ESG Economist

Decarbonizing international shipping

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- **The drive to decarbonize the economy affects all sectors including shipping, but for the shipping industry it will be an enormous challenge.**
- **The International Maritime Organization (IMO) strategy currently targets a reduction of 50% by 2050 and 100% within the century, but it has signalled it is working on a more ambitious strategy. The IMO aims to agree on a revised strategy with more ambitious targets in spring 2023. According to IRENA a 1.5 degree scenario should see an 80% reduction by 2050. This is broadly in line with the IEA's scenario.**
- **International shipping has various ways to reduce its carbon footprint, however all currently have significant drawbacks. A change in energy carrier is the most crucial step to take but the future shipping fuel of choice has not been defined yet resulting possibly in reluctance to replace old vessels.**

Shipping is a capital-intensive industry characterized by large, long-life assets (vessels and bunkering infrastructure 20-30 years), thin margins and a high-dependence on a global supply of energy-dense fuels. Ship owners are cautiously watching developments on the regulation front (more on this below) regarding the direction of decarbonisation. They would like to avoid that they invest in a vessel with new technology and having the risk that this new technology is subsequently punished by a shift in regulation. So, it takes time to decide to change the shipping portfolio by investing in new vessels. The proportion of fuel costs in the operating costs of ships can range from around 35% of the freight rate of a small tanker to around 53% for container/bulk vessels. Moreover, the price differential between conventional marine fuels of fossil origin and renewable low-carbon fuels remains high. Furthermore, there are no commercially viable zero-emissions technologies especially for deep shipping that accounts for 85% of emissions. For short routes and smaller vessels, a battery may be an option. In this ESG economist we focus on the decarbonization ambitions for international shipping, the pathways for international shipping and the decarbonization options.

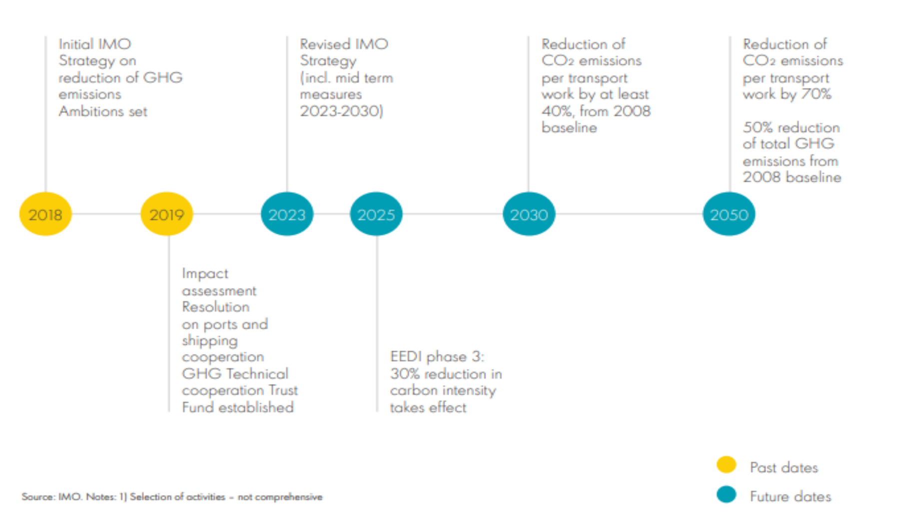
Decarbonization ambitions for shipping

The shipping industry has to play a role in achieving a net zero pathway, which would limit global warming to 1.5 degrees. However, due to the factors discussed above, the path to decarbonize shipping is likely to be a long one. The shipping industry is tied to several regulations and ambitions of a number organizations such as the ambition of the International Maritime Organization (IMO), and the Poseidon principles and the European Commission's Fit for 55. We set out the ambitions of these organizations.

UN International Maritime Organization

The International Maritime Organization (IMO) is the UN specialized agency responsible for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships. In 2018 the IMO set decarbonization targets and the IMO is aligned with the UN's sustainable development goals. The IMO has the ambition to reduce the shipping industry's greenhouse gas emissions by at least 50% by 2050 (to around 470 Mt CO2 equivalent) and to reduce the carbon intensity of emissions by 40% by 2030 and 70% by 2050 compared to 2008 levels (from round 940 Mt CO2 equivalent). For the timeline see the graph below. For the 1.5-degree pathway, steeper reduction targets need to be set and the IMO has recognized this.

IMO Timetable to reduce GHG emissions



Source: IMO

At the Marine Environment Protection Committee meeting (MEPC 76) in June 2021, the IMO adopted new requirements for Energy Efficiency of Existing Ships (EEXI), a Carbon Intensity Indicator (CII) and an Enhanced Ship Energy Efficiency Management Plan (SEEMP) Part III effective from 1 January 2023. The EEXI requirement is a technical measure for existing ships similar to the EEDI requirements for newbuilds that have been in force since 2013, whereas the new CII requirement is an operational measure that will get stricter and stricter each year from 2023 to 2030 to ensure international shipping follows the decarbonization strategy that was adopted by IMO in 2018.

