FINANCING

DECARBONISING THE GLOBAL MARITIME TRANSPORT SECTOR

OCTOBER 2021

MUFG Bank Ltd
A member of MUFG, a global financial group

Contents

Introduction

Decarbonising the global economy is an urgent priority if the world is to avoid the worst impacts of climate change. Global maritime shipping, referred to as "Shipping" hereafter, is a material contributor to carbon emissions and is responsible for around 3% of global CO2 emissions[1]. Should insufficient action be taken then Shipping's share of emissions could increase to 17% as emissions from other sectors decline[2].

Shipping is the cornerstone of international trade, being the primary means by which physical goods are transported over long distances. Shipping accounts for around 70% and 80% of global freight transport activity by value and volume[3] respectively and is the least energy-intensive method to carry heavy goods over long distances, being around five times more energy efficient than road freight. However, Shipping today relies almost entirely upon carbon intensive oil-based fuels (heavy fuel oil and marine diesel) burned in diesel engines. With global trade set to rise in the coming decades, the Shipping sector faces growing pressure to address its carbon footprint.

In 2018 the International Maritime Organization ("IMO"), the United Nations body responsible for global regulation of the sector, set a target to reduce emissions by 50% by 2050 from 2008 levels ("IMO Target"). Since then numerous governmental, inter-governmental and supranational institutions have echoed their support. For an

1 IMO, 2020

2 IMO, 2020

3 UNCTAD, 2018

industry that has often been accused of being too slow to act, prompt and decisive action must be taken lest regulators step in and apply more stringent targets and penalties in an increasingly climate focused world.

This poses a real challenge for an industry which is notoriously difficult to decarbonise. Given the distances often involved, Shipping requires large quantities of energy dense fuel and existing alternatives to oil-based fuels, other than Liquefied Natural Gas ("LNG"), are either not available at scale and / or are very costly. Compounding the issue is a "chicken and egg" conundrum - the decarbonisation of Shipping depends on the availability of zero and net-zero fuels (together referred to as "Carbon Free Fuels" hereafter) yet their associated land-based production facilities are unlikely to scale up without reliable and large sources of demand. Herein lies the challenge and the opportunity. On the one hand, with no visibility on which Carbon Free Fuels will develop quickly and economically combined with the capital intensity of ordering new-build vessels, one can perhaps understand why many vessel owners are currently sitting on the fence. On the other hand, shipping has a generational opportunity to act as a key enabler for the land-based Carbon Free Fuels facilities to develop.

Challenges acknowledged, we believe there are a number of promising pathways towards decarbonising the sector to 2050 and beyond:

- In the short term, there is potential for reducing fuel consumption with energy efficiency measures, optimisation of supply chains and slow steaming. LNG will also play a role in the short to medium term, although views vary on whether LNG will play a "transitional", "temporary" or "limited" role in the decarbonisation of the sector.

- Yet the above measures will be far from sufficient to achieve the IMO Target by 2050. So in the medium to longer term, significant emissions reductions will need to be achieved by switching to zero-carbon fuels such as green ammonia and hydrogen. Bio-fuels, sometimes labelled as "net zero" fuel, could also play a role in offering a pathway to further decarbonising LNG-fuelled vessels.

This paper seeks to outline both the challenges and the opportunities that the decarbonisation of the sector presents. To start with we set the scene by considering where Shipping's emissions are as of today and where they need to reduce to in order to achieve IMO Target and ideally exceed it. We then consider regulatory measures and developments in terms of vessel efficiency as well as some of the technical challenges around moving to propulsion systems which use Carbon Free Fuels. The core of the paper then considers the role that LNG could play alongside Carbon Free Fuels to 2050 and beyond in this transition. Finally, we explore a number of other factors which could facilitate the transition, such as market-based incentives and financing considerations, before concluding with some key-takeaways.

Decarbonising the Global Transport Maritime Sector

1. Emissions from the Shipping Sector and the IMO Target

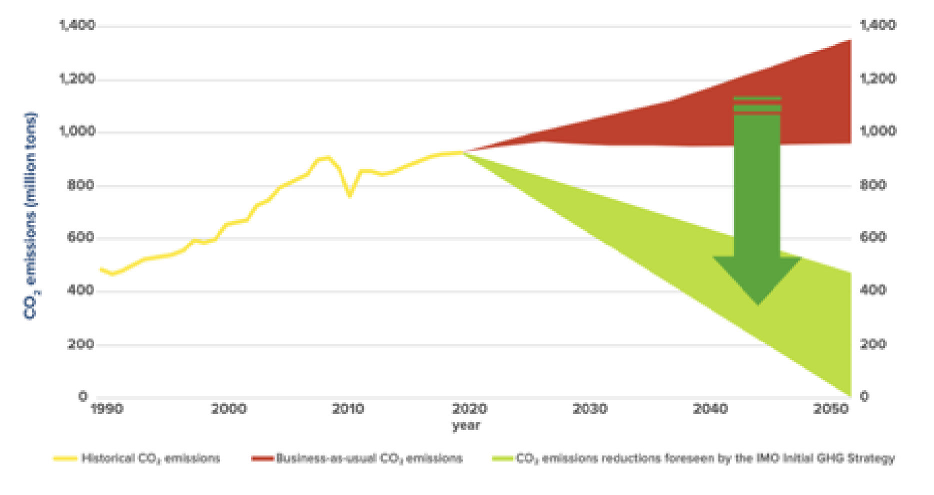
1.1 Emissions from the Shipping Sector

At the outset, it is worth considering why Shipping's greenhouse gas ("GHG") emissions are under the spotlight:

Shipping is responsible for ca. 3% of CO_2 emissions today: Shipping is a key facilitator of trade and economic development carrying around 70% and 80% of global trade by value and volume respectively. Today it is responsible for ca. 3% CO2 emissions (1 billion tonnes equivalent) but what is often missed is that Shipping also emits around 15% of some of the world's other major pollutant GHGs (i.e. SOx and NOx and particulates) annually. These stem from the burning of heavy fuel oil which means that, according to some press assertions just 15 of the biggest vessels emit more SOx and NOx than all the world's cars put together[4]. Whilst instinctively such estimates appear to be on the high side, we cannot dispute that Shipping emits a disproportionally large share of such pollutants. NOx in particular is a very potent GHG and has a Global Warming Potential ("GWP") of almost 300 times that of CO2[5].

Emissions from the sector are set to rise materially without prompt attention: GHG emissions from Shipping are on an upwards trajectory. Between 2013-2018, the sector's total GHG emissions increased by ca. 10%[6]. According to a range of plausible long-term economic and energy business-as-usual scenarios, the IMO in its fourth GHG report considers that emissions could represent 90-130% of 2008 emissions by 2050[7]. Other forecasts are considerably more pessimistic and under some scenarios Shipping emissions could almost treble from 2018 levels[8].

