air through liquid air distillation or an oxidative process where air is burnt and the

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[2] https://en.wikipedia.org/wiki/Hydrogen_economy (accessed Sep. 7, 2018)

[3] https://cleanenergypartnership.de/en/faq/hydrogen-production-and-storage/ (accessed Sep. 7, 2018)

[4] https://carbonpositivelife.com/co2-per-kwh-of-electricity/ (accessed Sep. 7, 2018)

residual nitrogen is recovered[5]. As such, in addition to the GHG effects of hydrogen and NG (being the primary source of hydrogen), the CO_2/GHG effects of nitrogen synthesis must be added to ammonia's lifetime GHG effects. The advantage of ammonia over hydrogen is that it can be stored as liquid in an easier temperature to maintain (-34 C) while, being a hydrogen carrier, its liquid form allows more hydrogen storage per cubic meter than liquid hydrogen itself (OECD, 2018). Ammonia used as fuel could offer GHG reductions to the extent that it is processed using renewable energy and is sourced from hydrogen made from electrolysis using renewable sources.

3.7 Biofuels (Ethanol, Bio-Diesel, etc.)

Biofuels are fuels produced from organic material such as biomass, plants, animal waste, etc. Although they may offer a good potential for reducing CO_2, they have several downsides. One is the requirement for large agricultural land potentially resulting in food supply reduction, deforestation and other environmental damage (OECD, 2018). One important aspect of this damage is the associated loss of plant and forest carbon sinks, as well as cost increases in food. These aspects have prompted the California legislature to stop considering corn ethanol as carbon neutral and start the process of repeal of incentives for the production of corn ethanol (May 2018). Depending on the assumptions and data used, studies vary widely on the effectiveness of biofuels to reduce GHG and it is not clear whether the energy used in the day to day farming practices, production and application of fertilizer, pesticides and herbicides, and the production of bio-fuels offsets their GHG combustion benefits. In addition, concerns of air quality exist as the combustion of biofuels produces toxic and carcinogenic chemicals such as formaldehyde and acetaldehyde (Rio de Janeiro, where cars running on ethanol are common, has 160% more formaldehyde and 260% more acetaldehyde in the air than Tokyo or other cities where ethanol fuels are not used[6]). For marine use, caution should be exercised since some biofuels have a tendency to oxidize and degrade, due to bacteria development when stored over a few months. The current biofuel supply is limited and could only cover about 15% of the total fuel demand (OECD, 2018). Attempts to produce biofuels from engineered "crops" such as algae, have so far proved unsustainable, while any production of large-scale biofuels (e.g bio-LNG or ethane from agricultural and animal waste) is not considered realistic for the near to medium term future.

3.8 Fuel Cells

As also mentioned in Chapter 2, fuel cells convert the chemical energy of compounds, through electrochemical oxidation, to electric power, without combustion involved, releasing thermal energy in the process. The most usual fuel used is hydrogen, the exhaust being water. LNG, methanol and ammonia could also be used. There are several different fuel cell technologies available but none is mature enough to be used for main

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[5] https://ghgprotocol.org/sites/default/files/Calculating%20CO2%20Emissions%20from%20Ammonia%20Production_0.pdf Accessed Sep. 7, 2018.

[6] http://theearthproject.com/biofuel/ Accessed Sep. 25, 2018.

propulsion units of typical ships. This is due mainly to their limited lifetime and the large size required for both the fuel cells and the fuel tanks. Their GHG reduction potential is directly related to whether the fuel used was produced using renewable energy sources.

3.9 Conclusions on alternative fuels

For all the emphasis put by the IMO Initial Strategy on alternative fuels, it is clear that an essential step to assess if these fuels can deliver meaningful GHG reductions is the consideration of the environmental life cycle impacts of each proposed alternative fuel, and not just its combustion emissions. It is also essential to ensure that wider implications of fuel switches are properly accounted for. Failure to take up-stream emissions into account risks locking-in the sector to carbon intensive solutions. As regards bio-fuels, their impact associated with cultivation, land-use change and fertilizer use must also be assessed (Gilbert et al., 2018). Many studies underestimate the true up-stream and combustion GHG effects of most alternative fuels by, among others, ignoring real measured data on methane slip or using 100-year GWP factors. Obviously, there are no easy solutions toward GHG mitigation of marine fuels and it would be unfortunate if regulators, in their urge to act, promote fuels with worse lifetime GHG effects than current conventional fuels.

