Shipping en route to Paris Agreement overshoot

MAN Energy Solutions
Future in the making

– a solutions-based pathway to decarbonization

Table of Contents

Executive summary

The shipping sector will have a massive carbon overshoot where annual actual emissions and expected future emissions greatly exceed what is required to limit the global temperature increase to 1.5°C by midcentury. The accumulated carbon overshoot is estimated at 25 gigatonnes CO_2 equivalents in 2050. Retrofitting single-fuel engine technology to dual-fuel may reduce the carbon overshoot by 1.6 gigatonnes CO_2 equivalents (6%) before 2050. International regulation of newbuildings and the existing fleet, with a net zero CO_2 target year and ambitious intermediate targets, is required to limit the carbon overshoot, set a direction for well-to-wake decarbonization behavior, and avoid stranded assets. Further, carbon pricing is required to equalize the difference between the price of fossil energy and energy with a smaller or no carbon footprint. Engine technology is no hindrance to ambitious regulation and reduction of CO_2 in the shipping sector.

Shipping sector expected to grow 60% over the next 30 years

The shipping sector discussed in this paper is defined as the combination of the two-stroke segment, with container carriers, tankers, bulkers, gas carriers and general cargo vessels larger than 2,000 deadweight tonnes, and the four-stroke segment with cruise ships, dredging vessels, offshore vessels, passenger vessels, general cargo and smaller merchant ships, etc. The fleet weighed in at close to 3.0 bn dwt in 2020. The sector as a whole is expected to grow to 5.1 bn dwt in 2050 (Fig. 1). The 2022 figure is 3.14 bn dwt. The primary drivers of the sector growth are foreseen to be increased globalization and transport as well as a focus on elevating standards of living in developing countries. This will trigger cross- and intracontinental transport. Arguments against further sector growth are geopolitical uncertainties and increasing nationalism/regionalism. The sector growth is not expected to be linear, however, the direction remains.

Perspectives of 60% growth until midcentury add to the challenge of decarbonizing a hard-to-abate sector. Together with agriculture, aviation and industrial processes, shipping is typically described as “hard to abate” due to challenges with electrification and high abatement costs. Further, the sector requires vast amounts of energy with large distances between bunkering facilities. Shipping is internationally regulated through the International Maritime Organization (IMO), and because it is international it is harder to establish which country is responsible for the emissions. For the same reason, the shipping sector is not included in the Paris Agreement. However, all sectors must contribute their part to limit the temperature increase to 1.5°C [1]. As this paper shows, there is no technological hindrance for decarbonizing the shipping sector to a net zero CO_2 emission level by 2050.

In addition to the well-proven single-fuel engines, which can also be operated on sustainable biofuels and synthetic fuels, MAN Energy Solutions already offers dual-fuel engines capable of operating on LNG, methanol, ethane and LPG. The development of ammonia and hydrogen engines (focus on four-stroke) engines is ongoing.

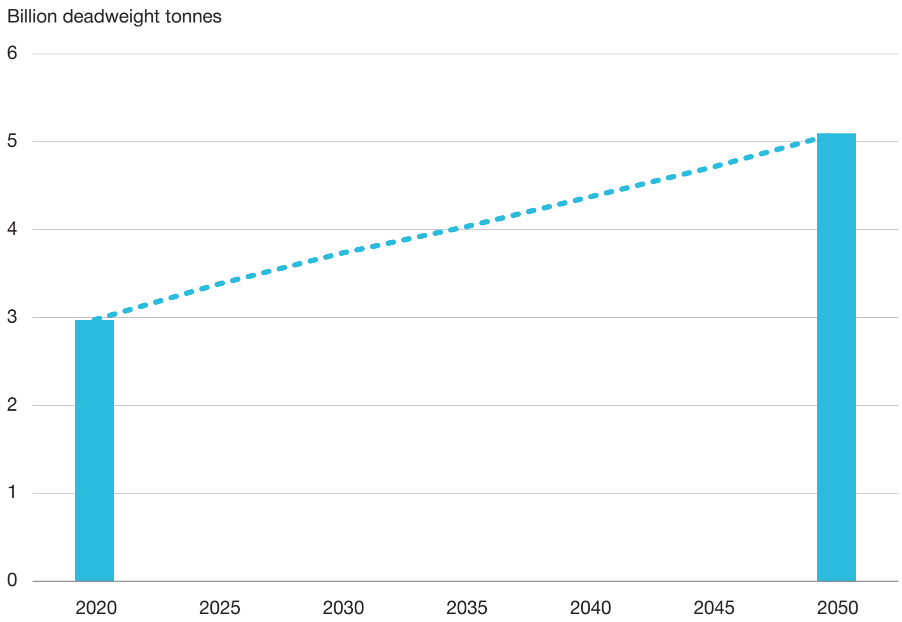

Fig. 1. Expected sector growth of shipping 2020-2050

Fuel mix expected to power the fleet

Unless energy efficiency is increased across the fleet, the fleet weight increase indicates that the shipping sector's energy demand will also increase by 60% until midcentury, from 13,400 petajoules in 2020 to an estimated 22,600 in 2050. The sector's total energy demand in 2022 is estimated at 14,039 petajoules. Historically, the demand has been composed of single fuel, such as heavy fuel oil and a small share of methane in the form of LNG. However, according to estimations made by MAN Energy Solutions, shipping is about to enter a period of fuel diversity, first with the rise of methanol in the 2020s and, later, with the rise of ammonia especially in the 2030s (Fig. 2). By 2050, single fuel is still expected to be dominant at 7,300 petajoules, with ammonia coming in second at 5,900, methanol third at 4,500, and methane at 3,800. In terms of weight, shipping will demand in 2050: 300 million tonnes of ammonia, 225 of methanol, 180 of single fuel, and 80 million tonnes of methane (Fig. 3).

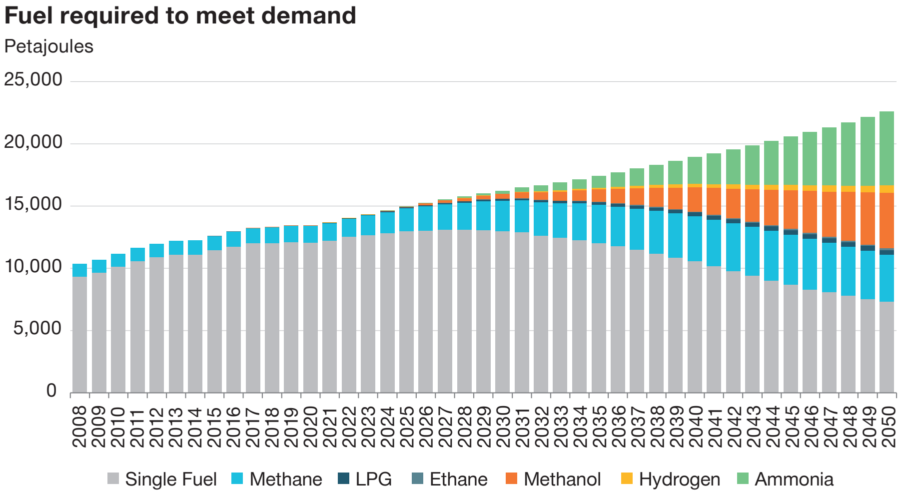

Fig. 2 MAN Energy Solutions expectation to fuel mix, here shown in energy

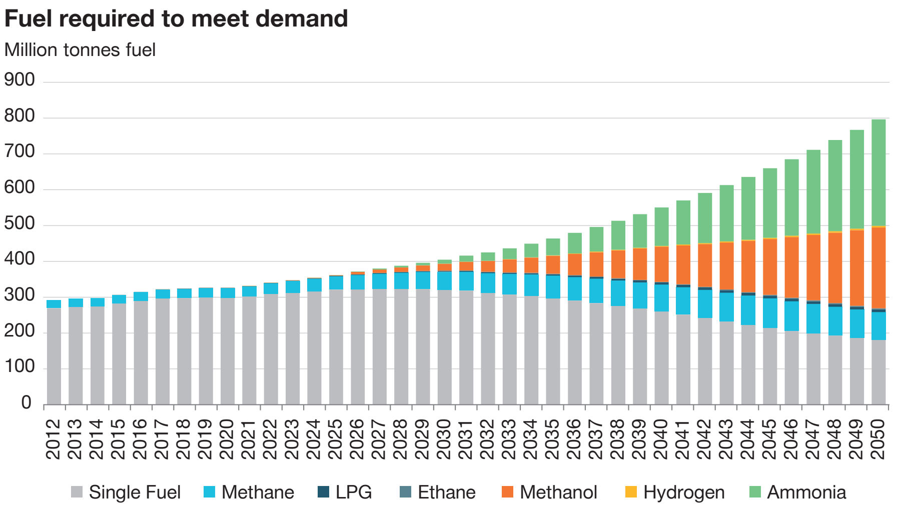

Fig. 3. MAN Energy Solutions expectation to fuel mix, here shown in weight

From 2020 to 2050, the fuel mix will transition from being fossil-based to being largely based on renewable energy (Table 1). This transition is expected to favor the fuels that can be produced using the least amount of renewable energy, and hydrogen-derived fuels such as methanol and ammonia. As a rule of thumb, fuel carrying ships, e.g. LNG carriers, will most likely burn the fuel that is transported, which is often fossil-based. The first ships to burn renewable-based fuels will most likely be non-fuel carriers fitted with, for example, methane, methanol, or ammonia engines, or ships transporting renewable fuels such as methanol or ammonia. Ships such as large container vessels with a methanol dual-fuel two-stroke engine are likely to run on renewable methanol unless the price difference to conventional fuel is too high, in which case they will run 100% on fuel oil or biofuels. Therefore, ships capable of burning methanol, hydrogen, and ammonia in 2030 are expected to run on at least 90% renewable fuels going toward 100% by midcentury. Other fuels will transition more slowly, depending on operation. Conventional fuel engines can be operated with net zero CO_2 emissions by running on certain types of biofuel.

Fuel type	2020	2030	2040	2050
Single Fuel	0%	10%	50%	100%
Methane	0%	10%	50%	100%
LPG	0%	10%	50%	100%
Ethane	0%	20%	50%	100%
Methanol	90%	90%	95%	100%
Hydrogen	90%	90%	95%	100%
Ammonia	90%	90%	95%	100%

Table 1. MAN Energy Solutions assessment of share of renewable fuels by fuel type

Well-to-wake emissions of the expected fuel mix

The assumed fuel mix and the share of renewable fuels enable a calculation of expected future CO_2 equivalent emissions (Fig. 4), using preliminary default emission factors presented in an IMO intersessional working group report [2] and FuelEU Maritime [3] (see Table 2).

It is crucial that future regulation of GHG emissions from shipping is based on a well-to-wake approach. Without considering the lifecycle emissions of marine fuels there is a risk of pushing emissions upstream without any benefit to the climate. Replacing conventional fuels with hydrogen or ammonia that is produced using fossil energy could lead to increased GHG emissions in a lifecycle perspective. Additional to the lifecycle emissions perspective, the production of marine fuels also requires a social perspective. For example, the production of certain biofuels may have an adverse effect on global food supply.

Sound guidelines for the assessment of lifecycle GHG emissions of marine fuels, possibly also including social factors, are therefore essential to support informed decision-making in the industry, and to ensure GHG reductions in a global perspective. Such guidelines should be transparent, scientifically sound, and based on recognized international or regional standards.

IMO's Initial GHG Strategy aims at reducing CO_2 emissions per transport work by 40% in 2030 and by 70 in 2050, and to reduce the total GHG

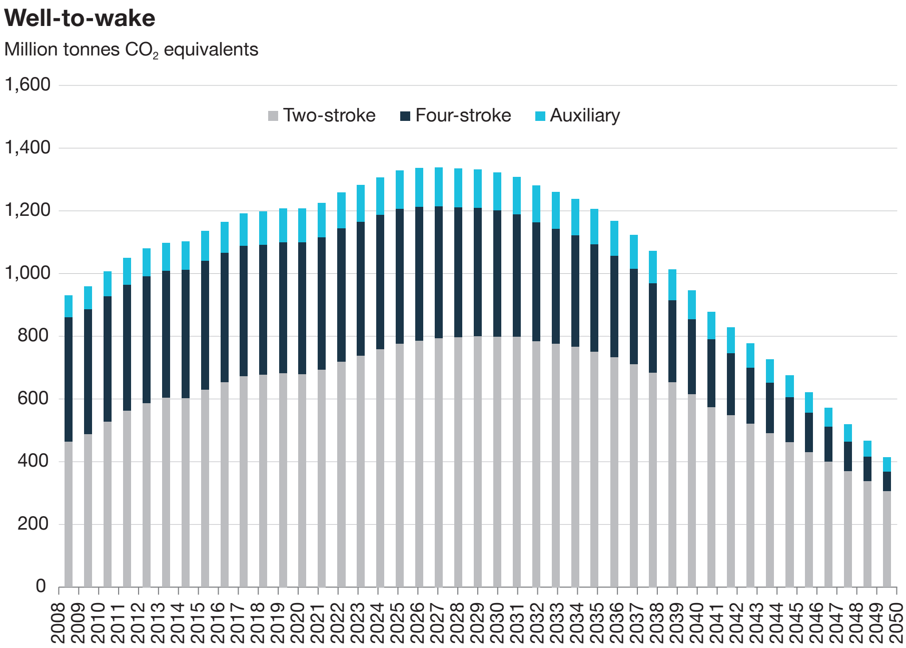

Fig. 4. Well-to-wake CO_2 equivalent emissions of the expected fuel mix

Feedstock	Fuel type	Well-to-tank	Tank-to-wake	Well-to-wake
Fossil	Hydrogen (natural gas)[a]	132.0	0.0	132.0
Fossil	Ammonia (natural gas)[a]	121.0	0.0	121.0
Fossil	Methanol (natural gas)[a]	31.3	69.1	100.2
Fossil	HFO[a]	13.5	78.1	91.6
Fossil	LNG (medium Otto)[a]	18.5	72.6	91.1
Fossil	LNG (large Otto)[a]	18.5	65.4	83.9
Fossil	LNG (large Diesel)[a]	18.5	57.7	76.2
Fossil	LPG[a]	7.8	65.5	73.3
Liquid biofuels	Bio-diesel (waste mix)[b]	-26.1	77.5	51.4
e-fuels	e-Methane (large Diesel)[c]	-52.1	57.7	5.6
e-fuels	e-Methanol[b]	-67.1	71.6	4.5
e-fuels	e-Hydrogen[a]	3.6	0.0	3.6
e-fuels	e-Ammonia[a]	0.0	0.0	0.0

Table 2. CO_2 emission factors in gCO_2eq/MJ ([a]FuelEU Maritime [3], [b]IMO [2], [c]Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping)

emissions from international shipping by 50% in 2050. IMO has adopted regulation aiming at increasing the technical and operational efficiency of ships. However, further measures aiming at promoting the uptake of low- and zero carbon fuels, such as a CO_2 tax, are still under negotiation.

The expected future well-to-wake CO_2 equivalent emissions are based on current regulation as well as an expectation of future additional CO_2/GHG regulation. As targets and target years of new regulation are currently unknown, Fig. 4 shows the development of emissions from the shipping segment based on the expected fuel mix shown in Fig. 3. When international regulations are passed, the figure can be adapted to show the effect. Based on the above assumptions, CO_2 equivalent emissions from the shipping segment are expected to peak in the late 2020s followed by a steady decline. The largest share of CO_2 emissions comes from the merchant fleet with two-stroke engines. Although a very effective technology, the sheer size of the sector results in relatively large CO_2 emissions. Emissions are foreseen to drop faster for the four-stroke segment than the two-stroke segment thanks to the increased electrification of especially coastal-near shipping.

Considering the massive fleet, the speed of change will be slow. If net zero is not reached by midcentury (Fig. 4) it will be the direct result of the lack of regulation: The target year can be sooner or later, depending on the ambitions of regulators.

Substantial carbon overshoot

Irrespective of a net zero target year for shipping, the intermediate CO_2 overshoot will be a huge challenge. CO_2 overshoot describes how shipping emits too much CO_2 annually compared to a line from actual CO_2 equivalent emissions in 2008 to net zero in 2050. If all emissions above this line are accumulated, shipping will have a CO_2 overshoot of 25 gigatonnes by 2050, peaking with an overshoot of approx. 900 mio tonnes CO_2 in 2031 (Fig. 5). The implication is that the shipping sector's possibility of contributing to the Paris Agreement targets is threatened, even if net zero CO_2 operation is achieved by 2050. The real challenge of decarbonizing shipping is to limit the CO_2 overshoot. Shipping's overshoot could be partly compensated by additional carbon capture or carbon negative activities in other sectors.

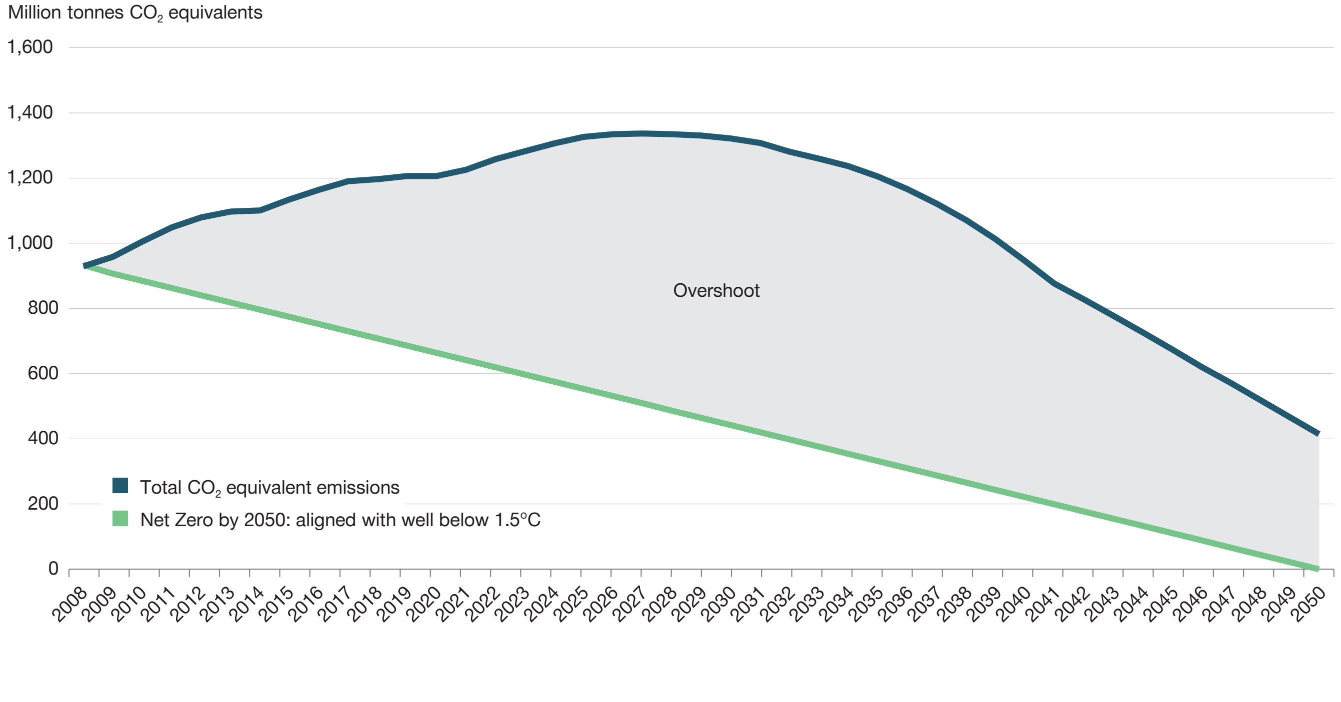

Fig. 5. CO_2 overshoot is the area between the net zero line and the total actual/expected CO_2 equivalent emissions

Retrofit as a means to reduce carbon overshoot

In addition to new ships operating on fuels with low- or zero GHG intensity, a multitude of technologies can help reduce the CO_2 overshoot of the shipping sector. Digitalization can be used as a means to optimize operations, and increase energy efficiency. However, due to the long lifetime of ships, retrofit of the existing fleet is necessary to substantially reduce the carbon overshoot.

Retrofitting a single fuel engine to a new technology that lends itself to operation on new fuels such as methanol and ammonia has the possibility to accelerate the maritime energy transition. Retrofitting requires mature main engine technologies and shipyard capacity to be operationalized and scalable. MAN Energy Solutions expects retrofit solutions to shave off 6% of the CO_2 overshoot, namely 1.6 gigatonnes (Fig. 6). Retrofit of two-stroke engines will be particularly interesting for ultra large container vessels, new-Panamax, post-Panamax, and to some extent Panamax and feeders, very large gas carriers, very large bulk carriers and very large crude oil carriers. Retrofit of four-stroke engines will be particularly interesting for cruise, RoPax, and feeder container vessels.

Retrofitting has historically been limited and based on converting conventional single-fuel engines to methane technology and, for niche vessels, to LPG. With the advent of large-bore methanol engines, a larger share of retrofitting could be to methanol. Later, once the ammonia technology for two-stroke and four-stroke engines is matured, ammonia too could take a fair share of retrofits. By 2025, 70% of two-stroke retrofits are expected to be to methanol technology and 30% to methane, whereas by 2030, 50% is expected to be to ammonia, 40% to methanol, and 10% to methane. Similarly, 90% of four-stroke main engine retrofits are expected to be to methane technology and 10% to methanol in 2025, whereas by 2030, 70% is expected to be to methanol, 20% to methane, and 10% to ammonia.

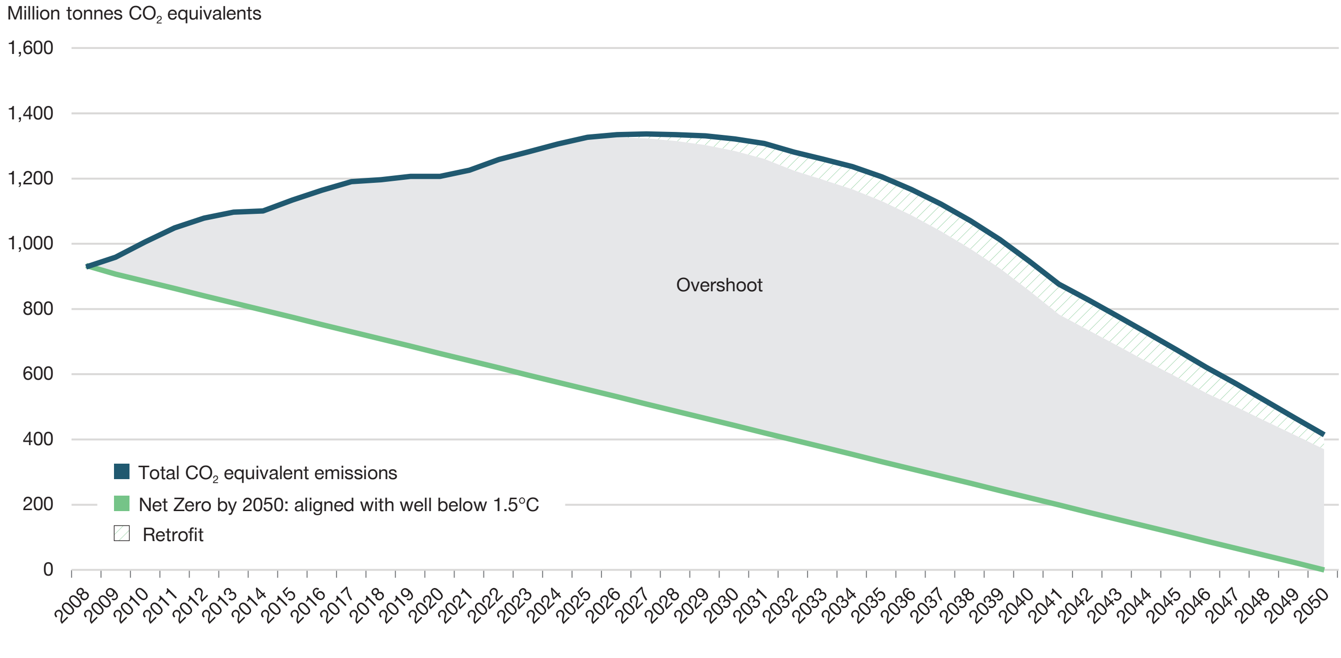

Fig. 6. Expected retrofitting reduces the CO2 overshoot area with 6%

Discussion

The CO_2 overshoot that is accumulating yearly until regulated is highly problematic due to the global warming potential of CO_2. Two key elements are essentially needed to decarbonize shipping: Net zero carbon fuels and energy efficient ships capable of operating on those fuels. Medium-sized two-stroke methanol engines are already in operation. The first large-bore methanol engines will be delivered by the end of 2022. Ammonia engine technology needs maturing, but will sail the seas by the mid-2020s. It will start with medium-sized two-stroke engines where proof of concept, particularly concerning safety, will need to be made. Technology that naturally lends itself to net zero CO_2 operation is therefore essentially already available. Thus, from a propulsion technology perspective, there is no technological hindrance to pass ambitious international regulation of CO_2 emissions from shipping. Regulation is paramount for driving the investments in production and infrastructure for new net zero carbon fuels, thus enabling decarbonization of shipping.

For regulation to be effective, it will first of all need to be international. Regional or national CO_2 regulation may precede international regulation and could have a particularly positive effect on infrastructural preparations at ports, energy logistics, and energy production. Second, it will require a specific newbuilding focus. Today, around half of propulsion contracting measured in kW is dual-fuel, but ship owners need a general direction for the investments to avoid stranded assets. Third, it will require a specific existing fleet focus to tackle the massive installed base that is delivered to fossil technology. Additionally, a carbon/GHG pricing scheme is required to promote uptake of net zero fuels and to offset the price difference between fossil fuels and net zero fuels. Most importantly, intermediate targets on the way to the net zero target year are required. In this way, the CO_2 overshoot could be somewhat reduced.

Two central operational challenges in decarbonizing the shipping sector are that it requires large volumes, and thus scalability, and that several sectors need to be coordinated to implement the transition. This is the case with energy supply, shipyard capacity, engine builder capacity, as well as test facilities for relevant fuels. Regarding energy supply, shipping is dependent on the general transition of the global energy system from fossil fuels to renewable energy. Once international regulation is passed, all sectors will have a shared direction, and investment opportunities will be made transparent. Investments in production and supply chain of renewable fuels will be significantly larger than investments in ship-based technology and, therefore, the long term direction is required to facilitate such investments.

Additionally we will likely see a positive impact from investments in vessel energy efficiency. Such investments could be of a technical nature such as various wind-assisted technologies, hull air lubrication, waste heat recovery, or shaft generators. Or investments could be of an operational nature such as slow steaming and just-in-time arrival. In particular, digitalization could have a significant impact on operational savings.

The goal of the maritime energy transition is to limit the temperature increase to 1.5°C by midcentury. The challenges are not insurmountable. In fact, their solutions are largely known. By proper planning, they can be operationalized. However, to avoid a spray-and-pray implementation, leading to many separate initiatives with a limited scalable effect, a central direction and targets are needed. To achieve it, international regulations with ambitious intermediate targets are needed to reduce the intermediate CO_2 overshoot on our way to net zero shipping.

References

[1] IPCC, “Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change,” Cambridge University Press, Cambridge, UK and New York, NY, USA, 2022.

[2] IMO, “Development of draft lifecycle GHG and carbon intensity guidelines for maritime fuels (draft LCA guidelines) ISWG-GHG 11/2/3,” 2022. [Online]. Available: https://www.ics-shipping.org/wp-content/uploads/2020/08/draft-life-cycle-ghg-and-carbon-intensity-guidelines-for-maritime-fuels-1.pdf [accessed 13 Oct 2022].

[3] European Commission, “Proposal for a Regulation of the European Parliament and of the Council on the use of renewable and low-carbon fuels in maritime transport and amending Directive 2009/16/EC,” 2021. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0562 [accessed 13 Oct 2022].

The figures for two-stroke CO_2 equivalent emissions were calculated through the following steps:

1. The fleet size in deadweight tonnes 2022-2050 was forecasted
2. The two-stroke fleet size was calculated in kW
3. Energy consumption per year was calculated as the product of average sailing hours, kW, average load percentage; load percentage and kW are corrected for EEDI effects
4. Yearly energy consumption was converted to yearly fuel demand based on MAN Energy Solutions technologies; specific fuel consumption was corrected to account for relevant calorific values (MJ/kg) and fuel mix forecast
5. Fuel demand per year was converted to CO_2 emissions.

The figures for four-stroke were calculated through the following steps:

1. Engines in each ship type and size were counted
2. Fleet growth was forecasted based on MAN Energy Solutions review of Clarkson Newbuilding Market Report - forecast fleet development (June, 2021)
3. Table O.7 in Fourth IMO GHG Study 2020 was used to calculate share of CO_2 emissions.

The figures for auxiliary were calculated as a percentage of two-stroke main engine with the assumption that auxiliary engine fuel follows main engine fuel. It is assumed that auxiliary engines have the following CO_2eq emissions of the main engine: bulk 12%, container 13%, general cargo 17%, LNG carrier 17%, LPG carrier 15%, tanker 16%, VLCC 15%, all others 43% (e.g. ferries).

MAN Energy Solutions
2450 Copenhagen SV, Denmark
P +45 33 85 11 00
F +45 33 85 10 30
info-cph@man-es.com
www.man-es.com

All data provided in this document is non-binding. This data serves informational purposes only and is not guaranteed in any way. Depending on the subsequent specific individual projects, the relevant data may be subject to changes and will be assessed and determined individually for each project. This will depend on the particular characteristics of each individual project, especially specific site and operational conditions.

Copyright © MAN Energy Solutions.
5510-0253-00ppr Nov 2022. Printed in Denmark