Historical and projected CO2 emissions from international shipping



Source: IMO (2020)

Maritime vessels are almost entirely dependent on fossil fuels: Shipping's need for autonomy requires a large amount of energy dense fuel to be carried on board. Currently the dominant shipping or "bunker" fuel is fuel oil, comprising Heavy Fuel Oil ("HFO") which accounts for the large majority of fuel oil usage as well as Low Sulphur Fuel Oil. HFO is a high-carbon, high-sulphur residual fuel which is highly viscous until heated. HFO currently accounts for around 80% of the sector's fuel mix. The remaining 20% of the sector's energy mix is composed of other fossil fuels, such as marine diesel oil and lower carbon LNG [9]. So far, the share of Carbon Free Fuels is negligible.

4 Economist, 2017

5 EPA website. CO2 has a GWP of 1 by definition. NOx has a GWP of 265-298 over a 100-year time-scale, so 1KG of NOx = > 265KG of CO2

6 IMO, 2020

7 IMO, 2020

8 European Parliament, 2015

9 Lloyds Register and UMAS, 2017

Technological improvements and lower emission fossil fuels, such as LNG, have a role to play but they are not enough on their own to achieve the IMO Target: There are a lot of ways of boosting the carbon efficiency of new-build ships by optimising fuel consumption via various energy efficiency measures or opting for lower carbon fuels such as LNG or LPG. Nevertheless, one thing that has been pointed out throughout numerous studies on decarbonisation is that the technological solutions - even if combined with lower emitting fossil fuels such as LNG - will on their own not be sufficient to achieve the IMO Target.

Therefore the development of Carbon Free Fuels will also be required if the IMO Target is to be met.

1.2 The IMO Target - a 50% GHG emissions reduction by 2050 from 2008 levels

IMO commitment to achieve at least a 50% reduction in GHG emissions from 2008 levels by 2050: In April 2018, the IMO set out their commitment to reduce GHG emissions from international shipping and to phase them out as soon as possible in this century. Their "Initial Strategy" envisaged for the first time a reduction in total GHG emissions from international shipping and identified three levels of ambition:

- Carbon intensity of vessels to decline through implementation of further phases of the energy efficiency design index ("EEDI") for new ships;
- Carbon intensity of international shipping to decline via reducing CO2 emissions as an average across international shipping by at least 40% by 2030 whilst pursuing efforts towards 70% by 2050 from a 2008 base-line; and
- GHG emissions from international shipping to decline by at least 50% by 2050 from a 2008 base-line whilst pursuing efforts towards phasing them out entirely within this century.

A clarion call to the industry: The IMO's Initial Strategy envisaged for the first time a reduction in total GHG emissions from international shipping and has acted as a clarion call to the industry. Many other institutions have since confirmed their commitment to the IMO Initial Strategy.

2 Technological Developments

2.1 Energy Efficiency Regulation and Efficiency Measures

Key Regulatory policies: There are numerous international regulatory policies covering air pollution and GHG emissions which act to incentivise the efficiency technologies under development. Besides the IMO Target, the main policy at present to foster improvements in energy efficiency in the maritime sector is the EEDI (2013, IMO regulated) which requires energy efficiency improvements in new vessels as cross referenced in the IMO Target. Many others, such as the Ship Energy Efficiency Management Plan (2016, IMO regulated) then monitor and submits data to enhance ships to improve operational efficiency, thereby complementing the EEDI.

Broadly speaking, energy efficiency measures for shipping can be divided in two categories:

Technical measures: these reduce the power requirement of the propulsion system by improving fuel efficiency. Leading technical measures to improve energy efficiency include:

- Waste heat recovery which consists of reusing the heat dissipated by the engine with savings in the range of 5-10% of fuel;
- Hull coating and air lubrication systems which are technologies that improve the vessel's aerodynamics to limit drag and thus the power requirement, achieving fuel savings ranging between 3-12%; and
- Flettner rotors, sails and kites which exploit aerodynamics or wind assist to gain propulsion, reducing fuel consumption by between 5-20%[10].

10 DNV, 2019

These technical measures are mainly suitable for new vessels as retrofitting is usually uneconomic or not possible. A further tightening of the EEDI targets (which is currently being discussed by the IMO) could promote more R&D on these technologies.

Operational measures: These reduce fuel consumption via improved operation and maintenance of the vessel. Operational measures can be implemented both by existing and new vessels and do not require significant investment in additional equipment. One often cited example is slow steaming, which consists of reducing the vessel's speed and as a consequence its specific fuel consumption. A 10% reduction in speed will typically save around 30% fuel consumption and when considering the longer vessel journey, the total fuel saving is typically around 20%. A larger decrease in speed may yield total fuel savings of up to 50%[11]. However, arguably slow steaming will only be economic and / or implemented when there is surplus shipping capacity.

2.2 Carbon Free Fuels propulsion systems

From a technical standpoint, progress on developing ammonia, methanol and hydrogen propulsion systems for new-build ships is not expected to be an insuperable impediment. In summary:

- For ammonia, methanol and biofuels the basic engine structure remains more or less the same compared to conventional diesel, LNG and LPG engines. The bedplate, crankshaft, cylinders and pistons remain more or less unchanged with different fuel delivery and safety systems add-ons. As such the current Wartsila and MAN Energy Solutions' ("MAN") engines operating on LNG vessels today are just modifications of existing diesel engines. Generally speaking engine manufacturers' experiments with new fuels are based on their existing engines developed for diesel fuel.

- For hydrogen the propulsion will probably be via fuel cells and electric motor as per existing cars (Honda, Toyota and Hyundai). Clearly there is a significant scaling element to address and there will need to be large banks of fuel cells.

- A major challenge for maritime vessels using these new fuels is going to be around the fuel storage and handling systems, the space these new fuel systems will require, as well as the safety of those systems. Hydrogen will have to be stored in liquid form at -253^{C} and once re-gasified, hydrogen is prone to leakage. Ammonia is notoriously toxic.

Marine engineering firms are already rising to the technical challenges: It is not the intention to understate the challenge of building ammonia and hydrogen fuelled marine propulsion systems. First of a kind technology risks will inevitably need to be addressed comprehensively. Indeed, the offshore marine engine technologies are not proven, arguably much less so than the component technologies for producing hydrogen and ammonia onshore which are already well understood. Nevertheless, the demand is clearly there, and engine manufacturers are currently rising to the challenge of developing Carbon Free Fuels marine propulsion systems. To reference just a few recent developments:

- Wartsila expects to have a diesel engine running on an ammonia blend in 2021 and anticipates having an engine concept with pure ammonia fuel in 2023. It is also focused on developing diesel engines that will be capable of transitioning to future fuels, including methanol and ammonia.

- MAN is working towards developing an ammonia-powered engine by 2024. It is looking to produce multi-fuel engines that can run on various biofuel and conventional fuels, including LNG. With minor modifications, the intention is that they will be able to transition to use any type of Carbon Free Fuels, including green ammonia. However, experience to date in converting so-called "LNG-ready" ships to burn LNG is far from encouraging, incurring massive costs.

- Kawasaki Heavy Industries, Yanmar Power Technology and Japan Engine have formed a consortium to develop hydrogen-fuelled engines for large commercial vessels capable of operating on international routes by 2025.

An observation on retrofitting: Retrofitting engines on existing vessels is worth touching upon as this is frequently discussed in the press. Whilst future developments of engines to operate on ammonia or methanol, for example,

11 Global Maritime Energy Efficiency Partnerships, 2019 will also be modifications of existing engine designs, it is difficult to assess how easy or commercially viable it may be to modify existing in-service engines to new fuels. In addition to the engine cost, a major element is the fuel storage and handling system. Ammonia is regularly carried in LPG type ships and any ships with LNG tanks could store ammonia but not hydrogen. New fuels could also require a complete re-design of the engine room ventilation system. After the initial (limited) number of "LNG ready" ships that were given much publicity a few years ago, it is not clear whether this route is being pursued further. Therefore, as with the significant large ships now operating on LNG, it seems likely that most Carbon-Free Fuels will be used by new-builds, not conversions.

The choice of propulsion technology is really dominated by onshore Clean Fuel production considerations: In the past, if a new-build met relevant industry criteria when constructed, the expectation was that the vessel would be "grand-fathered" for its useful economic life. Right now, the political environment and lack of clarity on which Carbon Free Fuels will develop most rapidly and economically makes this harder to assess. Ordering a vessel running on conventional fossil fuels means they face a risk of obsolescence or backing the "wrong" Carbon Free Fuel. As such we expect much focus on developing engines for Carbon Free Fuels that are dual-fuel or multi-fuel.

3 LNG's Role as a Transition Fuel for Shipping

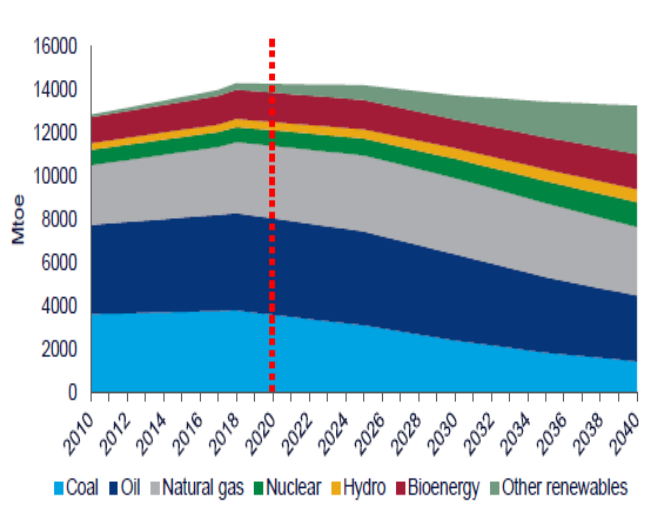
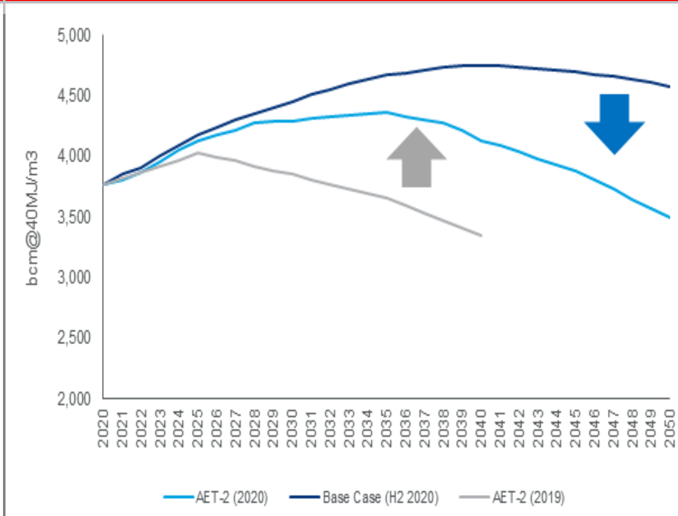
3.1 The Role of Natural Gas in the Energy Transition

The IEA Sustainable Development Scenario: Whilst there are a wide range of "Energy Transition" scenarios with different global warming outcomes, there has been some coalescence around the use of the IEA Sustainable Development Scenario ("SDS") as a consistent benchmark against which company and country performance can be measured. The SDS is fully aligned with the Paris Agreement's objective of "holding the increase in the global average temperature to well below 2^{C} above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5^{C} above pre-industrial levels". In summary:

- This SDS is highly ambitious and requires a reduction of carbon emissions by over 70% in the next 30 years using a combination of:
    - i. Decreasing burn of fossil fuels;
    - ii. Increasing energy efficiency; and
    - iii. Removal of CO2 from the system (e.g. carbon sinks, Carbon Capture and Storage ("CCS"), etc.)
- The IEA SDS will require some very significant developments for the re-balancing of the energy market, including:
    - i. The rapid growth of renewables to33% of Total Primary Energy Demand by 2040[12];
    - ii. Significant cost reductions in renewables and massive deployment of CCS (51 CCS facilities now with over 2000 needed by 2040);
    - iii. The decline in both coal and oil demand from now; and
    - iv. The slow decline of gas demand post 2030 and then increasing decline post 2040.

It is important to note that by 2040 (in the SDS) just under 50% of the world's energy demand will still be met by fossil fuels, albeit increasingly in conjunction with other technologies (CCS, CCUS etc.).

12 IEA, 2020 (renewables includes electricity heat derived from solar, wind, ocean, hydropower, biomass, geothermal, biofuels and renewable hydrogen)

Total Primary Energy Demand by Fuel (SDS)	Global Gas Demand to 2050 (WM)
	
Source: IEA (2019)	*Source: Wood Mackenzie (2021)*

Natural Gas and LNG demand to 2050: Wood Mackenzie's accelerated energy transition ("AET-2") scenario looks at how one interpretation of the Paris Agreement could be achieved, based on their fundamental analysis across the natural resource sectors. The AET-2 scenario calls for emissions reductions to start almost immediately – requiring a significant erosion of fossil fuel demand with coal and oil will bearing the brunt. In their view, gas demand remains resilient – indeed actually increasing compared to their 2019 view. Natural gas demand is supported by additional coal to gas switching in Asia, as well as large scale developments of CCS/CCUS and Blue Hydrogen. Consequently, global gas demand remains relatively flat through 2050, albeit with large regional variations depending on the various path's countries choose to take on their way to emissions reduction with demand growing in Asia and emerging markets that are still dependent on coal. However, demand will decline substantially in more mature markets, including Europe.

Net Zero by 2050: We acknowledge that there are a number of more ambitious targets which are sometimes quoted. The IEA (2021) has also outlined a "Net Zero by 2050" roadmap and others are even targeting net zero by 2030. MUFG strongly supports the ambition to exceed the IEA SDS scenario and indeed achieve Net Zero by 2050, yet we note that based on existing and announced policies – as described in the IEA Stated Policies Scenario (sometimes referred to as "STEPS") – there are still significant challenges to achieving even the SDS. Record growth in renewables during 2020 (and potentially 2021) is heartening and is a significant step in the right direction. Nevertheless, it is likely that natural gas and LNG, as the cleanest of the fossil fuels, will play important roles until 2050 and beyond, in conjunction with CCS, CCUS and carbon sinks.

Availability of LNG as Transition Fuel for Shipping to 2050: On this basis, we anticipate that LNG will be widely available to 2050 as a transition fuel for LNG fuelled vessels.

3.2 The Role of LNG in Shipping

A growing order book – although from a low base: At the end of 2020, less than 400 out of a total of more than 80,000 registered (non-LNG tanker) ships, ran on LNG as fuel source[13]. In 2021, LNG-fuelled vessels account for around 13% of the current new-build order book and their share of the new-build market is set to grow in the 2020s[14].

Material CO_2 emissions savings (vs other fossil fuels) upon combustion: LNG used as a bunker fuel has the potential to offer important reductions in GHG emissions from the Shipping sector. "Well to wake" LNG emits around 23% less CO_2 on an energy equivalency basis to fossil fuel alternatives[15]. It also emits virtually no SOx or particulate matter while dramatically limiting (up to 95%) NOx emissions. Fundamentally, LNG bunker fuel is widely available

13 Reuters, 2020, referencing Petronas Marine

14 Maritime Executive, 2021

15 Sphera Second Life Cycle GHG Emissions Study, 2021 now, there are 160+ LNG bunkering ports around the world and it is the lowest emission fuel available at scale in the shipping sector today. Major industry players, such as Shell, see LNG playing a fundamental role towards meeting the IMO targets, complementing the Carbon Free Fuels which are yet to be developed at scale.

Holistic life-cycle carbon emission savings may be lower: The lower carbon content of LNG allows for a significant reduction in CO_2 emissions at the point of use, yet it remains under debate whether there is a holistic lifecycle GHG benefit relative to oil-derived bunker fuels. The counter-argument is that LNG is liquefied methane, and methane is itself a highly potent GHG. Over 20-year and 100-year time horizons, methane is respectively 86 times and 36 times more potent a GHG than CO_2[16]. Therefore, any saving from lower CO_2 emissions could be quickly offset by a relatively small amount of methane leakage. LNG is still widely considered to be the cleanest fossil fuel readily available today for Shipping, particularly where the entire value chains are operated and monitored to a high standard. However, this view is not accepted by all.

World Bank Scenario Analysis: The World Bank (April 2021) has outlined that, broadly speaking, Shipping stakeholders currently take three basic positions:

- *Scenario 1*: Transitional Role – "Use and reuse": use of some form of liquefied methane gas in 2050, either as LNG (with carbon offsetting or without carbon offsetting), or as zero-carbon Liquefied Biomethane ("LBM") or Liquefied Synthetic Methane ("LSM"). Hydrogen or ammonia would not be compatible without expensive retrofitting of both supply infrastructure and vessels.

- *Scenario 2*: Temporary role – "Use and then stop": fossil-derived LNG could help reduce air pollutant emissions and make some contribution toward GHG emission reductions in the immediate future before zero-carbon bunker fuels become widely available. LNG could then be gradually superseded for new-build ships when those zero-carbon energy sources become available at scale, especially after 2030.

- *Scenario 3*: Limited role – "Limited use overall": LNG is not used as a bunker fuel for shipping except in niche applications where it is already in use or in circumstances where there is a particularly strong justification. The use of natural gas as an energy source (in combination with CCS) to produce zero-carbon bunker fuels is foreseen though, for example to manufacture hydrogen and ammonia.

No industry consensus for the role of LNG: The World Bank's view is that LNG is likely to follow Scenario 3 with limited growth to 2030, a decline thereafter and a likely end to demand for new-build ships in the early 2040s. Some major shipping companies / charterers have postponed LNG orders (e.g. FMG) whilst others say they have decided against ordering LNG-fuelled ships (notably Maersk). At the other end of the spectrum CMA CGM, Shell and Hapag Lloyd – to name just a few - are strategically expanding their fleets with dozens of (owned or chartered) new build LNG-fuelled vessels on order. Their position was complimented in July 2022 by the EU "Fit for 55" package which recognised that commercially available LNG and LBM provides an important transitional role in the decarbonisation of the sector. Targets have been set which should boost the use of LNG and LBM as well as spur the development of LNG infrastructure in Europe's key ports.

New-build LNG fuelled vessels are on the increase: Whilst some have noted that vessel owners are reluctant to place new-build orders for LNG fuelled vessels, lest they not be grand-fathered in future, shipping giants and engine manufacturers are announcing significant investments into LNG-fuelled new-builds:

- *LNG Fuelled Tankers:* The world fleet of LNG tankers, including FSUs and FSRUs, currently numbers over 600. With the exception of Qatar's Q-Max and Q-Flex fleet, which can only burn oil for fuel (re-liquefying their boil-off), all other LNG tankers use gas from the cargo (mainly boil-off gas) as their main fuel. There are a good number of new-build LNG tankers on order and under construction. Indeed the press reports that Qatar Energy alone is looking to secure 100 LNG vessels this decade for its LNG expansion projects. While these new-build LNG tankers are mainly to transport the increasing industry volumes of LNG, some are to replace smaller, less fuel-efficient 20 – 40 year old "steam" tankers. A typical new-build LNG tanker today has a diesel engine and a cargo capacity of ~177,000m^3.

- *LNG-Fuelled Vessels (excluding LNG Tankers):* However, beyond the LNG tanker fleet, many ship-owners are signalling that LNG is simply the best fuel choice right now. For example, NYK Line is currently looking to order 12 LNG-fuelled car carriers with a view to increasing this fleet to 20 by 2028 ($1.8bn). The Ship-owner identified

16 EPA website

the IMO Target as the key determinant in choosing the fuel, also noting "the use of LNG fuel, in addition to hull modification to improve fuel economy will contribute to a reduction of CO2 emissions by about 40% compared to ships using heavy fuel oil". This is not quite the 50% required by the IMO Target – but if the 40% is achieved – it still provides meaningful near-term emissions savings.

In support of increasing uptake, LNG infrastructure continues to build out quickly. According to Shell's recently published LNG Outlook 2021, LNG bunker demand is expected to expand from just above one million tons in 2020 to 3.5 million tons in 2023. This rapid growth is based on the addition of more than 250 LNG-fuelled ships to the current fleet, supplied by the 45 bunker vessels planned to be in operation by 2023. Engine manufacturer MAN says that around one-third of all new engines ordered are dual-fuel with LNG accounting for the largest portion of these orders. Martin Christian Wold, Principal Consultant at DNV, recently noted that nearly 20% of vessel orders placed in 2021 are LNG-fuelled, with the majority of the orders for large vessels trading globally.

Decarbonisation pathway: LNG proponents argue there is a clear decarbonisation pathway for LNG via LBM and eventually LSM. Both can be "dropped-in" and blended with LNG with no changes required to the vessel or bunkering facilities. Production is also scaling up. Specifically, on LBM, within the last 12 months TOTAL and UECC both blended LBM on to vessels in 2020 in Rotterdam and Gasum bunkered 100% renewable LBM onto a vessel in Finland. The IEA estimates that net-zero bio-methane production in Europe has the potential to grow from 18 bcm today to 125 bcm by 2050 – representing more than 25% of today's total EU gas consumption. Depending on the production process it can capture methane that would otherwise be vented into the atmosphere. This results in a fuel that is not just carbon neutral but has the potential to be carbon-negative in terms of lifecycle GHG emissions[17].

Transitional Role for LNG: On balance, we see a "Transitional Role" for LNG. As the MD of Fleet for Hapag-Lloyd has said: "Choosing the perfect fuel for the future should not be confused with choosing the best fuel for now". Considering the near elimination of SOx and NOx emissions, as well as the significant reduction in CO2 emissions, then LNG is the cleanest fuel readily available today for the shipping industry. When it comes to replacing fossil fuelled vessels, we believe the 90%+ of the world fleet running on fuel oil or marine diesel should be replaced before replacing the relatively clean LNG-fuelled vessels. Waiting for Carbon Free Fuels to become available may mean that the vessels of today (which will remain the fleets of the coming decades) could contribute materially towards cumulative GHG commissions over a time-frame with no real certainty. Challenges remain in scaling up biofuel production but many leading industry participants see this as a realistic and credible route for already cleaner LNG-fuelled vessels to further decarbonise. LNG is not the end-game but it is a good starting point to achieve meaningful GHG emissions in the immediate to medium term.

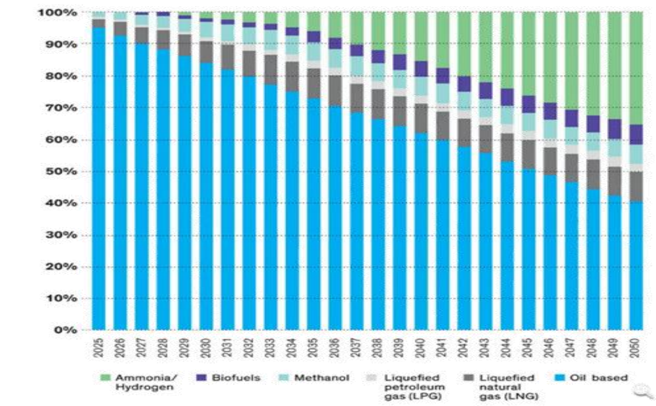
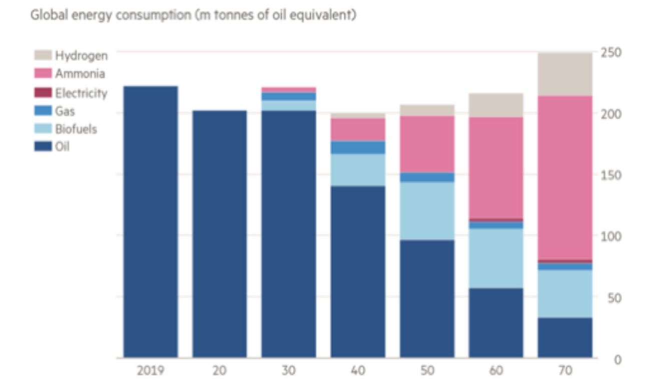
4 Carbon Free Fuels in the Shipping Sector

4.1 Greener fuels are expected to power international shipping in future - but widespread adoption will take decades and not come cheaply

Industry participants and observers are backing different pathways: Whilst all credible industry projections agree that Carbon Free Fuels will be required to achieve the IMO Target, there is divergence on which ones will come to the fore. For example, some such as the IEA see widespread deployment of green bio-fuels whilst others such as the World Bank see a more limited role. Others, such as the American Bureau of Shipping ("ABS"), see LNG playing a far more prominent role in the transition to meeting the IMO Target. However, virtually all see clean hydrogen and ammonia playing the defining roles, at least in the long term. There has also been a recent, although far from consensus, industry trend towards ammonia as the expected future dominant Carbon Free Fuel in the sector.

Forecast of Clean Fuel Adoption in Maritime Sector: Bearing in mind that forecasts vary significantly, we have included two illustrative projections to demonstrate potential pathways to meeting the IMOs Target in 2050 – and then beyond to 2070 - in the case of the Energy Technology Perspectives (IEA) forecast.

17 Sea LNG, 2021

ABS Projected Maritime Fuel Evolution – 2025 to 2050	IEA Projected Maritime Fuel Evolution - 2020 to 2070
	
Source: ABS, 2021	*Source: IEA, Energy Technology Perspectives 2020 (rev. Feb 2021)*

Elemental economics: A 2020 study estimates an expected cost of $1 - 1.4 trillion to meet its 2050 target to halve CO_2 emissions from 2008 levels - 87% of the cost being associated with land-based green fuel production and infrastructure[18]. Herein lies one of the major challenges - the decarbonisation of the sector depends on the availability of clean energy but the scaling up of green ammonia / hydrogen production will not happen without large and reliable sources of demand. It is within this context that Ship-owners are considering what vessels to order – and with the large capital cost of a new-build and lack of visibility on which Carbon Free Fuels will develop most successfully, it is hardly surprising many Ship-owners are sitting on the fence. The problem will be solved but it will require sponsors, charterers, shipyards, governments, financiers and regulators to work together to make it happen under any of the time-scales considered within this paper.

4.2 Zero / Low Carbon Hydrogen – Green and Blue

Production: Green hydrogen is produced using electricity generated from renewable sources to electrolyse water (H_2O) to separate the hydrogen atoms from the oxygen atoms and is considered to be "zero-carbon". Blue hydrogen is produced using natural gas via steam methane reforming together with CCS, albeit noting around 10-20% of the CO_2 cannot be captured so is perhaps best described as "Low Carbon"[19]. Grey hydrogen is the most common form of hydrogen production and is produced using natural gas via steam methane reforming without the use of CCS/ CCUS. There are other forms of hydrogen such as brown/ black hydrogen (from coal) and turquoise hydrogen (methane pyrolysis). In % terms on a global scale, 99.6% of the 112 million tonnes of hydrogen produced today comes from grey, brown and black hydrogen[20].

Positives: Hydrogen used as a fuel does not produce CO_2 emissions and it produces only water as waste product in a fuel cell (albeit noting NOx is produced if combusted). Unlike ammonia, it is not toxic and it is less corrosive.

Drawbacks: Highly flammable and seen as even more challenging to store and transport vs ammonia. To store it on a vessel as a liquid, it needs to be liquefied using cryogenic temperatures of -253^{C} (vs LNG at -163^{C}) which is capital intensive and energy inefficient. Considering its energy and density, liquid hydrogen will use 4.6x as much storage space as HFO and over double the storage space of LNG[21].

4.3 Zero / Low Carbon Ammonia – Green or Blue

Production: Green or blue ammonia can be made by using green or blue hydrogen and nitrogen separated from the air. These are then fed in to the Haber Bosch process powered by sustainable electricity whereby the hydrogen and nitrogen are reacted together at high temperature and pressure to produce ammonia (NH3). Ammonia is also labelled as "green" or "blue" ammonia, depending on the feedstock used to produce the hydrogen input. In practice, "green" ammonia, like "green" hydrogen, is simply unavailable at scale today.

---

18 UMAS and the Energy Transitions Commission, 2020

19 For simplicity we refer to Blue Hydrogen and Blue Ammonia as Carbon Free Fuels within this paper

20 Wood Mackenzie, 2020 Energy Transition Outlook

21 American Bureau of Shipping, 2021

Positives: Ammonia (NH_3) does not contain carbon and it is less flammable than hydrogen. When compared to hydrogen, ammonia as a fuel for engine propulsion has a higher (around 50%) volumetric energy density than liquid hydrogen thereby using less storage space, is less expensive and complex to transport and store and has a higher liquefaction temperate (-34^C) and so does not require cryogenic temperatures to store.

Negatives: The main negative is that ammonia is highly toxic to humans and aquatic life. However, ammonia is already a major commodity which is traded globally in bulk quantities by sea so we see the challenges associated with its safe storage and handling as addressable. Another negative is that green hydrogen is a building block of green ammonia and as such there is a further efficiency loss in conversion – and therefore cost incurred in production - vis-à-vis green hydrogen.

4.4 Net-Zero Carbon Biofuels

Production: Biofuels, such as bio-methanol, bioethanol, and LBM, are produced from biomass and waste streams of biogenic origin. First generation streams are often in direct competition with (i.e. are made from) food crops, although waste can be used as a feedstock. Second and third generation streams (wood, waste streams, lignocellulose and algae) should not compete with food-crops. Often referred to as “net-zero” carbon because they retrieve CO_2 from the atmosphere during production but emit CO_2 in broadly the same quantities as their fossil fuel equivalents when burned. Demand is likely to be concentrated in hard to electrify sectors such as Shipping.

Positives: These biofuels may be blended at gradually higher shares into HFO or marine diesel which avoids the need for new engines. Generally considered to be more cost effective than synthetic fuels. Bioethanol and bio-methanol can be stored as liquids at ambient temperatures using cost-effective tank materials given their relatively high energy densities to the carbon free alternatives. LBM has similar characteristics to LNG.

Negatives: Competition with food crops and required changes in land-use are the most frequent criticisms. Some such as the World Bank doubt whether there will be sufficient bio-fuel available to service the Shipping industry as well as other sectors.

4.5 Synthetic Biofuels

Production: Synthetic carbon-based fuels (man-made fuels that contain both hydrogen and carbon) such as green LSM, green synthetic methanol or blue synthetic methanol, require a source of hydrogen and carbon for their production. During the land-based production process, this carbon input is captured from the atmosphere in the form of CO2 using direct air capture technology. This is then synthesised with either blue or green hydrogen, using renewable electricity in the production process.

Positives: Synthetic carbon-based fuels are chemically very similar to the conventional fossil bunker fuels such as marine diesel and LNG in use today. Consequently, these Carbon Free bunker fuels would have significant advantages from the perspective of requiring smaller changes to the existing fleet and fuel supply infrastructure. The synthesis processes for methane and methanol are mature using technology already operated at scale.

Negatives: Expensive to produce given production pathway involves multiple energy-intensive steps. Green hydrogen is a fuel in its own right and then direct air capture and synthesis is required which leads to poorer energy efficiency overall. In turn, this results in higher fuel costs relative to other zero-carbon candidate bunker fuels.

4.6 Observations

Onshore availability is the real challenge: We expect both ammonia and hydrogen will, in the medium to long term, both play important roles in the decarbonisation of the Shipping sector. However, green ammonia and green hydrogen are simply not available today at scale. Indeed, without the widespread availability of these fuels in the 2030’s and 2040’s we do not believe it will be possible to achieve the IMO Target. Even if we take the more ambitious Getting to Zero Coalition estimate which requires full decarbonisation by 2050 (vs IMO Target of 50%), this requires zero-emission fuels to make up 5% of the international fuel mix by 2030. Whilst the 5% objective by 2030 seems relatively modest at first glance even in the such an ambitious transition scenario, it is simply illustrative of the fact that zero emissions fuels are scaling up from a more or less non-existent base as of today.

Costs of producing Carbon Free Fuels are falling rapidly and will continue to fall: Currently the cost of brown and grey hydrogen ranges between $1-2/kg, whereas that of green hydrogen currently ranges between $4-8/kg depending on location. Costs are declining rapidly though and the cost of producing green hydrogen has fallen by around 50% since 2015. This trend will clearly continue and reducing the cost to $2/kg (equivalent to natural gas priced at $15/ MMBtu) should make the fuel more or less competitive. Bloomberg New Energy Finance consider this is achievable in some parts of the world by 2030 with prices falling to $0.8 to $1.60/ kg (equivalent to natural gas priced at $6-12/ MMBtu). Green ammonia uses green hydrogen as its building block, so will track (at a premium) the economics of green hydrogen. However, ammonia infrastructure and bunkering facilities will be cheaper than the cryogenic facilities required for hydrogen, so there is an offset here. In all likelihood, without an imposed price on carbon or significant subsidies, it will take many more years before these fuels are competitive with fossil fuels.

Industry beginning to increasingly focus on ammonia as the long-term Carbon Free Fuel of choice: As of today, hydrogen continues to have its strong backers over ammonia. However there has been some trending towards ammonia as the zero-carbon fuel of choice for the long-term decarbonisation of the sector. Like hydrogen, ammonia can be carbon free. Unlike hydrogen it has reasonable energy density, is relatively easy to store and transport as it does not need cryogenic temperatures to liquefy. Its acute toxicity is the main issue to be addressed but we believe this can be managed, noting the commodity has been widely transported (but not used as a fuel) for a long time already in the Shipping sector.

Biofuels can easily be blended and may offer a pathway to decarbonisation of oil and LNG fuelled vessels: There are many detractors to the widespread roll-out of biofuels. The World Bank, amongst others, notes that the first-generation biofuels are often in competition with crops. Therefore, second and third generation biofuels (for example, wood, waste, lignocellulose, and algae) are preferable to first generation biofuels since their feedstocks do not compete with food or feed crops. However we anticipate bio-fuels, including synthetic ones, will likely play some role, particularly in the short to medium term given they can easily be blended with existing fuels and could provide a pathway to decarbonisation of vessels fuelled by oil and LNG. Indeed, some leading shipping companies may do some initial switching in the next few years, with Maersk planning to launch its first carbon neutral vessel in 2023 using either bioethanol or e-methanol and CMA CGM expecting to follow close behind with biomethane vessels.

Electrification of Shipping using batteries will have limited application: Carbon Free Fuels derived from renewables are an inescapably inefficient option. Electricity from a wind turbine via a battery can convert up to 86% of the wind turbines' output into forward motion, whereas for a fuel cell this figure is 40-45%[22]. Yet it is currently envisaged that batteries, due to their low energy density, will only be an option for short-haul Shipping. Carbon Free Fuels will therefore be required to decarbonise the majority of maritime Shipping that electrification cannot reach.

5 Market-based carbon pricing measures

A global approach to a carbon levy will always be the most effective: The combination of new technology, unavailability of Carbon Free Fuels today and lack of visibility over which ones will be most cost effective in the future means that many Ship-owners will postpone investment decisions on new orders for fear of obsolescence as early as the 2030s. Without some form of market-based system, the transition to Carbon Free Fuels will progress more slowly. Shipping is a highly competitive international business, CO2 is everywhere and the case for a common global regulation will always be the most effective vs single companies or regions going it alone. "The worst thing for the global shipping industry is to have a patchwork of regional schemes" (Anne Steffensen, CEO of Danish Shipping).

Carbon levies – we've been here before but this time it's different, maybe…: Banning fossil fuels outright is unrealistic, so many in the industry are pressing hard for policy measures that impose costs on GHG emitting fuels in the industry in order to promote the required transition. Regional or national subsidies would alleviate the cost of transition but many believe that the IMO, as the global regulator, should consider a global CO_2 tax on shipping companies. CO_2 taxes have been mooted for decades and there remain many vocal opponents, particularly in developing countries reliant upon shipping for economic development. Nevertheless, voices within the industry in support of a carbon tax are getting louder. This is a complex subject beyond the scope of this paper, so only a few key highlights are referenced below:

- In June 2021, delegates from 174 countries were in week long-discussions with the IMO over measures to reduce carbon intensity in the sector. There are signs of a sea change from within the industry itself with Maersk, the world's largest shipping container group, suggesting a US$50 per CO_2/tonne tax starting around 2027 that rises to more than US$150 per CO_2/ tonne. Interestingly, the Marshall Islands and the Solomon Islands put forward the most meaningful financial incentive to decarbonise shipping at $100 per CO_2 tonne. Whilst usually aligned with industry interests given their large shipping registries, the islands are mostly low lying and at risk

22 Climate Change Committee, 2020

of rising sea-levels. The industry has also proposed a payment of $2 per fuel tonne ($0.7 per CO_2/ tonne equivalent) to create a US$5bn pool for R&D of Carbon Free Fuels.

- The EU announced in July 2021 that it will look to include shipping under the regional carbon trading system, the EU Emissions Trading System ("EU ETS"). A survey released last month by the International Emissions Trading Association found members expect carbon prices in the EU ETS to grow to €47.25 per tonne between 2021 and 2025, and €58.62 per tonne between 2026 and 2030. Since 2018 it has been running a mandatory emissions reporting system.

The threat of carbon levy is already driving investment decisions but its introduction could act as the decisive factor for the transition: Although the introduction of a carbon levy or another market-based measure is extremely difficult to agree upon internationally, its prevalence in discussions across various forums is already generating pressure and challenging the status quo. In the short term its potential implementation drives interest in precautionary transitional investment by Ship-owners and some adjacent stakeholders. This is an area to watch closely over the coming years. If implemented globally and at an appropriate level, such a measure could decisively act as the tipping point.

6 Financing Considerations

6.1 Trending towards greener investments

ESG sits front and centre for financial institutions: All reputable financial institutions are increasingly focused on the effect of climate change on their asset portfolios, including upon physical risks from climate change and "stranded asset" risk, whereby assets suffer from unanticipated losses if the Energy Transition occurs more rapidly than expected. The financial industry is monitoring the effect of the climate change issue upon financial risk through bodies such as the Task Force on Climate-related Financial Disclosures and the EU Taxonomy is seeking to introduce new reporting standards whereby all companies (above 500 employees) have to report what share of their activities satisfy environmental thresholds and can be considered to be Taxonomy compliant. The current proposal (April 2021) is that vessels, yet to be manufactured, running on zero-emission fuels can be considered "green" with the exception of vessels transporting fossil fuels (i.e. crude tankers, LNG tankers etc.) even if they are running on zero emission fuels.

Net-Zero Banking Alliance: MUFG was the first Japanese bank to join the Net-Zero Banking Alliance ("NZBA"). The founding of the UN Net-Zero Banking Alliance, which was launched on 21 April 2021 and was a milestone development from an environmental perspective for the international banking industry, who are seeking to align their businesses with the 2050 net zero targets set by governments and other international institutions. The Alliance consists of 62 Members from 31 countries covering almost a quarter of global banking assets (US$39 trillion). As of August 2021, MUFG has been an elected member of the 12 bank Steering Group (the Group) in the NZBA and confirmed its membership of the Partnership for Carbon Accounting Financials[23].

The Poseidon Principles: The most targeted and prominent initiative related to climate risk in the Shipping industry is the Poseidon Principles, launched in June 2019. MUFG and 26 other leading banks/ \financial institutions, jointly representing around US$185 billion[24] in shipping finance, have come together to commit to the Poseidon Principles whereby they undertake to disclose the carbon intensity of the vessels financed under their lending portfolios, comparing these emissions to given abatement trajectories. It is expected that, with time, such transparency is going to translate into external and internal pressures channelling capital towards low emission vessels.

6.2 Considerations when raising finance for "Green Shipping"

Sponsorship on "first of a kind" projects: These will always be easier to finance with corporates with a strong balance sheet. For project finance structures, lenders will be focused on the commitment and recourse to strong sponsors. Clearly a backstop corporate wrap, as has occasionally been structured in the vessel sector before, will ensure raising a project financing will proceed more smoothly. But for other corporates this will defeat the point of project finance and so intermediary positions may need to be explored in-between. Lower gearing, forms of guarantee, technology wraps, and robust long-term charter contracts are all levers to be considered.

---

23 Please see MUFG's "Decarbonising the global maritime transport sector" paper to published November 2021 for more details on the NZBA.

24 Poseidon Principles website, 2021

Value chain risks and potential for co-investment along the chain: The capex spend for the zero-carbon value chain is predominantly onshore with up to 87% of the costs associated with fuel production. A synergy would therefore appear to exist along the value chain, whereby upstream and midstream sponsors could seek to share risks and lower financing costs through co-investment across onshore production, infrastructure and vessel projects. This could be a route which could be explored with both IOCs and NOCs. Government involvement on the upstream value chain (direct subsidy, tax breaks, direct lending via concessional loans, guarantees or even equity stakes) is also likely to be a relevant consideration.

Export Credit Agencies: Comprehensive cover from an Export Credit Agency will always widen out bank market liquidity. Direct lending from Export Credit Agencies could also be considered, if for example a fleet of zero-carbon vessels are to be ordered and there are funding constraints.

Green Loans and Bonds: The marketing of a project with a "green" designation could play an important role in drawing in support from financial institutions, sponsors and governments (i.e. Export Credit Agencies) actively seeking to support the Energy Transition. MUFG benefits from an established footprint in both arranging and structuring green, social, sustainability and sustainability linked loans and bonds. For FY 2020, MUFG ranked 2nd in Bloomberg's Clean Energy Finance League Tables. This was the 11th straight year that MUFG has been in the top two among private sector banks in the ranking, including five years as the top bank in this space. Broadly, there are three types of funding available:

- Green bonds or loans: These can be used to fund low or zero-emissions vessels and/or to retrofit ships so long as these vessels are not transporting fossil fuels. Use of Proceeds, Project Evaluation and Selection, Management of Proceeds and Reporting Requirements are all usually easily met through a project finance structure with little to no changes to what is usually required in the documentation.
- Sustainability-linked loans: These are usually the simplest form of sustainable finance. The idea is to incentivise the borrower's achievement of ambitious, predetermined sustainability performance objectives with a link through to low margin pricing should such objectives be met. The Use of Proceeds, which is a core focus for green bonds or loans, is not a determinant in its categorisation. This approach opens the door to a wider pool of borrowers.
- *Climate transition bonds*: These are also gaining momentum as a bridge between green bonds and sustainability bonds. Proceeds are used to fund the transition towards a lower environmental impact or to reduce carbon emissions – for example, in July 2021 NYK Line announced its plans to issue the country's first transition bonds, targeting to raise around ¥20bn for investment in climate transition efforts, such as development of LNG- and LPG-fuelled vessels, and carbon-neutral projects like ammonia-fuelled and hydrogen fuel-cell vessels.

7 Key Takeaways

- "This is the fourth energy revolution in shipping — from rowing our boats to sails to the steam engine to diesel engine and we have to change it once more." (Alex Saverys, CMB CEO).

- This revolution needs to happen. Representing 3% of global CO2 emissions today, by 2050 the sector's share of global emissions may increase by a factor if insufficient action is taken.

- In the short-medium term, it is likely energy efficiency measures, increased use of LNG, blending of biofuels with bunker fuels and some limited switching from oil-based fuels to bio-fuels will all play a role in reducing emissions from the sector. In the medium-term biofuels, including LBM and LSM may well play important roles as availability of clean hydrogen and ammonia pick up in the 2030s.

- In the long term, there is no question that clean ammonia and hydrogen will be required to de-carbonise the sector. Some such as Shell and Torvald Klaveness back green hydrogen. Others such as Maersk back green ammonia. Others, such as CMB, are exploring both, focusing more on hydrogen for the smaller vessels in its fleet. However, overall there seems to be some industry trending towards ammonia as the Carbon Free fuel of choice in the long term. Although toxic, when compared to hydrogen, it is easier to liquefy, it is already widely transported and traded and has far higher energy density.

- Natural gas may still play an important role, beyond LNG. A key finding from a leading industry study concluded that ammonia produced from natural gas combined with CCS (blue ammonia) would likely be the most realistic and lowest cost zero-carbon option when considering timeframes to 2050[25].

- There are notable challenges though. In our view, the technical challenges associated with the deployment of Clean Fuel propulsion systems will be overcome in the next few years. The real challenge is really around the lack of availability of Carbon Free Fuels and the rate at which these fuels become economic vis-à-vis their fossil fuel alternatives. Green hydrogen prices, for example, have dropped dramatically over the last few years and will continue to do so – but they will remain uneconomic for Ship-owners in the short-medium term if others are not playing on a level playing field. Therefore, some form of market incentive, such as a global, IMO enforced, pricing system for CO_2 would act as a much-needed catalyst in facilitating Ship-owners' new-build investment decisions for vessels with (dual-fuel / multi-fuel) Clean Fuel propulsion systems.

- To conclude, Shipping is at a crossroads. LNG has a transitional role to play, as do efficiency gains derived from the march of technology and tightening regulations. But it is only with the massive scale-up of Carbon Free Fuels that the IMO Target can be achieved. Long term, ammonia seems to show the most promise but hydrogen and biofuels will almost certainly play a role. This presents the Shipping sector with an exciting opportunity in that it can act as a key enabler for the land-based Carbon Free Fuels production facilities to develop by providing end-demand at scale. In turn this would spur many countries, particularly developing ones, without significant fossil fuels to develop onshore production and / or bunkering facilities for Carbon Free Fuels whilst simultaneously modernising their maritime and energy infrastructure. In our view, the "fourth energy revolution in shipping" provides at least as many opportunities as it does challenges.

25 Lloyds Register and UMAS, "Techno-economic assessment of zero-carbon fuels" (2020)

Contacts

If you would like to speak to MUFG about any of the topics discussed in this paper, please contact:

Christophe Maurat
Head of Natural Resources

christophe.maurat@uk.mufg.jp

Simon Davies
Director, Natural Resources

simon.davies@uk.mufg.jp

Peter French
Director, Natural Resources

peter.french@uk.mufg.jp

Sources

Websites (multiple articles / pages)

- DNV https://www.dnv.com/
- Economist https://www.economist.com/
- EPA https://www.epa.gov/
- European Parliament https://www.europarl.europa.eu/portal/en
- Financial Times https://www.ft.com/
- Getting to Zero Coalition https://www.globalmaritimeforum.org/getting-to-zero-coalition
- Global Maritime Energy Efficiency Partnerships Project https://glomeep.imo.org
- IMO website https://www.imo.org/en
- Lloyds Register https://www.lr.org/en-gb/
- MAN Engines https://www.engines.man.eu/global/en/index.html
- Maritime Executive https://www.maritime-executive.com/
- Poseidon Principles https://www.poseidonprinciples.org/
- Reuters https://www.reuters.com/
- Sphera https://sphera.com/
- UMAS https://www.u-mas.co.uk/
- Wartsila https://www.wartsila.com/

Reports

- American Bureau of Shipping
  - https://absinfo.eagle.org/acton/media/16130/setting-the-course-to-low-carbon-shipping-pathways-to-sustainable-shipping-outlook-ii-low

- IEA
    - https://www.iea.org/reports/energy-technology-perspectives-2020
- NOGAPs
    - https://www.globalmaritimeforum.org/content/2021/06/The-Nordic-Green-Ammonia-Powered-Ship-_Project-Report.pdf
- UMAS
    - https://www.globalmaritimeforum.org/content/2020/01/Aggregate-investment-for-the-decarbonisation-of-the-shipping-industry.pdf
- World Bank
    - https://openknowledge.worldbank.org/handle/10986/35435
    - https://openknowledge.worldbank.org/handle/10986/35436
    - https://openknowledge.worldbank.org/handle/10986/35437

MUFG