To these authors, this leads to the conclusion that to drastically reduce GHG emissions we need new technologies that would provide the necessary “quantum leap” vis-à-vis BAU. These can be better batteries, synthetic fuels, synthetic bio-fuels, or others. Until and unless these technologies become technically and economically viable, and as things stand, current conventional liquid fuels have –sometimes by far- the smallest GHG footprint of all the above alternative fuels.

4. Looking at the crystal ball cont’d

The reception of the April 2018 IMO/MEPC 72 decision was almost universally laudatory. Industry associations including the International Chamber of Shipping (ICS), the Baltic and International Maritime Council (BIMCO), the European Community Shipowners Associations (ECSA), the International Association of Ports and Harbors (IAPH), the European Seaports Organisation (ESPO), but also the European Commission, the Organisation of Economic Cooperation and Development (OECD), and several non governmental organizations (NGOs), hailed the result as an important first step towards the eventual full decarbonization of shipping. There were very few expressions of dissatisfaction. For instance, the United States, which has backed out of the Paris Agreement anyway, did not vote for the Resolution. So did Saudi Arabia. Some environmental NGOs expressed disappointment with the result, and so did some members of the European Parliament.

Realizing that we are currently at a crossroads and the track that will be followed from now on is subject to many uncertainties, below we make a cursory and non-encyclopaedic attempt to comment on some additional issues that we think are important as international shipping moves towards 2050. In these comments, we make clear that we only express our sincere and honest personal opinion, and we make no attempt to sound or appear politically correct.

1. Seven years after the adoption of the Energy Efficiency Design Index (EEDI), which is still (together with the Ship Energy Efficiency Management Plan- SEEMP) the only mandatory GHG emissions reduction measure, there is no doubt that the April 2018 IMO/MEPC 72 decision was a landmark decision. Achieving GHG emissions in 2050 which are at least 50% lower than they were in 2008 is a substantial and ambitious target that has to be taken very seriously by all involved.
2. We profess ignorance on whether or not the above target is compatible with the goals of the Paris Agreement. Climate experts are more competent to comment on this point. However, we think that this issue is probably of lesser importance as compared to some of the other issues that are raised below.
3. Any hope that substantial GHG reductions can be achieved by improvements on EEDI is in our opinion grossly unsubstantiated. Aside from the considerations of Chapter 3 of this book, in a recent study conducted for Danish Shipping, Smith et al. (2016) showed, among other things, that the existence of EEDI vs a scenario in which there is no EEDI as we move to 2050 amounts to a GHG emissions difference of about 3%.
4. The two stated principles that are centrally included in the Initial Strategy (a) non-discrimination/no more favorable treatment and (b) Common But Differentiated Responsibilities and Respective Capabilities (CBDR-RC) are in direct conflict with one another. The latter principle was included so as to please the group of developing countries (mainly Brazil, Saudi Arabia, India, and others) who stood and continue to stand firmly behind CBDR-RC. In our opinion however, if there is a *single major obstacle* for any progress on maritime GHG emissions reduction, it is definitely CBDR-RC, and one will need to find a way to circumvent or even eliminate this principle altogether if any serious progress is to be made. We obviously realize that doing so may not be politically correct, and the risk is that the issue may destabilize an already rather very delicate process.
5. There is no sense of priority among the wide array of candidate measures, all of which are on the table. Market Based Measures (MBMs) have been put into the medium-term class (to be agreed upon between 2023 and 2030) *but only as a possibility*, even though the Damocles sword of an European Union (EU) Emissions Trading System (ETS) is looming. There appears to be no sense of urgency for any MBM, not even for reopening the MBM discussion. Some industry circles seem to favor a bunker levy, but no one dares propose it at this point in time.
6. Related to this, it is unclear at this time what the EU will do. As stated in Chapter 11, the European Parliament decided in November 2017 to align itself with the IMO process on GHGs but that the European Commission will monitor the IMO process very closely. Depending on the pace of the IMO process, and in particular if that pace is not deemed satisfactory, one could not rule out a scenario that the EU unilaterally moves on early, so as to include shipping within the EU ETS, or at least

do this conditionally. Already the European Commission (DG-CLIMA) has issued a tender for a study to investigate possible global regulatory measures to reduce GHGs from ships, focusing on two sets of measures: (a) clean fuels and (b) MBMs. The study is expected to be concluded in the second half of 2019.

