Technological, operational and energy pathways for maritime transport to reduce emissions towards 2050

A recent study undertaken by Ricardo on behalf of the Oil and Gas Climate Initiative (OGCI) and Concawe identified various combinations of alternative fuels and technologies that could provide possible pathways for meeting the IMO's ambition for 2050. This article provides a summary of the outcomes of the study. A link to the complete study report is provided at the end of the article.

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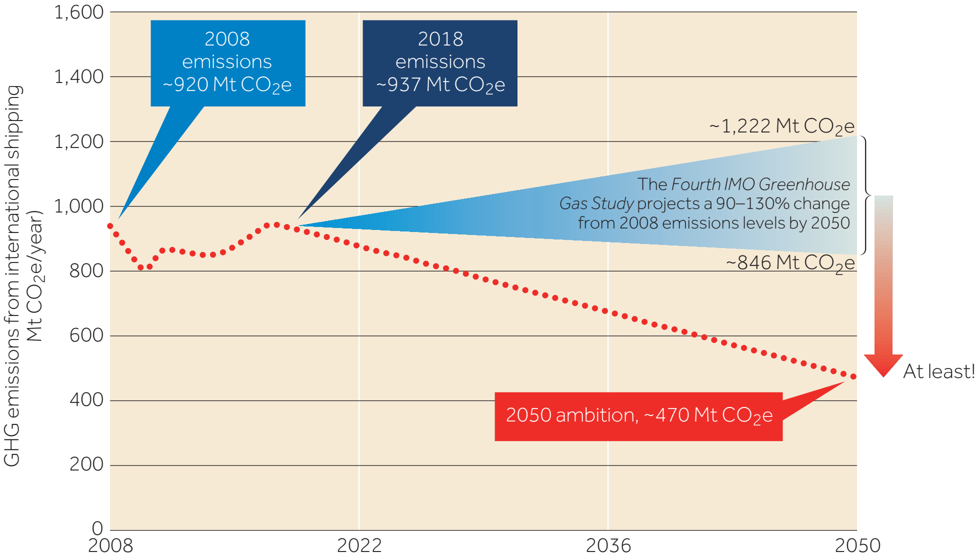
Introduction

The International Maritime Organization's (IMO's) fourth greenhouse gas (GHG) study, published in 2020, gave its forecasts for the future development of emissions from international maritime transport (see Figure 1), based on long-term global economic scenarios consistent with limiting the global temperature rise to less than 2°C. These projections emphasised the considerable challenges that the industry faces in meeting the 2050 ambition.

Figure 1: Carbon dioxide equivalent (CO_2e) emissions from international shipping from 2008 to 2018, and projections to 2050 under scenarios consistent with a 2°C global temperature rise



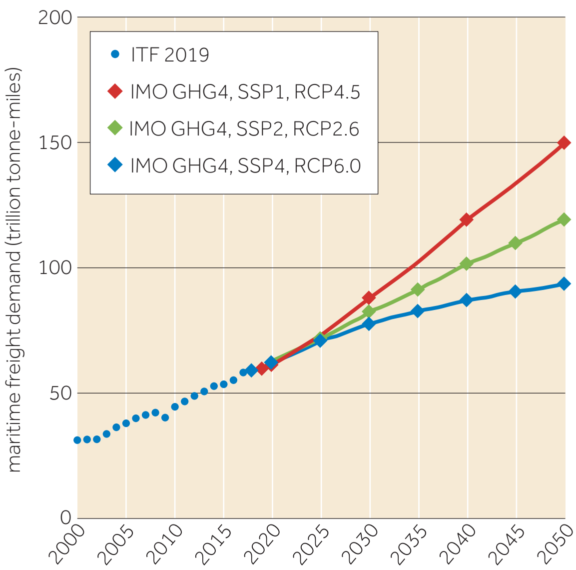
Historically, seaborne trade has been closely correlated with world gross domestic product (GDP), at least since 1990. World seaborne trade grows approximately in line with world GDP and has more than doubled over the past 20 to 25 years. Therefore, with anticipated growth in global GDP, there is a need to decouple international shipping emissions from economic growth.

The rapid growth in demand over the past 20 years has led to significant changes in the structure of the fleet, with increases in the size of new ships to leverage economies of scale. This has been largely driven by the requirements to reduce fuel costs, as these costs are one of the strongest incentives for operators. This has been particularly evident in the container sector, which has also been supported by a trend of increased containerisation of goods for transport, a trend that is expected to continue.

Because of the structure of the shipping sector, the introduction of new technologies is more difficult, because of the 'split incentive' issue, than in other transport sectors. This is because responsibilities such as fuel charges, operational measures, technological investments and cargo loading can be allocated to either ship owners or ship charterers. Whether or not there is an incentive for a ship owner to implement energy efficiency measures is often highly dependent on the charter rate that the charterer pays to the ship owner. If the benefit of the energy efficiency measure is not accrued by the party paying for its implementation, this can act as a barrier to the adoption of the measure when ordering a new ship.