At the IMO Marine Environment Protection Committee meeting (MEPC 77) from 22 to 26 November 2021, held in the wake of the COP26 event in Glasgow, the IMO commenced the review of the initial IMO Strategy on GHG emissions reduction for ships. There was general consensus that, to stay consistent with the 1.5 degrees Celsius goal of the UN Paris Agreement, international shipping needs to accelerate the decarbonization and target zero GHG emissions or at least net-zero CO2 emission by 2050. The discussions will continue at IMO with the aim to agree on a revised strategy at the MEPC 80 meeting in 2023. More research and the Technological Readiness Level (TRL) of new technologies, innovative design solutions and alternative fuels need to be sufficiently advanced to be adopted for new ship designs and retrofit for existing vessels as soon as possible prior to 2030.

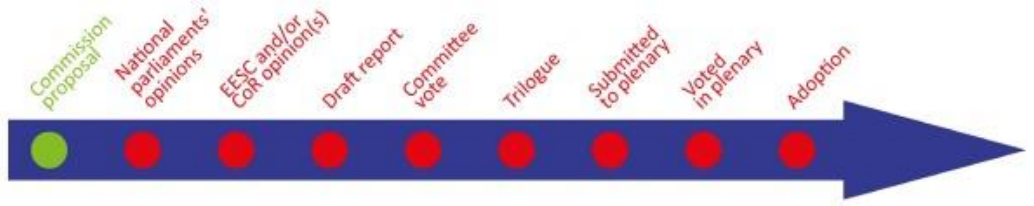
Poseidon Principles

The Poseidon Principles provide a global framework for integrating climate considerations into lending decisions to promote international shipping decarbonization. The Poseidon Principles are the world's first sector-specific, self-governing climate alignment agreement amongst financial institutions. Signatories to the Poseidon Principles are committed to improving the role of maritime finance in tackling shipping's climate impacts. They believe not only that this step will improve financial institutions' decision-making at a strategic level but also shape a better future for the maritime industry and society. ABN AMRO is among the signatories of the Principles. The Principles establish a global framework for assessing and disclosing the climate alignment of ship finance portfolios. They are consistent with the policies and ambitions of the IMO, including its ambition for greenhouse gas emissions to peak as soon as possible and to reduce shipping's total annual GHG emissions by at least 50% by 2050.

Fit for 55

On 14 July 2021 the European Commission adopted the 'Fit for 55 package'. It adapted the existing EU climate and energy legislation to the new EU objective of a minimum 55% reduction in greenhouse gas emissions by 2030, in accordance with the new European Climate Law. But this is a proposal that still needs to be approved and adopted by individual countries (see the graph below), which will take time.

EU Fit for 55 process



Source: European Commission Research Centre

Maritime shipping carries close to 80% of global trade and accounts for 2-3% of global greenhouse gas (GHG) emissions annually. To achieve climate neutrality, a 90% reduction in transport emissions is needed by 2050. The lower emissions reductions in transport relative to other sectors like for example power generation is in recognition of the fact that emissions in some transport modes, in particular aviation and maritime, are more difficult to abate. All transport modes, including maritime transport, will have to contribute to the reduction efforts. Achieving significant reductions in CO_2 emissions of international maritime transport requires using both less energy (increasing energy efficiency) and cleaner types of energy (using renewable and low-carbon fuels). Depending on the policy scenario, renewable and low carbon fuels should represent between 6-9% of the international maritime transport fuel mix in 2030 and between 86-88% by 2050. The Dutch government supports the proposal to make the shipping sector more sustainable.

EU ETS

As of 2023 shipping will become subject to the EU Emission Trading Scheme (EU ETS). All intra EU emissions will be included, but only 50% of the emissions for voyages when arriving in or departing from the EU. There will also be a phase-in period starting with 20% coverage in 2023 and increasing to 100% in 2026. Non-compliance is fined and may eventually lead to a ban from EU waters.

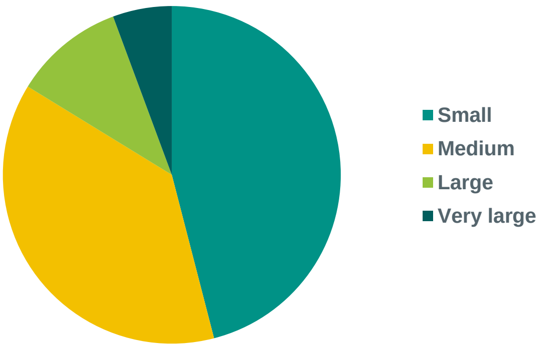
FuelEU Maritime Regulation

The FuelEU Maritime Regulation is a new regulation coming into effect in 2025, imposing life cycle GHG footprint requirements on the energy used on board of ships. It will apply to the same ships that are covered by the EU MRV regulation and will, in addition to CO_2, cover methane and nitrous oxide, all in a well-to-wake perspective. The GHG intensity of the energy used will be required to improve by 2% in 2025 relative to 2020, ramping up to 75% by 2050.

Pathways for international shipping

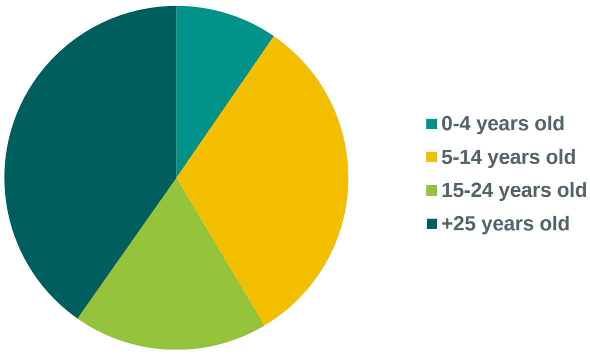
Shipping carries the vast majority of international trade with its share ranging between 80-90%, i.e. bulk and container carriers, as well as oil and chemical tankers (27% of global fleet, Equasis 2020). But shipping is only responsible for 3% of the global greenhouse gas emissions.

Ship type



Source: World fleet Equasis 2020

Ship age



Source: World fleet Equasis 2020

In 2018 **greenhouse gas emissions** of total shipping (international, domestic and fishing) were 1,076 million tonnes (Mt). This is including carbon dioxide, methane and nitrous oxide expressed in CO2 equivalent. The share of shipping emissions in global man-made emissions was 2.89% in 2018 (IMO Fourth Greenhouse Gas Study). Bulk and container carriers as well as chemical tankers are responsible for 85% of the net GHG emissions associated with the shipping sector (IRENA, 2019a A Pathway to Decarbonise the Shipping Sector by 2050).

Shipping's carbon footprint

Mt CO2 emissions, %

	Man-made emissions CO2						
	Global	Total shipping	% of global	International shipping		% of global	
				Voyage based	Vessel based	Voyage based	Vessel based
2008				776			
2012	34,793	962	2.8	701	848	2.0	2.4
2013	34,959	957	2.7	684	837	2.0	2.4
2014	35,335	964	2.7	681	846	1.9	2.4
2015	35,239	991	2.8	700	859	2.0	2.4
2016	35,380	1,026	2.9	727	894	2.1	2.5
2017	35,810	1,064	3.0	746	929	2.1	2.6
2018	36,573	1,056	2.9	740	919	2.0	2.5

Source: IMO Fourth International Greenhouse Gas Study

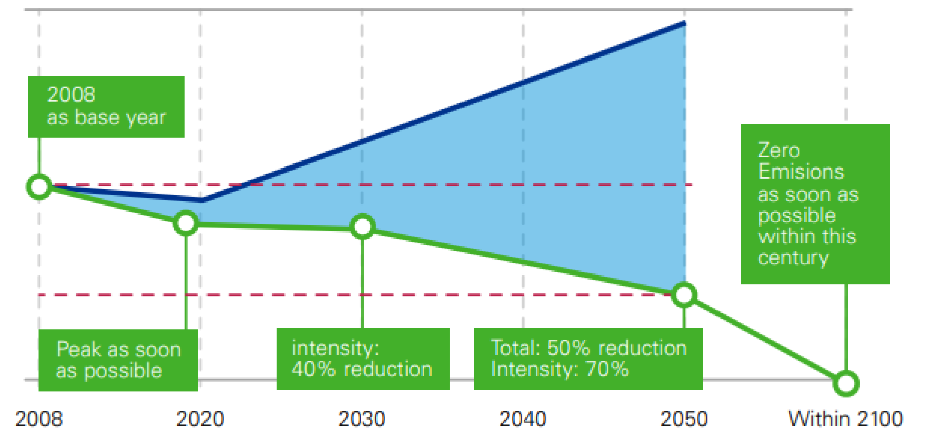
On a new voyage-based allocation approach **CO2 emissions** for international shipping were 740 million tonnes (Mt) in 2018 (approximately 2% of global CO2 emissions). Using the previous vessel-based allocation of international study this amount was 919 million tonnes in 2018 for international shipping.

IMO current strategy to reduce emissions in international shipping (click here)

The International Maritime Organization (IMO) is the UN specialized agency with responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships. In 2018 the IMO set decarbonization targets and the IMO is aligned with the UN's sustainable development goals. The IMO has the ambition to reduce the shipping industry's greenhouse gas emissions by at least 50% by 2050 and to reduce the carbon intensity of emissions by 40% by 2030 and 70% by 2050 compared to 2008 levels.

Pathways Business as Usual (BAU= blue line) and IMO GHG strategy (green line)

GHG emissions



Source: DNV-GL 2019

IMO current strategy

Mt

	GHG CO2 equivalent Mt						
	Total shipping	International shipping		IMO GHG reduction target		Approx IMO CO2 reduction target	
	Approx	Voyage based	Vessel based	Voyage based	Vessel based	Voyage based	Vessel based
2008	1,109	794	940	794	940	776	923
2012	977	713	862	713	862	701	848
2013	971	695	851	695	851	684	837
2014	968	693	850	693	850	681	846
2015	995	712	874	712	874	700	859
2016	1,034	740	910	740	910	727	894
2017	1,062	760	946	760	946	746	929
2018	1,076	755	937	755	937	740	919
2030							
2050	555			397	470	388	462
2100	-			-	-	-	-

Source: IMO Fourth Greenhouse Gas Study, red numbers are calculations based on IMO data

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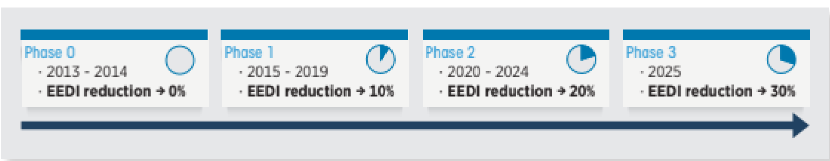
EEDI phase, implementation periods



Note: Time period refers to 1 January of the starting year to 31 December of the end year.
EEDI reduction in reference to the baseline year, 2013.

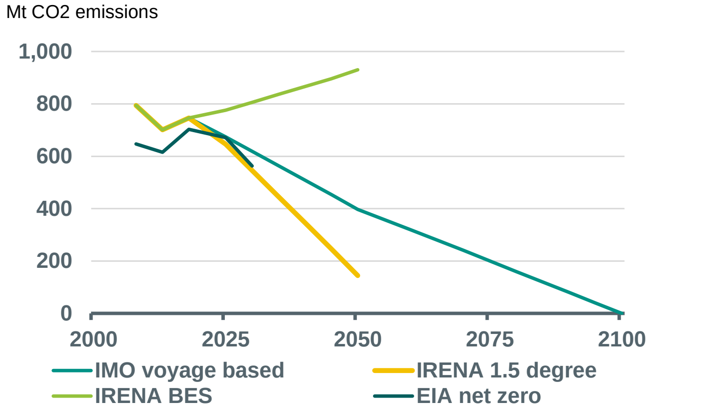
Source: Based on IRCLASS (2013a)

IMO to revise its decarbonization strategy for international shipping in 2023

At the IMO Marine Environment Protection Committee meeting (MEPC 77) from 22 to 26 November 2021, held in the wake of the COP26 event in Glasgow, the IMO commenced the review of the initial IMO Strategy on GHG emissions reduction for ships. There was general consensus that, to stay within reach of the 1.5 degrees Celsius goal of the UN Paris Agreement, international shipping needs to accelerate the decarbonization and target zero GHG emissions or at least net-zero CO2 emissions by 2050. The discussions will continue at the IMO with the aim to agree on a revised strategy at the MEPC 80 meeting in 2023. More research and the Technological Readiness Level (TRL) of new technologies, innovative design solutions and alternative fuels need to be sufficiently advanced to be adopted for new ship designs and retrofit for existing vessels as soon as possible prior to 2030. For the 1.5-degree pathway, steeper reduction targets need to be set and the IMO has recognized this.

It is likely that IMO will address and could even change how emissions are measured. Current IMO regulations only address tank-to-propeller CO2 emissions from fossil fuels (DNV Maritime Forecast 2050 2021). Other GHGs with significant emissions from shipping include methane (CH4) and nitrous oxide (N2O). The other way of measuring CO2 is on a well-to-tank perspective, depending on the primary energy source, the fuel processing and the supply chain. The IMO is working on guidelines to determine CO2 and GHG emission factors for all types of fuels (DNV Maritime Forecast 2050 2021). The IMO is also currently considering market-based measures, including a carbon levy and/or cap-and-trade system, to reduce GHG emissions from international shipping. The carbon levy would be applied to bunker fuels, starting at USD 100/tCO2equivalent from 2025 with upward ratchets on a five-year review cycle. The cap-and-trade system would be combined with a fuel GHG limit, the latter of which would act as a command-and-control measure. Potential carbon revenues are deemed significant, with estimates of the total by 2050 being between USD 1 trillion and USD 3.7 trillion, or USD 40-60 billion annually according to the World Bank. In 2023 it is expected that the IMO will move to lifecycle GHG/CO2 emissions factors and revise the initial IMO GHG strategy including the ambitions and assessment of further measures so that its strategy comes into line with reaching the 1.5 degree pathway.

IMO strategy versus IRENA and IEA



Source: IMO, IRENA, IEA

IRENA pathways (click here)

The International Renewable Energy Agency or IRENA has already defined different pathways including the 1.5 degree scenario. In this scenario the shipping sector embarks on a deep decarbonisation path in the years leading up to 2050. The utilisation of renewable fuels and the adoption of energy efficiency measures characterise the future of the maritime sector. While energy intensity levels improve significantly, the use of green H_2-based fuels outweigh the use of fossil fuels. The IRENA 1.5 degree scenario explores a pathway for shipping with a 70% share of renewable fuels to be achieved by 2050 resulting in 144 Mt of CO2 in 2050, an emission reduction of 80% compared to 2018 levels. IRENA also has a business-as-usual scenario which is called BES. In this scenario the socio-economic and technological development are primarily based on harnessing fossil fuels. Future energy demand and supply in the shipping sector follow the historical trend. Heavy fuel oil, Very Low Sulphur Fuel Oil and marine gas oil continue as the dominant fuels by 2050. EE measures are not embraced. The graph above shows the different pathways of the IMO, IRENA and the net zero pathway of IEA (click here). It shows the new IMO voyage based calculation method, the two IRENA pathways and IEA net zero. Albeit with a different starting point the net zero IEA pathway seems to resemble the IRENA 1.5 degree scenario. For the IMO to align the scenario with the 1.5 degree scenario, aggressive steps to reduce emissions are necessary.

Decarbonisation options for international shipping

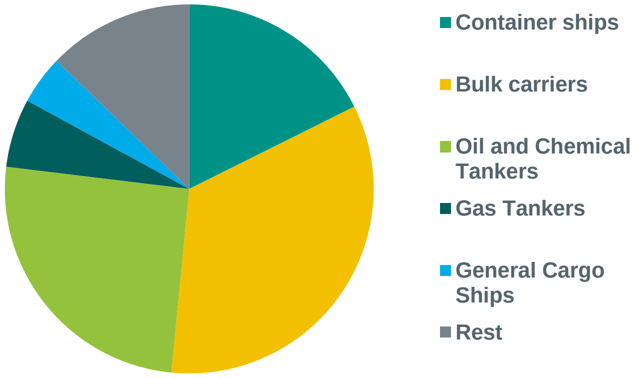
Having looked at the current regulatory framework for shipping and different emission pathways, we now focus on decarbonisation options for shipping. The good news is that there are a number of options, the bad news is that each of these have drawbacks for now. We start we the breakdown of the fleet and the age of the vessels. The type of vessel is important for the possibility of decarbonation options. The age of the vessel indicates when a certain type of vessel is expected to be replaced by a new vessel. This is the moment to significantly improve the carbon foot print. However during the life of a ship certain measures could be taken and the vessels could be adjusted to reduce already some emissions. After the fleet breakdown we discuss the decarbonisation options for international shipping.

Breakdown of fleet of vessels

Before getting into the decarbonisation options, it is helpful to put these into context by briefly settling out the breakdown of the global fleet of vessels in terms of type and age. Shipping carries the vast majority of international trade with its share ranging between 80-90%, bulk and container carriers, as well as oil and chemical tankers - make up 27% of global fleet in terms of the number of vessels. However, if the gross tonnage of the ship is taken into account the share of these vessels is much larger. Container ships, bulk carriers, oil and chemical tankers and general cargo ships account for 87% of the global fleet in terms of gross tonnage (see graph on the left below, Equasis 2020). Gross tonnage is a nonlinear measure of ship's overall internal volume.

World fleet in gross tonnage

1000gt



Source: World fleet Equasis 2020

Age of the world fleet based on gross tonnage

1000 gt

World fleet	Gross tonnage	%	0 - 4 years old	%	5-14 years old	%	15-24 years old	%	+ 25 years old	%
Container ships	256,721	17.6	50,004	3.4	142,174	9.8	58,905	4.0	5,637	0.4
Bulk carriers	493,288	33.9	95,095	6.5	311,970	21.4	73,310	5.0	12,914	0.9
Oil and Chemical Tankers	369,205	25.4	79,325	5.5	181,602	12.5	98,984	6.8	9,293	0.6
Gas Tankers	87,459	6.0	26,413	1.8	40,961	2.8	14,857	1.0	5,229	0.4
General Cargo Ships	62,279	4.3	5,203	0.4	26,846	1.8	13,769	0.9	16,462	1.1
Rest	186,051	12.8	24,517	1.7	70,382	4.8	45,787	3.1	45,366	3.1
	1,455,003	100.0	280,557	19.3	773,935	53.2	305,612	21.0	94,901	6.5

Source: World fleet Equasis 2020

The life of a vessel is around 25 to 30 years. Based on the number of ships around 60% of the world fleet is older than 15 year and 40% is older than 25 years. This means that a large percentage of ship needs to be replaced in the next 5 years. However, based on gross tonnage this is much smaller. Then 27.5% of the total fleet is older than 15 years. Again, taking gross tonnage as the basis, 17.6% of the vessels in the group of container, bulk, tankers and cargo ships are between 0-4 years old, 48% between 5-14 years old, 18% 15 – 24 years old and only 3.4% is older than 25 years.

Decarbonisation options

Shipping is only responsible for 3% of the global greenhouse gas emissions. Despite the relatively low share of international shipping to global greenhouse gas emissions to limit global warming to only 1.5 degree international shipping also has an important role to play in lowering greenhouse gas emissions. This mainly addressing deep-sea shipping which accounts for the largest part of GHG emissions and has fewer available solutions compared to short-sea shipping. There are several options to do this: change the energy carrier, alter the design of the ship, voyage optimization, machinery and after treatment measure.

Change of energy carrier

The first and most important way to reduce greenhouse gas emissions is the choice of energy carrier. The main proportion of energy consumption in international shipping relates to propulsion of the ship at steady speed over long distance. Vessels mainly have diesel engines that use marine fuel oils. The industry is working on other alternatives such as methanol, ammonia, hydrogen and biofuels. All alternative fuels for shipping face challenges and barriers to their uptake – although the severity of each barrier will vary between fuel types. Typical key barriers include the cost of required machinery and fuel storage on board vessels, additional storage space demand, low technical maturity, high fuel price, limited availability of fuel, and a lack of global bunkering infrastructure. Safety will also be a primary concern, with a lack of prescriptive rules and regulations complicating the use of such machinery and storage systems (**DNV**). So, the options for the deep-sea trade are currently limited to LNG and LPG. Below we provide more details on the different energy carriers.

LNG

Liquified Natural Gas (LNG) is an attractive option to meet the new regulations on sulphur content in marine fuels, as sulphur levels are less than 0.004% by mass (**KPMG**). LNG is the least polluting fossil energy source, which compared to heavy fuel oil, could reduce sulphur emissions by 99 per cent, nitrogen oxides by 80 per cent, and CO2 emissions by up to 20 per cent, along with most particulate matters (**UNCTAD**). LNG/dual-fuel engines emit fewer grams of CO2 equivalent per kw than diesel engines. Dual-fuel engines can use existing technology, enabling ships to be operated on different types of fuel and comply with regulations while remaining competitive. In January 2021 the IMO sulphur cap (IMO2020) entered into force, prompting greater investment in bunkering port infrastructure and in LNG-fuelled ships. Currently, these represent a small share of the fleet and of the orderbook. But their numbers are expected to grow significantly in the 2021–2022 period (**UNCTAD**). According to Shell LNG is the 'cleanest' fuel currently available to shipping in meaningful volumes. But it has a methane slip. This is the methane that is not used as a fuel in an engine and escapes into the atmosphere. So even as it lowers the CO2 emissions and has lower sulphur levels, the methane slip needs to be reduced as well. Methane is a more potent greenhouse gas emission than CO2 is. The industry is working on the technology could reduce the methane slip. There is a risk that LNG ships and infrastructure will become stranded assets in the future as it is not (or not sufficiently) reducing lifecycle greenhouse gas emissions. Next to this the energy density of LNG is lower than marine fuel oil (see table below) so LNG tanks take up vessel space. Plus LNG is still a fossil fuel and thus a temporary solution towards 2050, unless the emissions can be compensated elsewhere leading to a net zero situation

Comparison of different marine fuels

GJ = gigajoules, m3 = cubic metres

Fuel type	Lower heating value (MJ/kg)	Volumetric energy density (GJ/m3)	Storage pressure (bar)	Storage temperature (Celsius)
MGO	42.7	36.6	1.0	120
LNG	50.0	23.4	1.0	-162
Methanol	19.9	15.8	1.0	20
Liquid Ammonia	18.6	12.7	1.0	-34
	18.6	12.7	8.6	20
Liquid H2	120	8.5	1.0	-253
Compressed H2	120	7.5	700	20

Source: IRENA (2019a)

Methanol

Methanol has one of the lowest carbon and highest hydrogen (H2) contents compared to other fuels. Furthermore, methanol reduces emissions of sulphur oxide (SOx), and nitrogen oxide (NOx) by up to 60% in comparison to heavy fuel oil (ITF, 2018), including reductions in particulate matter emissions of 95%. Currently, most methanol is produced from coal or natural gas, but methanol can also be produced from lignocellulosic feedstocks such as agricultural waste, from biomass (preferably) collected from sustainable managed forests to produce bio-methanol. Methanol can be used today as a ship fuel in an internal combustion engine (ICE). Despite the success of using methanol fuel in ship engines and its commercial availability, the technology is still in development, and existing vessels are required to replace fuel injectors and the fuel supply system. Methanol's storage temperature varies between -93°C to 65°C, making it significantly cheaper to store and transport than other fuels such as H2, ammonia and LNG. Methanol can be stored in integral fuel tanks for liquid fuels if modifications are made to accommodate its low flashpoint properties. Energy density is a main concern with methanol. This means that the tanks take up much more storage compared to marine gas oil (**IRENA**).

Ammonia

One of the most promising alternative shipping fuels is carbon-free ammonia ("green ammonia"), as a means to achieve IMO's GHG emission goals. According to IRENA it is estimated that reductions of life cycle GHG emission would be between 83.71 and 92.1%. Ammonia-fuelled ships need pilot fuels to trigger combustion in an internal combustion engine, although H2 can play this role. Ammonia has various advantages compared to other alternative fuels. These include an existing logistical infrastructure with no need for cryogenic storage. It is easier to store and to transport because ammonia becomes liquid at more ambient temperature than H2 fuel. In addition, as the table above shows ammonia has a significantly higher energy density than hydrogen. Ammonia seems to be the preferred alternative for the shipping sector as it has more similarity to conventional fossil fuel sources in terms of physical characteristics, is simple to store and transport, and as opposed to e-methanol, the production cost of e-ammonia does not depend on the costs associated with carbon capture and removal technology because it has a no-carbon content in its molecular structure. The ammonia engine is expected to be ready in 2023 and this will be a key milestone in unlocking the use of renewable ammonia.

But there are also cons to ammonia as the future shipping fuel. First ammonia-fuelled ships would require between 1.6 and 2.3 times the volume of fuel compared to conventional heavy fuel oil ships. So compared to heavy fuel oil, ammonia weighs twice as much and requires three time more space to contain the same amount of energy. This needs to be taken into account when designing new vessels. Second, ammonia is currently produced via natural gas so the life cycle greenhouse gas emissions are high. If these are taken into account ammonia may not be a good alternative. Third as with hydrogen (see below), there are two ways of utilising ammonia as a fuel, in a fuel cell and in an internal combustion engine (**DNV GL, 2019c**). But current technology for both ammonia fuel applications, fuel cells and internal combustion engines, are still in the development and research stages, with few real-world applications in the shipping industry at present. Fourth, using ammonia comes with safety challenges – such low flammability, corrosion and toxicity (**IRENA**) and nitrous oxide (N2O) and potential ammonia slip (**DNV**). Ammonia slip refers to the unreacted ammonia that goes into the atmosphere. Due to its toxicity, the introduction of ammonia as fuel creates new challenges related to safe bunkering, storage, supply and consumption. Last but not least, there is limited to no ammonia bunkering infrastructure (**DNV**).

Hydrogen (H2):

The cleanest marine fuel with zero carbon emission is green hydrogen, which is produced by using renewable energy. It can be produced in many ways such as by electrolysis of renewable matter and by reforming natural gas. Hydrogen is the lightest of all gas molecules, thus offering the best energy-to-weight storage ratio among all fuels (**KPMG**). H2 as a shipping fuel can be stored either as compressed gas or as a cryogenic liquid, or it can be used to produce e-fuels, e.g. e-ammonia or e-methanol.

Current barriers to using hydrogen as marine fuel include lack of safety requirements; low maturity of technology; onboard storage space required (because of low energy density); and, the high investment cost. Hydrogen is not transported as a marine cargo, and the experiences as a marine fuel are currently limited to small-scale R&D projects. The safety implications of storing and distributing hydrogen on board ships are not clear. For hydrogen the potential explosion risk related to the low ignition energy and the wide flammability range requires special attention. The very low boiling temperature for hydrogen makes it more challenging to store in its liquefied form (**DNV**). The main issues with using H2 as a fuel for ships are the costs associated with engine retrofits, storage on ships and bunkering of H2.

Biofuels

Biofuels are considered unlikely to be the dominant future fuel for shipping. This is because the sector would need huge volumes, and other sectors such as aviation and road transport are likely to be more able to pay the cost (**Shell**). Biomethane production costs are highly dependent on feedstock availability and feedstock market price, leading to wide cost rages. Biogas produced via anaerobic digestion for the subsequent production of liquid biogas and compressed biogas has high technological maturity, making it an attractive option for displacing LNG. However, due to scalability and logistical issues, the role of renewable gaseous fuel may be limited. Biogas may be more effective in end-use applications other than for fuelling the shipping sector. Renewable methanol, i.e. bio-methanol and renewable e-methanol, requires little to no engine modification and can provide significant carbon emission reductions in comparison to conventional fuels (**IRENA**).

Design of the ship

Choosing the right fuel strategy is one of the most important decisions an owner will have to make for a current newbuild. The key will be to optimize the fuel storage and propulsion system of the ship to accommodate current and future fuel requirements. The question is how their potential to reduce greenhouse gas emissions can be maximized. A vessel built now faces a significant risk that the most competitive fuel type in the ship's early life will not be the same at a later stage (**DNV**). As a result it could become a stranded asset in the future.

Apart from the right fuel strategy there are other ways to improve the efficiency of the ship. A ship should be designed to allow for the needed upgrades or fuel changes later in its lifetime. Fuel Ready refers to a new DNV Class Notation and indicates that a conversion to an alternative fuel has been accommodated and verified in the newbuild design such as Fuel Ready LPG, LNG, ammonia and/or methanol/ethanol. There are mono fuel internal combustion engines (ICEs) or dual fuel ICEs using LNG, LPG or methanol as fuel (**DNV**) and then ammonia ready. All designs must have a steadily increasing blend-in of carbon-neutral fuels as the ship follows the diminishing carbon-intensity trajectory. From a design point of view, the main challenge with ammonia and other less carbon-intensive fuels is in most cases to find space to store a suitable amount of fuel without affecting the cargo capacity of the ship to an unacceptable degree. Safely managing fuel properties like high flammability and toxicity is also a challenge, both for design and in operation. From a volumetric energy density perspective, ammonia will require significantly more space than marine gas oil to store the same amount of energy. strengthening the support structure below the tank(s) and, in some cases, reinforcement of the hull girder (**DNV**).

To design the ship more lightweight materials could be used, a more slender hull design, hull-form optimization and improvement in propulsion, advanced hull coatings and an air lubrication system (**UNCTAD**). The change in design could result in a reduction of greenhouse gas emissions of 5-15% (**DNV**).

Voyage optimization

Voyage optimization is how to get from A to B using the least energy and to be the most efficient. The easiest and cheapest way to reduce emissions is to reduce ship speed (**UNCTAD**). Slow steaming is a very efficient way to save fuel, as a speed reduction of 3% causes a reduction in fuel use of 10%. However, slow steaming also carries safety risks, as it provides less propulsive power and therefore less manoeuvrability (DTU). Moreover, transporting the same cargo volumes at slower speeds will also require more ships. The report estimates that the IMO short-term measures will require 13 per cent more vessel capacity. Drewry estimates that global shipbuilding capacity is equivalent to 7 per cent of the global fleet and that, while maintaining also normal fleet replacement and growth, increasing vessel capacity by 13 per cent would require a ramp-up period of around five years (**UNCTAD, 2021b**). Next to reduce ship speed, a higher percentage of the fleet could be used or be used more efficiently.

Machinery

Currently combustion engines (diesel) continue to dominate the fleet. Going forward these engines need to able to operate on two or more fuels and be ready for a future fuel such as ammonia. Moreover, marine fuel cells are expected to be integrated in power systems over the next years (**DNV**). Fuel cells are just like batteries — they produce electricity with a high frequency through an electrochemical process. They offer higher electric efficiencies with lower noise. Fuel cells need hydrogen-rich fuel such as natural gas, methanol and diesel using chemical reactors for the cells, apart from pure hydrogen (**KPMG**). Today fuel cells are more expensive than internal combustions engines on a $/KW basis. The solid state nature of fuel cell technology lends itself to lower operating costs, less need for intervention from crew and high reliability (**Shell**).

Next to fuel cells, a battery is also an option for smaller ships that travel short range. Batteries provide abilities to store electricity critical for the use of ship propulsion. Recent technologies in batteries such as lithium-ion have made it possible for battery-powered propulsion systems to be engineered for smaller ships. The lower power density and greater weight limit the usage for many applications. Hence, for larger vessels, engine manufacturers are focused on the hybrid electric solutions. However, using batteries as a standalone solution is not possible in the current technology status; it may be combined with other renewable sources of energy such as solar and wind (**KPMG**).

Another way to reduce the carbon footprint is a waste heat recovery. When the fuel is burnt in the engine, the heat released could be used to heat the water and generate steam. This reduces the carbon footprint as only the main engine is consuming the fuel.

CCS

Onboard carbon capture and storage (CCS) is a potential option for decarbonizing the deep-sea portion of the world fleet. However, there has not yet been any largescale demonstration or implementation of onboard CCS systems on merchant ships for substantial recovery rate (**DNV**).

Conclusion

Overall, the change in energy carrier will be responsible for the largest reduction in greenhouse gas emissions in international shipping. But with that comes major challenges. But at this point in time, it is uncertain which fuel will be the future shipping fuel. All alternative fuels have lower energy densities that marine gas oil and this means that there is a need to have larger tanks on the ships resulting in lower storage capacity and or the refortification of the structure of the ship. Moreover, different safety measures are needed dependent on the future fuel. Next to this, the ship design could be further modified to increase the efficiency and the engine could be adjusted. DNV estimates that hydrogen and ammonia technologies are ready for commercial use in four to eight years. Fuel cells are far less mature than internal combustion engines, for all fuels. Ammonia, hydrogen and methanol can with internal combustion engines ICE (now methanol, in 2027 hydrogen and ammonia) and with Fuel cell in 2030 (**DNV**). The uncertainty about the future shipping fuel of choice could make shipping owners more reluctant to replace old vessels and to invest in new design and vessels. Because they would like to avoid that their new ships become stranded assets in 10 to 15 years from now.

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