7. In the event that shipping is included in the EU ETS, which in our opinion would be unfortunate as it would create distortions, it would be interesting to see what the IMO would do. A plausible (in our opinion) scenario is for the IMO to reopen the MBM discussion soon, at least so as to preempt EU action on ETS. But the political will to do so seems at this point invisible.
8. There is no clear link between any of the targets and the respective measures. The question is, for any of the reduction targets that were chosen, how can one be reasonably confident that these targets can be met by the measures proposed? (and which measures)
9. That GHG emissions are to reach a peak as soon as possible is a laudable goal, but raises the obligatory question, how soon. According to the third IMO GHG study (IMO, 2014), in 2008, the baseline year as far as comparison to target values is concerned, CO_2 emissions of international shipping were estimated at 920.9 million tonnes, and declined to 795.9 million tonnes in 2012, even though they reached 849.5 million tonnes in 2011. As of yet, and pending the fourth IMO GHG study (which will be commissioned in 2019 and finalized in 2020) there is no consensus on GHG emissions figures after 2012. And even the above figures are based on the "bottom up" (activity based) method, whereas emissions figures based on the "top down" (fuel sales based) method are significantly lower (624.9 million tonnes in 2008 versus 648.9 million tonnes in 2011- there was no top down estimate for 2012). There should certainly be consensus on which method is used ("bottom up" numbers are 30% to 50% higher than "top down"), plus consensus on when the GHG peak is expected to occur. Barring any major world trade slowdown, it seems self-evident that for any GHG peak to be reached, some measures will have to be implemented- no peak will happen by itself.
10. The same is true as regards consensus on how "transport work" figures are defined. These are important so as to check the target of at least 40% GHG emissions per transport work reduction in 2030 versus 2008 levels (and at least 70% by 2050).
11. (Mandatory) "speed reduction" (or, speed limits) is included as a potential short term measure, even though the term "speed optimization" was added so as to make the measure more palatable to Chile and Peru, who are concerned about carrying cherries to China (as per Chapter 10). Speed limits may seem at first glance like a reasonable measure, however they are plagued by various deficiencies and would create distortions and other problems (see again Chapter 10). Still, it is a victory for the speed limit lobbyists (Clean Shipping Coalition and others) that this measure is now on the table at the IMO, only a few years after the IMO previously rejected it (at MEPC 61 in 2010). We note that this measure is also being considered by the European Commission, among other possible measures to reduce maritime GHG emissions.

Lack of prioritization among measures being an observation, and in the quest to meet the 2030 and 2050 targets, is there any measure that should receive priority? In our opinion there is.

As also mentioned in Chapter 11, and irrespective of the fact that MBMs are not up for discussion at the IMO in the foreseeable future, one idea that might be worth considering would be to impose a *significant* bunker levy at a global level. By significant we mean not 10 or 20 USD per tonne, as is being occasionally contemplated by industry, but *at least one order of magnitude higher*.

To put it very simply, if society truly does not like fossil fuels, or any other fuel that produces GHGs (and this includes LNG), and cannot, for obvious reasons, mandate their outright ban, society should at least try to implement the *"polluter pays"* principle by internalizing (even partially) the external costs of GHGs. The only way to do so is by putting a significant price on the fuels that produce these GHGs. Conversely, and so long as these fuels are affordable, there is no doubt that they will be used. All the debate on LNG, hydrogen, and other alternative fuels (see Section 3 above) critically hinges upon the economic dimension: we would like to know not only how much GHGs these alternative fuels would avert, but also what is the cost of producing and using them. Conversely, and barring a technological quantum leap, for as long as these alternative fuels are not viable economically, they will not be used.

An important parenthesis here is that, and in order to avoid modal shifts to land-based modes, such a levy should not be confined to the maritime mode, and care should be taken to prevent modal shifts which could increase overall GHG levels. This is particularly true not only for short sea shipping (SSS) scenarios but also for longer distance deep sea services, especially now that the Belt and Road Initiative (BRI) is being pursued by China so as to link Asia and Europe.