Analyses of different sources of data have shown that global CO_2 emissions from international shipping were about 860 million tonnes in 2019, with a growth rate of more than 2% per annum from 2013 to 2018. The three main ship categories for CO_2 emissions were bulk carriers, container ships and tankers. Projections of future demand growth from different sources show considerable variations, ranging from 58% to 153% growth by 2050 (relative to 2018). The different future growth scenarios analysed for this study are shown in Figure 2.

Figure 2: Future growth scenarios for maritime freight demand



Notes:

Data sources: International Transport Forum (ITF) *Transport Outlook* (2019) and IMO's *Fourth IMO Greenhouse Gas Study* (2020).

GHG4 = *Fourth IMO Greenhouse Gas Study*

SSP = Shared Socio-economic Pathways — alternative plausible trajectories for societal development

RCP = Representative Concentration Pathways — GHG concentration trajectories adopted by the Intergovernmental Panel on Climate Change (IPCC)

Many operators have implemented reduced vessel speeds to reduce fuel consumption, emissions and costs. Speed reductions are especially effective in reducing fuel consumption when waiting times at ports are converted to a slower cruising speed (just-in-time arrival) and the cargo carrying capacity of vessels is maximised. Speed reductions of up to 30% have been used, though not for time-sensitive cargos. The use of reduced vessel speeds also requires more ships to be at sea to achieve the same delivery rates, reducing the overall effectiveness of the measure. Nonetheless, it is seen as having overall benefits, which will increase further as new ships are delivered with lower design speeds.

Analyses of ship demolition ages show that, for most categories, the average retirement age is about 25 years, while for roll-on/roll-off (Ro-Ro) ships it is about 35 years. These long lifetimes limit the rate of penetration of new technologies into the operating fleet, and developments such as lower design speeds can take several years to have an effect on the overall fleet efficiency. Some technologies, such as waste heat recovery have the potential to be retrofitted to the in-service fleet, thus accelerating the penetration of such technologies. However, these technologies tend to have a smaller impact on the overall fuel efficiency than other technologies that need to be incorporated at the design stage.

Meeting the IMO's 2050 decarbonisation ambition will need significant change in the shipping industry

The *Fourth IMO Greenhouse Gas Study*, published in 2020, indicated that significant progress has been made, with global emissions in 2018 being almost the same as those in 2008. However, the IMO's future projections of emissions from the sector in 2050—between 90% and 130% of 2008 levels—miss the 2050 ambition by a considerable margin. To achieve the IMO's ambition will require the introduction and large-scale deployment of new technologies and/or alternative low-carbon fuels across international shipping.

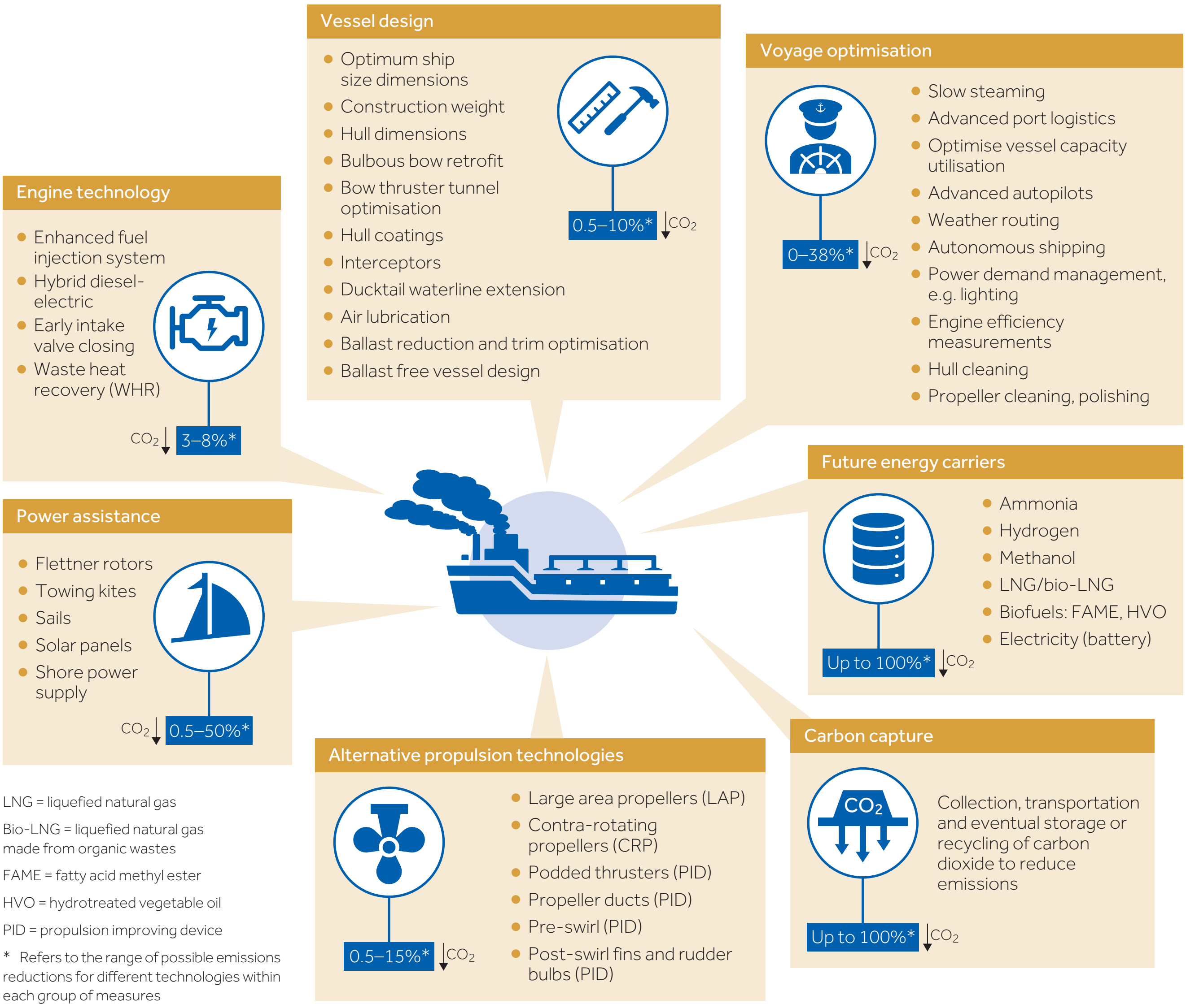
Traditionally, the demand for maritime transport has been well correlated with global GDP. Although projections for future development show changes in the nature of goods transported—largely due to decarbonisation efforts in other sectors, leading to a reduction in demand for transporting oil and coal but a commensurate increase in demand for transporting raw materials and products—the majority of projections continue to show a strong growth in demand.

Alternative fuels and technologies required to decarbonise international shipping

The study reviewed the available literature and interviewed multiple stakeholders to identify the technologies and alternative fuels that would be available to decarbonise international shipping. The different technologies and fuels are shown in Figure 3.

Each of the technologies considered was assessed for its applicability (ship categories), availability (entry-into-service dates), carbon reduction potential and cost (capital and operating).

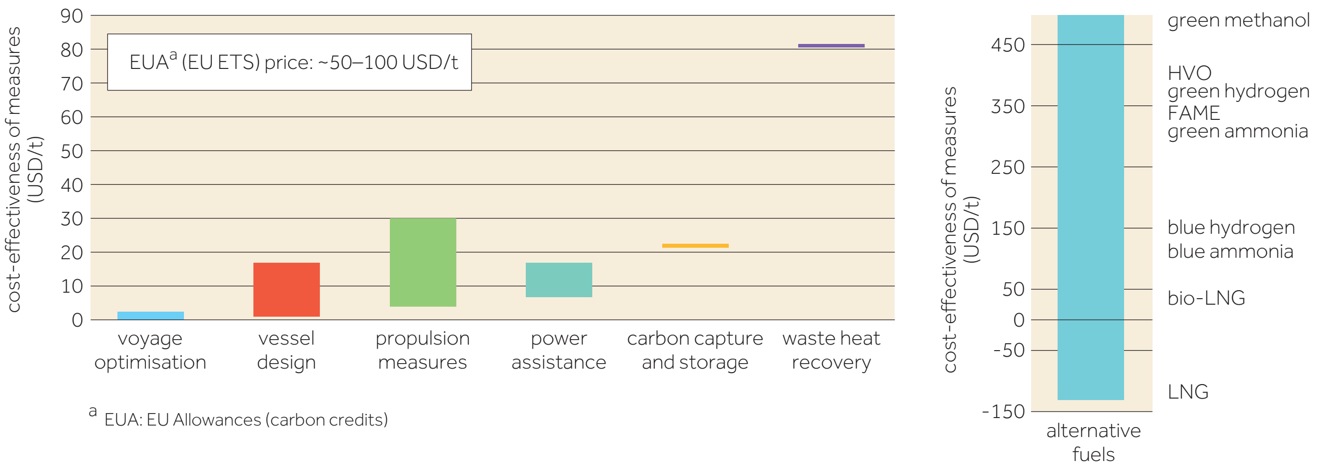
Figure 3: Options to decarbonise shipping — alternative fuels and technologies



Identification of the most cost-effective fuels and technology measures

A number of alternative fuels and technology measures were identified which have a wide range of cost-effectiveness, mostly below today's current EU ETS[1] prices. These are summarised in Figure 4.

Figure 4: Cost-effectiveness of the various technologies and alternative fuels considered



Three 'fuels and technology options' packages

Three different combinations of alternative fuels and technology options were defined as 'packages' depicting possible pathways for achieving the IMO's ambition. Each package was subsequently analysed to determine its potential impacts. The packages were not defined as the 'most likely pathways', but more to exemplify possible pathways, with significant variations to illustrate the range of routes available towards decarbonisation. These packages were characterised as shown in Figure 5.

Figure 5: The three 'fuels and technologies packages' defined for analysis in the study

Package 1	Package 2	Package 3
Characterised by an early pursuit of carbon-free alternative fuels	A moderate uptake of an interim alternative fuel (represented by LNG) in the short term	Maximum use of decarbonisation measures while using conventional fuels
Introduction of new-build ships using grey hydrogen and grey ammonia, and battery electric (coastal shipping) from 2025. Followed by a transition from grey to blue fuel pathways and to green from 2035 onwards. Medium take-up of energy efficiency technologies and operational measures. A 10% speed reduction is assumed for slow steaming. No on-board CCS.	From 2025, HFO and MDO use is assumed to be increasingly substituted with drop-in biofuels (FAME, HVO). LNG transitions to bio-methane (bio-LNG) from 2030 onwards. Medium take-up of energy efficiency technologies and operational measures. A 20% speed reduction is assumed for slow steaming. No on-board CCS.	Conventional fuels, HFO and MDO, with a later transition to reduced-carbon alternative fuels using pathways that provide some reductions in emissions. Gradual transition to use of bio-LNG, green methanol and green ammonia. High take-up of energy efficiency technologies and operational measures. A 30% speed reduction is assumed for slow steaming. On-board CCS post 2030.

[a] HFO = heavy fuel oil [b] MDO = marine diesel oil [c] CCS = carbon capture and storage

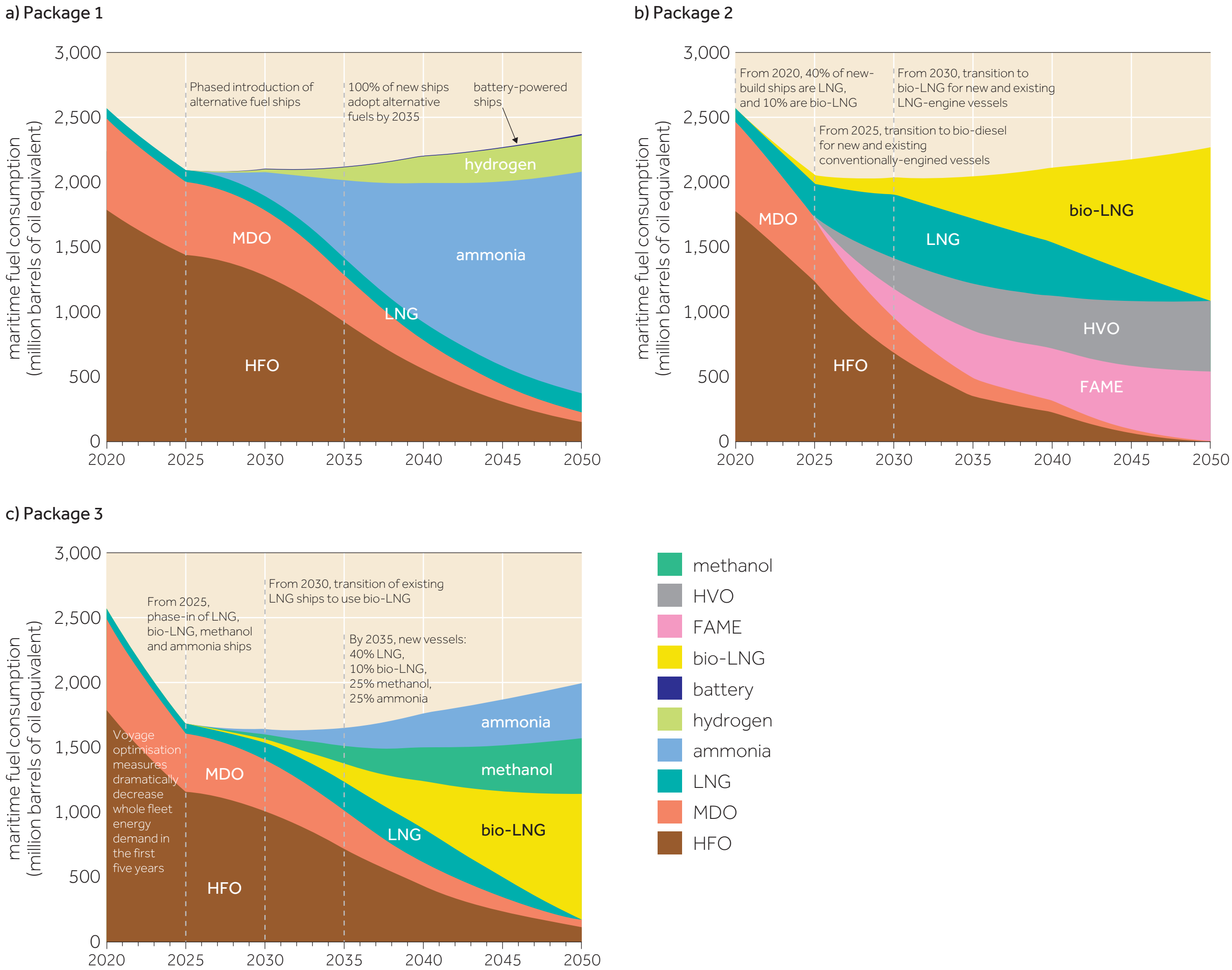
[1] European Union Emissions Trading System

The overall analysis presented in this study is based on a scenario model, investigating the potential emissions to 2050 under the three scenarios, together with the potential reductions in those emissions arising from the implementation of the sets of technologies and alternative fuels identified. It is important to recognise that these scenarios do not indicate the 'most likely' future, nor do they provide definitive indications of the costs to achieve particular levels of emissions savings, but indicate what can be achieved under certain assumptions.

Fuel consumption for the three packages up to 2050

The modelled fuel consumption for each of the three 'fuels and technologies' packages described above is shown in Figure 6.

Figure 6: Modelled fuel consumption to 2050 for each of the three packages defined in the study



The IMO's ambition is estimated to be met by all three packages when emissions are calculated on a well-to-wake basis

The results of the modelling showed that, by 2050, the emissions under the baseline scenario would be between 4% and 82% higher than in 2008, depending on the demand scenario assumed, compared to the IMO's ambition of a 50% reduction (also relative to 2008). These increases in emissions were calculated on a 'well-to-wake' basis, as this represents the full impact on the global climate and is important when considering the impact of alternative fuels.

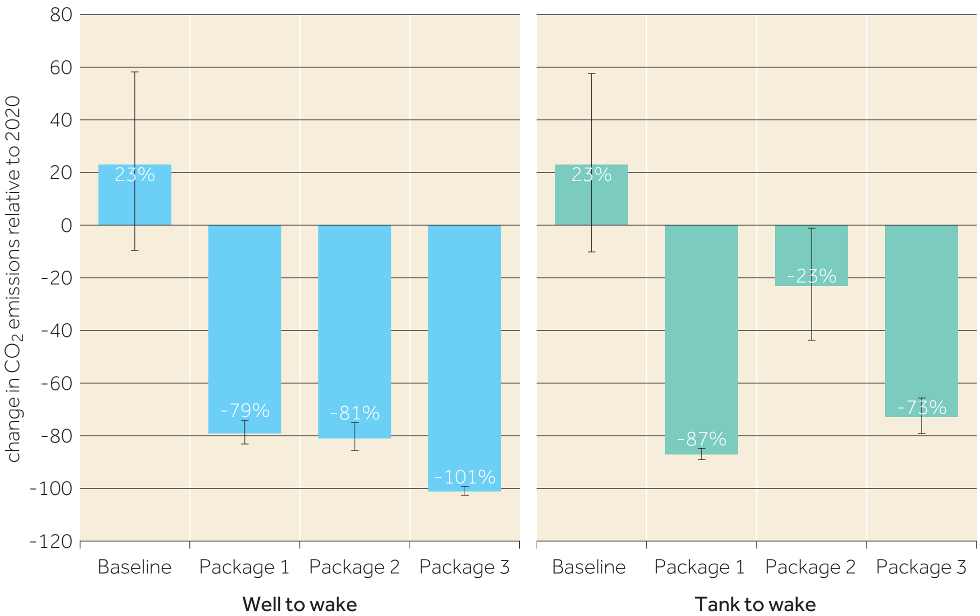
Under the three fuel and technology packages, these increased emissions (in the baseline scenario) are replaced by significant decreases in most cases by 2050:

- Under package 1, emissions are reduced by more than 70% relative to 2008 under all three demand scenarios, comfortably exceeding the IMO's ambition.
- Under package 2, the reductions in emissions are very similar to those under package 1.
- Under package 3, the reductions in emissions relative to 2008 reach approximately 100% under all three demand scenarios. The package includes a transition to 'green', but carbon-containing, fuels and the use of on-board carbon capture technology. The combination leads to a net capture of CO_2 over the complete fuel production and combustion process, leading to a net negative emission and a reduction of slightly more than 100%. Carbon capture is therefore assumed to be available in time for this scale of deployment; under the assumptions used in the modelling, for the central scenario, by 2050, approximately 35% of the global fleet is equipped with carbon capture technology. Carbon capture then contributes approximately 16% of the total well-to-wake emissions reductions under this package.

These changes in CO_2-equivalent (CO_2e) emissions are shown in more detail for 2050 (relative to 2020) in Figure 7 on page 25. Results are shown for both well-to-wake and tank-to-wake emissions, with the results for the central demand scenario shown as coloured bars and the range between the low and high demand scenarios represented by the error bars.

All three packages are estimated to exceed the IMO ambition on maritime decarbonisation by 2050, but this is only assured if the emissions are considered on a well-to-wake basis. Consideration may need to be given to reformulating the IMO's ambition on a well-to-wake basis and incorporating well-to-wake emissions in policy measures to capture the decarbonisation benefits of such alternative fuels and to enable their deployment.

Figure 7: Changes in CO_2e emissions in 2050 (relative to 2020) for all three packages under the central demand scenario (error bars indicate the range between the low and high demand scenarios)



Under package 3, about 16% of the total reduction in emissions to 2050 (relative to the baseline) is due to the use of on-board carbon capture. The relative contributions of vessel technologies, alternative fuels and carbon capture to the emissions reductions achieved under the three packages are shown in Table 1.

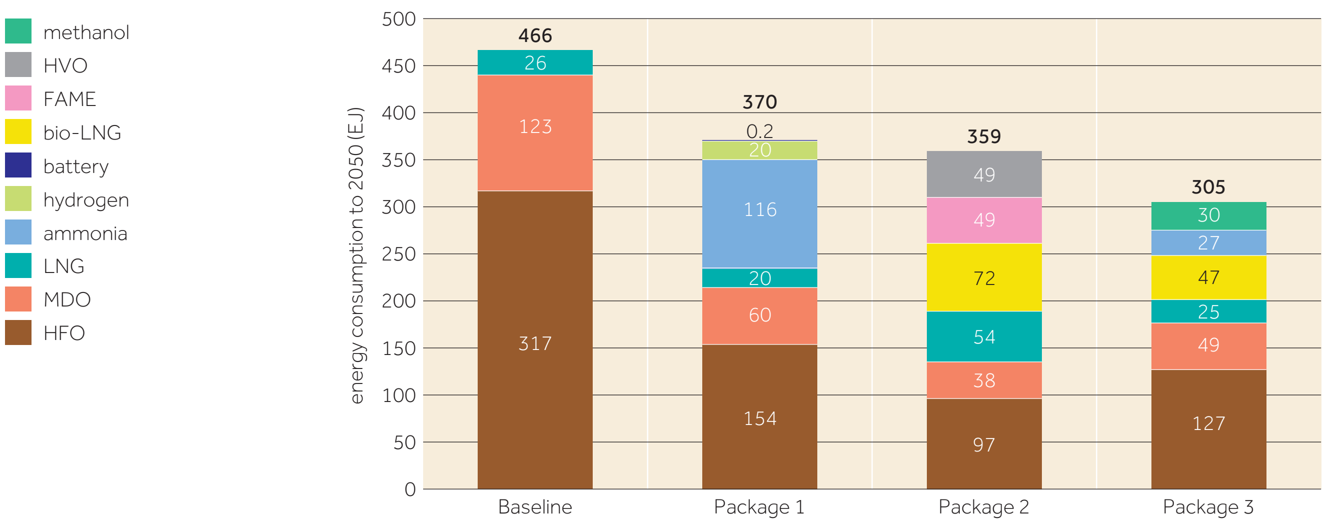
Table 1: The relative contributions of vessel technologies, alternative fuels and carbon capture to the emissions reductions achieved under the three packages

	Package 1	Package 2	Package 3
Technology	31%	34%	44%
Fuel	69%	66%	40%
Carbon capture	-	-	16%

The reductions in CO_2e emissions shown above are accompanied by improvements in carbon intensity (CO_2e emissions per unit work, expressed as g/tonne-mile) of between 50% (package 1) and 65% (packages 2 and 3) in 2030, relative to 2008, and between 91% (packages 1 and 2) and 101% (package 3) in 2050. These changes in carbon intensity are similar across the three demand scenarios.

The cumulative quantities of the different fuels required to 2050 under the three packages to achieve the emissions reductions described are shown in Figure 8.

Figure 8: Quantities of fuels required to 2050 to achieve the emissions reductions described in the study



Net present value of the accumulated additional total costs for ships from 2020 to 2050

The cost analyses show that achievement of the emissions reductions will increase costs by 4% (package 1), 9% (package 2) and 3% (package 3) over the central baseline scenario, based on total costs to 2050 (using a 10% discount rate). The total additional costs incurred are a combination of vessel capital costs, fuel costs and other vessel operating costs.[2] The fuel price projections used in this study were provided by IHS Markit. The modelling also includes estimates for the additional fuel bunkering costs. Some insight into the additional fuel production infrastructure costs is provided in Section 8 of the full report; however, as the additional fuel production costs are expected to be amortised through higher fuel prices, they are not included separately in the results discussed here. These costs are calculated for each of the fuel and technology packages and the baseline; the impacts of the packages are then seen as the difference from the baseline.

[2] The additional vessel capital costs include the addition of specific technologies but do not change with fuel type. The fuel costs are based on specific pathways for the production — these were selected from a range of options identified as providing high levels of well-to-wake emissions reductions, but they are not necessarily the pathways that would be adopted most widely.

These costs are calculated as incurred over the full period from 2020 to 2050; net present values (NPVs) are then calculated using a range of discount rates. The results for the central demand scenario using a discount rate of 10% are shown in Table 2.

Table 2: Cost analysis for the baseline case and each of the three packages from 2020 to 2050 (discounted costs, USD billion)

	Vessel capital costs	Fuel costs	Other operating costs[a]	Total NPV
Baseline	52	1,638	3,848	5,539
Package 1	91	1,751	3,932	5,774
Package 2	86	2,002	3,939	6,027
Package 3	465	1,452	3,803	5,720

[a] Other operating costs include crew costs, stores costs, lubricant costs, maintenance costs, insurance costs and administration costs

For packages 1 and 2, the additional total costs over the baseline are dominated by the increased fuel costs, while for package 3 vessel capital costs dominate (as expected as it has the highest level of additional vessel technologies applied of the three packages). The high fuel costs under package 2 are primarily related to the use of drop-in fuels, principally bio-LNG, FAME and HVO.[3] The investigations under this study identified higher projected fuel prices to 2050 for these fuels than other types.

Combining the calculated emissions reductions and additional costs, with a discount rate of 10% applied to both emission savings and costs, gives the cost-effectiveness values in USD/tonne CO_2e, as shown in Table 3.

Table 3: Cost-effectiveness analysis for the three packages (discounted cost-effectiveness, USD/tonne CO_2e)

	Vessel capital costs	Fuel costs	Other operating costs	Total NPV
Package 1	12	35	26	73
Package 2	8	84	21	113
Package 3	88	-40	-10	39

[3] There is a higher level of uncertainty in the price projections for bio-LNG as IHS Markit did not provide projections for it consistent with those for the other fuels; therefore, additional information was used when deriving the projection for bio-LNG for this study. Further information on the fuel price assumptions, and their contribution to the overall cost calculations, is given in Sections 6.2.1 and 7.3 of the full report.

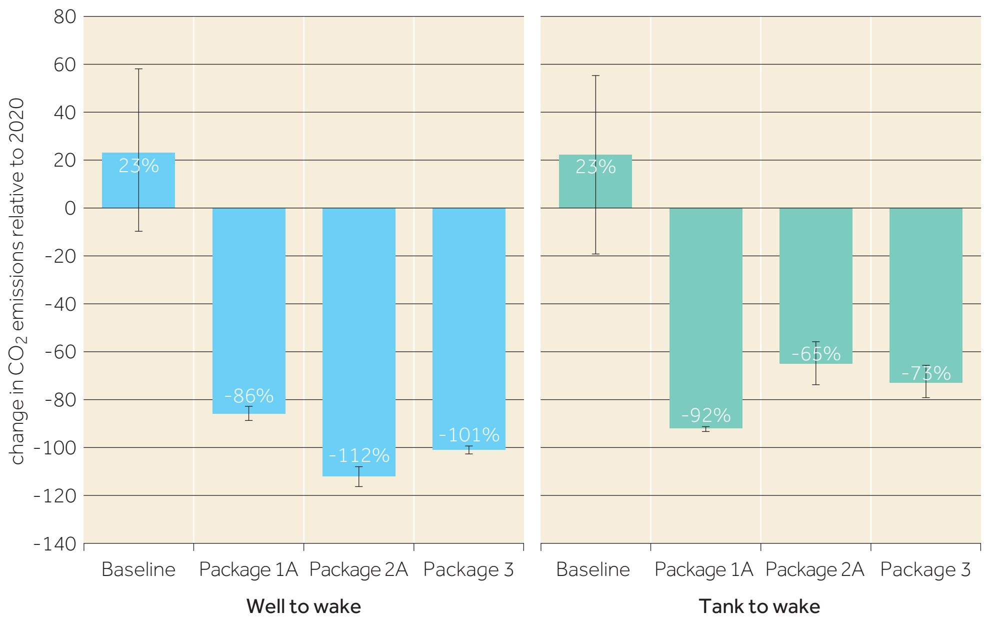
Package 3 has a slightly smaller cost increase over the baseline than package 1, and has significantly greater emissions savings, leading to a lower cost per tonne of CO_2.

The results of the emissions analyses indicate that the IMO's ambition can be met (and, indeed, surpassed) with a high confidence under the assumptions described — that is to say that if the fuels are switched as described, there is high confidence in the emissions that result from using these fuels; naturally, however, there is a lower level of confidence in the calculated costs. In addition to the uncertainty inherent in the fuel price projections, the actual costs will be sensitive to decisions made in the future (for example, a high uptake of one alternative fuel type could lead to prices for different fuel types that are significantly different from those assumed for this study, which were based on projections assuming a more balanced marketplace).

Sensitivity analysis based on increased deployment of vessel technologies

In addition to packages 1, 2 and 3 described previously, the alternative fuels assumptions of packages 1 and 2 were combined with the advanced technology assumptions of package 3, forming packages 1A and 2A, respectively. A sensitivity analysis was then undertaken to study the effect of the increased deployment of vessel technologies. Increasing the deployment of vessel technologies (relative to packages 1 and 2) gives increased emissions reductions, so that packages 1A, 2A and 3 all meet the IMO's ambition on both a tank-to-wake and a well-to-wake basis. These reductions in 2050, relative to 2020, are shown in Figure 9.

Figure 9: Changes in CO_2e emissions in 2050 (relative to 2020) for packages 1A, 2A and 3 under the central demand scenario (error bars indicate the range between the low and high demand scenarios)



The inclusion of the additional vessel technologies in packages 1A and 2A (compared to packages 1 and 2) reduces the energy demand and hence the fuel costs. Under package 1A, this reduction in fuel costs is greater than the increase in vessel costs associated with the additional technologies, leading to overall costs that are significantly lower than under package 1. Under package 2A, however, the increased vessel costs are almost equal to the reduction in fuel costs, leading to a small reduction in total costs compared to package 2. These results assume a 10% discount rate.

Table 4 shows the overall cost-effectiveness (USD per tonne of CO_2 abated) of the three packages studied under the main analysis (packages 1, 2 and 3), and the two additional packages formed to undertake the sensitivity analysis (packages 1A and 2A).

Table 4: Overall cost-effectiveness of packages 1, 2 and 3 (main analysis) and packages 1A and 2A (sensitivity analysis)

	10% discount rate (USD)	5% discount rate (USD)
Package 1	73	120
Package 1A	11	47
Package 2	113	149
Package 2A	83	120
Package 3	39	83

Risks and barriers

This study and others show that it should be technologically possible to decarbonise the global shipping sector to the level of the IMO's ambition. However, despite the technical feasibility, we have not so far seen rapid decarbonisation at the rate and scale required, and barriers to decarbonising the shipping sector remain — see Figure 10.

Figure 10: Risks and barriers to decarbonising the shipping sector

GHG reduction potential

- Uncertainty between 'tank to wake' and 'well to wake', and in how 'well to wake' is defined.
- 20-year global warming potentials make LNG/bio-LNG less palatable.

Price differential

- HFO price and scale is difficult to match.
- Regulatory intervention may help reach price parity.

Infrastructure

- Bunkering infrastructure and port refuelling facilities need to be scaled up.
- (Not a barrier for drop-in fuels.)

Production increase, location

- Alternative fuel production needs to be increased substantially and be appropriately located. (Dedicated new facilities? Or convert existing assets?)
- Renewable electricity sources may be in different geographies to existing assets.

Split incentives

- Customers and charterers not willing to pay for, or co-fund, lower-emission solutions.
- No clarity on how the preferred fuel(s) will be chosen to allow for scale.

Sustainability certainty

- Chemically identical brown/blue/green fuels need reliable certification schemes to provide assurance/guarantees.
- Uniform/standardised sustainability criteria may also need global consensus.

Conclusions

A range of fuel options are currently being assessed; multiple pathways involving different alternative fuels could meet the IMO's initial ambition for 2050. However, it remains to be seen whether the next edition of the IMO's '*Greenhouse Gas Study*' (due to be updated in 2023) will reflect a tightening of the IMO's current ambition level).

The IMO's ambition is estimated to be met by all three packages when emissions are calculated on a well-to-wake basis. However, only packages 1 (fuel switch: ammonia, hydrogen) and 3 (greater efficiency technology emphasis, CCS, bio-LNG, ammonia, methanol) would meet the ambition on a tank-to-wake basis.

Fuel costs are such a large component of total costs that energy efficiency measures to reduce fuel consumption are total cost savers (reduced spend on fuel; increased CAPEX spend on vessels; reduced impact on the fuel supply industry).

The 'drop-in' fuel package 2 (biofuel, bio-LNG), which faces fewer barriers to deployment, is estimated to be more expensive compared to the fuel switches in packages 1 and 3 that would require new vessel engine investments.

Long vessel lifetimes mean that emission pathways become locked in for longer (e.g. compared to road transport), hence it is important to act sooner rather than later to effect meaningful change.

The complete study report, entitled *Technological, Operational and Energy Pathways for Maritime Transport to Reduce Emissions Towards 2050*, can be downloaded from the Concawe website at:
https://www.concawe.eu/wp-content/uploads/Technological-Operational-and-Energy-Pathways-for-Maritime-Transport-to-Reduce-Emissions-Towards-2050.pdf