As mentioned in Chapter 11, a substantial bunker levy would induce technological changes in the long run and logistical measures (such as slow steaming) in the short run. In the long run it would lead to changes in the global fleet towards vessels and technologies that are more energy efficient, more economically viable and less dependent on fossil fuels than those today. A levy would also raise monies that could be used for "out-of-sector" GHG emissions reductions, aid to Least Developed Countries (LDCs) and Small Island Developing States (SIDS), and other purposes.

However, and for the reasons stated earlier (see again Chapter 11), we realize that the prospects of such a development are, as things stand, very slim. This is so mainly for political reasons. Aside from the fact that proposing such a measure would not sound politically correct, a frequent argument that is made in that regard is that there is no need for an MBM since fuel prices are expected to increase anyway in 2020 due to the global 0.50% sulphur cap. Advocates of such argument say that this fuel price increase would be tantamount to a global MBM, therefore there is no need to institute MBMs on their own right.

We respectfully consider such an argument as a poor excuse for not taking action on MBMs. First of all, the extent of the anticipated fuel price increase is largely unknown, and it is reminded that contrary to the “gloom and doom” predictions before the imposition of the 0.10% sulphur limit in European Sulphur Emission Control Areas (SECAs) in 2015, fuel prices actually dropped. Second, some ships will opt to install scrubbers and thus still burn the cheaper high-sulphur fuel. Third, and even if fuel prices go up in 2020 (as is a likely scenario), this would be no way to implement the “polluter pays” principle and internalize the external costs of GHGs. Society would get no benefits, and no monies would be collected for LDCs, SIDS or out-of-sector GHG emissions reductions. In that sense, we think that the 2020 sulphur cap will hardly institute an MBM.

In a recent paper that was published a few months *before* the April 2018 IMO decision (Psaraftis, 2018), the following statement was made: *“.. in spite of much talk about the maritime industry’s commitment toward serious GHG emissions reductions, it is fair to say that such reductions are, as things stand, only a wish at this point in time.”* Based on what we have seen since then, including IMO/MEPC 72, we see no significant reason to retract the above statement. It is true that the April 2018 IMO decision has opened a new door and maybe created some momentum. However, substance-wise and in order to guarantee significant GHG emissions reductions in the future, one would have to abandon the BAU stance that still seems to pervade much of what is done in the maritime industry today and not be afraid to take bolder steps, even if these entail some political cost.

Of course, it can be argued that in the quest for a substantial decarbonization of the shipping industry, an unfair burden has been placed on the shoulders of the ship owner. The potential unfairness stems from the argument that if ship designers, shipbuilders, engine manufacturers, fuel producers and other technology developers somehow fail to produce the set of technologies that would make the 2050 50% target feasible and viable, why should ship owners be held responsible for the failure? Ship owners of course have a substantial role to play by choosing appropriate ships to meet their need, or even influencing their design. However, their role is limited by what is available in the market. At the same time, ship owners do have a substantial role in the maritime regulatory process (IMO, EU, and other), and the aim is for that process, among other things, to provide technology developers a workable framework and substantial incentives to produce viable decarbonization technologies.

We note here that this situation is completely different from the automotive industry setting, where the main responsibility for emissions reduction is placed on the *vehicle manufacturer*, who actually has to meet emissions requirements *on a fleet level basis* and based *on a variable speed profile*. Why something similar is not done with the shipping industry and instead the ship owner is the main player responsible for emissions reduction at an individual ship level, is, in our opinion, intriguing. A governance model that is closer to what the automotive industry is doing may be, in our opinion, worth looking at. But doing this would surely necessitate some radical changes and could not happen overnight.

In Psaraftis (2018) it was also argued that *"..as things stand, the international scene for the decarbonization of maritime transport has been rendered way too complex and fragmented, as well as political. Unnecessary complexity and fragmentation, coupled with factors that are mostly within the political sphere, will not help a speedy resolution of the issue. In fact they will definitely hinder prospects for substantial progress in the years ahead. Conversely, a necessary condition for substantial progress on the GHG front is the removal, or at least alleviation, of such political obstacles."*

We see no reason to retract this last statement either. However, we sincerely hope that things move in the right direction and the international shipping community finds a credible way to remove the above obstacles.

We also hope that the contents of this book may be of some help towards the above goal.

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APPENDIX

RESOLUTION MEPC.304(72) (adopted on 13 April 2018)

INITIAL IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS