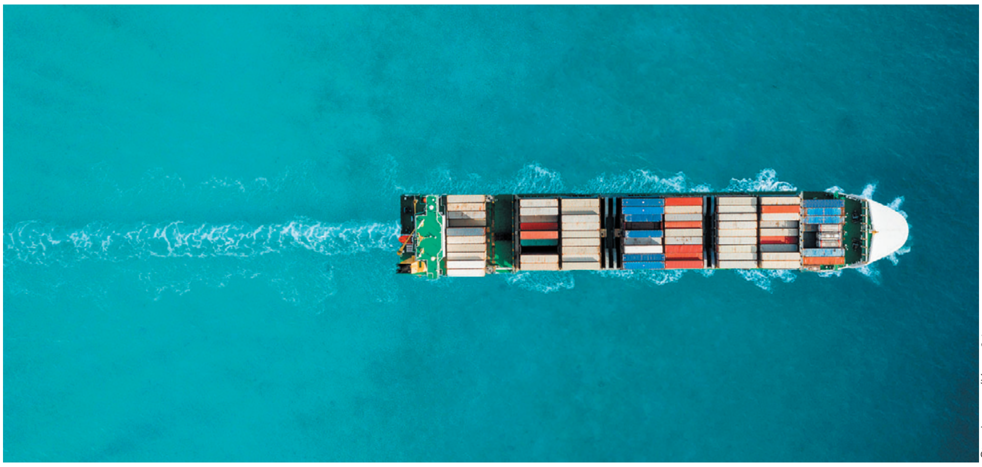
A review of the options for decarbonising maritime transport by 2050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This article summarises Phase 1 of a new research project being undertaken by Concawe to investigate potential technological, operational and energy pathways to reduce emissions from the maritime transport sector towards 2050. Phase 1 of the project provides the context, and describes the various measures identified for decarbonising the sector, including the options for alternative fuels and energy carriers.

Introduction

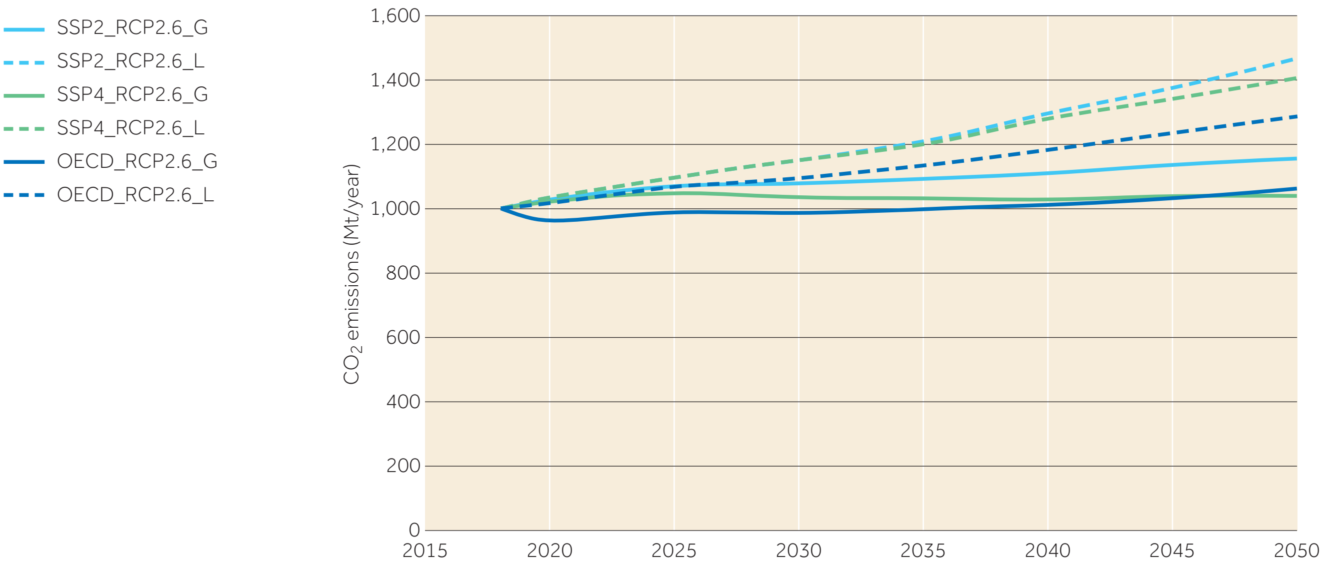
The main challenge for the maritime transport sector over the next decade is to develop a decarbonisation pathway to achieve the current 2050 ambition. The complexity of the sector requires the involvement of all of the industry's stakeholders in preparing a quantified and practical review of options to decarbonise the maritime sector by 2050.

Shipping is the backbone of international trade and commerce, and the maritime transport sector recognises the importance of decarbonisation to help reach the goals of the Paris Agreement. Maritime transport was responsible for 1,076 million tonnes of greenhouse gas (GHG) emissions in 2018—about 2.9% of global anthropogenic GHG emissions, according to the 4th International Maritime Organization (IMO) GHG study. In this study, in a business-as-usual scenario, emissions in 2050 range from 1,000 to 1,500 Mt/year, representing around 4–8% of global emissions. In this context, efforts are under way to achieve the IMO's ambition of reducing carbon emissions from international shipping by at least 50% in 2050 compared to 2008 levels (470 Mt CO_2eq versus 940 MT CO_2eq, respectively). This ambition also aims to reduce the carbon intensity of international shipping by at least 40% by 2030 and 70% by 2050 (again compared to a 2008 base year).

Concawe is funding a research project entitled 'Assessing technological, operational and energy pathways for maritime transport to reduce emissions towards 2050', which is being conducted by Ricardo Energy & Environment. The study will provide quantified, evidence-based and neutral analysis to support high-level decision-making, in particular with regard to investment scale-up. The analysis will include the identification of barriers and enablers to climate change responses in the maritime sector, from a broad range of technical, economic and regulatory perspectives.

This article is a summary of Phase 1 of the project, which provides the context for the maritime transport sector and its drivers, and describes the technological and operational measures identified for decarbonising the sector, as well as the options for alternative fuels and energy carriers.

Figure 1: Projections of total maritime ship CO_2 emissions in the business-as-usual scenarios
(GDP growth in line with recent projections, energy transition in line with the 2°C target)

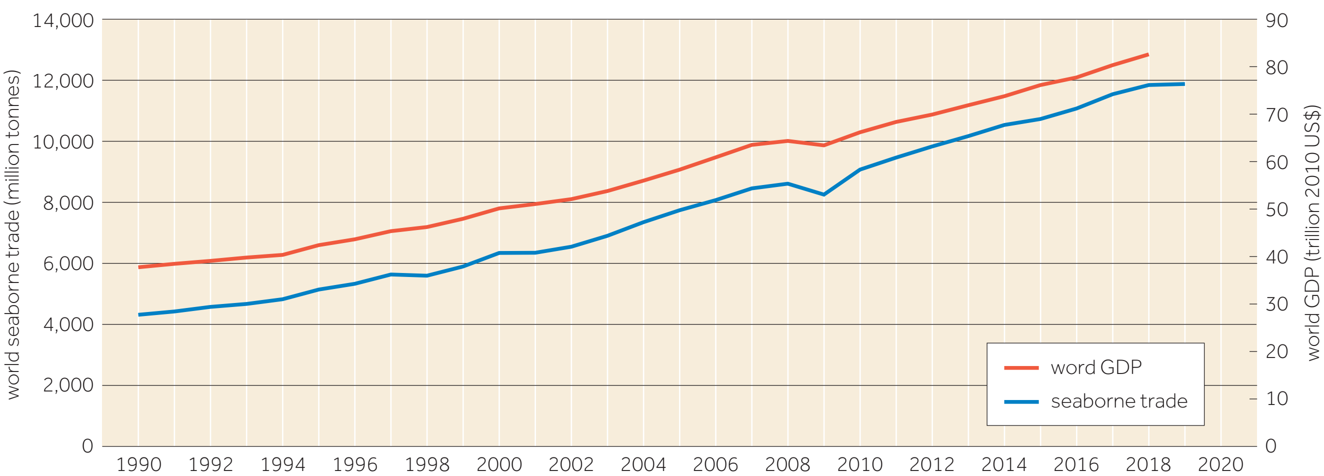


Context—historic and future trends

Historically, seaborne trade has been correlated with world GDP. World seaborne trade grows approximately in line with world GDP (it was slightly higher in the period 1990–2018), and has more than doubled over the past 20–25 years. In light of the anticipated growth in global GDP, there is therefore a need to decouple international shipping emissions from economic growth.

Figure 2: Correlation between world GDP and seaborne trade

Source: World Bank (world GDP data) and Clarkson Research Services Ltd (seaborne trade data)



Population and economic growth are the key drivers of the demand for all modes of transport. Higher levels of economic activity, triggered by an increase in consumption, production, intensification of trade, or a combination of several factors, usually implies an increase in demand for transport. With continued economic growth, the demand for the international transport of freight is expected to continue to grow in the future, although different levels of growth in different global regions are likely to lead to changes in the distribution of demand. Overall, the OECD expects global freight demand to triple by 2050, relative to 2015. If this is realised, seaborne trade will exceed 120,000 billion tonne-miles by 2050.

Projecting transport demand requires a deep understanding of economic growth and patterns of international activity; increased protectionism or a global economic downturn would have an important impact on the demand for transport. This is especially true for maritime transport, which is highly dependent on the intensity of international trade, and more so than other transport modes. The OECD notes that the future of the maritime freight sector depends, in particular on, international trade agreements, the development of transcontinental inland routes, changes in global energy use and the growth in e-commerce.[1]

Figure 3: Global shipping demand towards a 2050 horizon for a range of scenarios

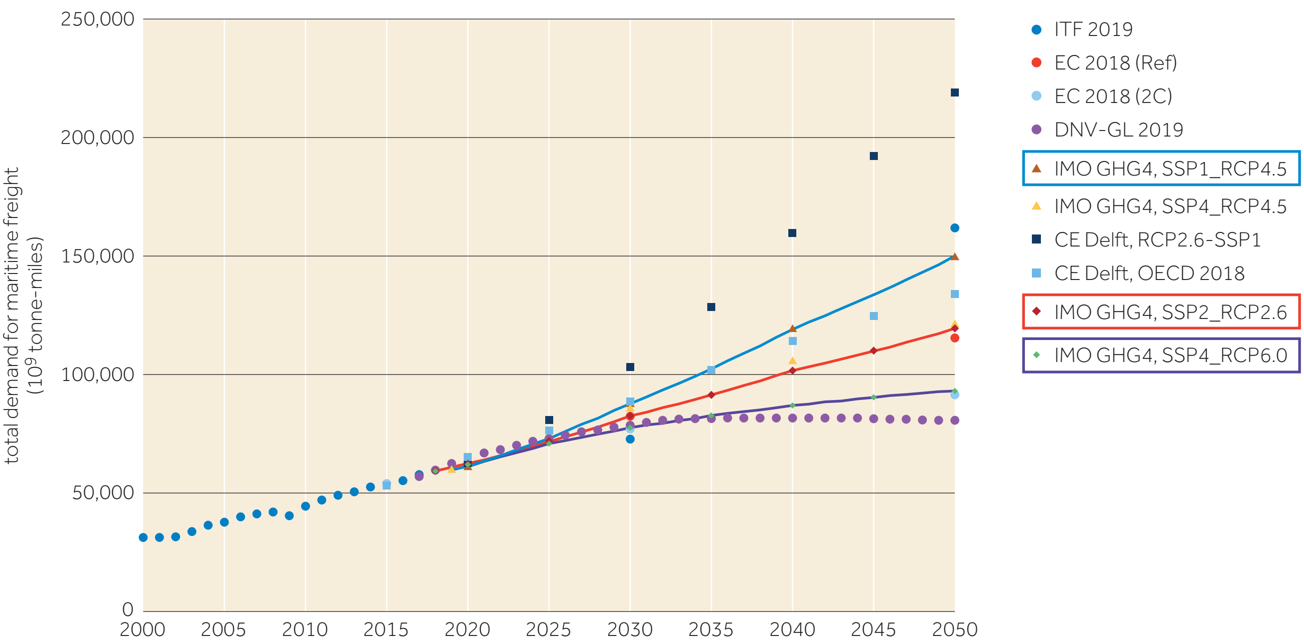


Figure 3 shows the projected demand for maritime freight shipping towards a 2050 time horizon for a range of scenarios. Three scenarios from the IMO's 4th GHG study were selected for the Concawe research project, as they are representative of the lower and upper bounds of the various scenarios identified. The projections shown in the Figure are based on GDP and population projections from the so-called Shared Socio-Economic Pathways (SSPs) developed by the IPCC, as well as the Representative Concentration Pathways (RCPs—long-term changes in energy use and atmospheric concentrations).

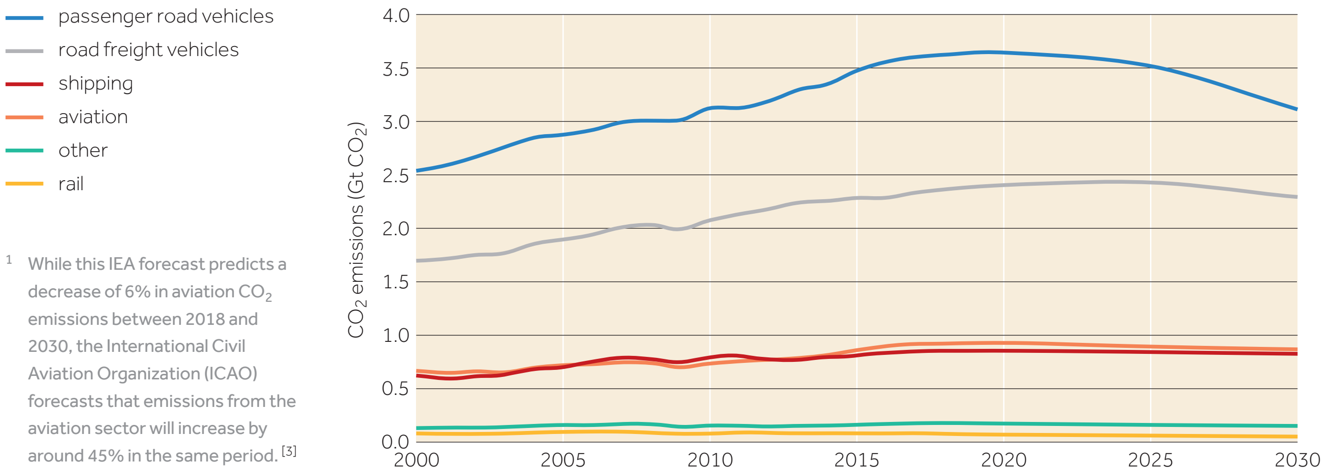
The three selected scenarios are defined as follows:

- High Demand scenario, IMO GHG4, SSP1, RCP4.5:
  - SSP1 = 'sustainable development — taking the High Road' + 2.4°C, medium-low mitigation
  - Annual GDP growth rate = 4.73%
  - Average growth rate for maritime transport (tonne miles) = +3.0% p/a
- Central scenario, IMO GHG4, SSP2, RCP2.6:
  - 'Middle of the Road", compatible with 2.0°C warming limit
  - RCP2.6 = 2.6 W/m^2 (watts per square metre of the Earth's surface) by the end of the century
  - Average growth rate for maritime transport (tonne miles) = +2.2% p/a
- Low Demand scenario, IMO GHG4, SSP4, RCP6:
  - SSP4 = 'inequality — a road divided', +2.8°C medium baseline, high mitigation
  - Annual GDP growth rate = 3.13%
  - Average growth rate for maritime transport (tonne miles) = +1.4% p/a

The three main ship categories for CO_2 emissions are container ships (~25% of sector emissions), bulk carriers (~20%) and oil tankers (~15%). Between them, these three categories of ships produced 60% of the total GHG emissions from international maritime shipping.

Figure 4: Transport sector CO_2 emissions by mode, historic and projected, 2000–2030[1]

Source: International Energy Agency [2]



[1] While this IEA forecast predicts a decrease of 6% in aviation CO_2 emissions between 2018 and 2030, the International Civil Aviation Organization (ICAO) forecasts that emissions from the aviation sector will increase by around 45% in the same period. [3]

As shown in Figure 4, road transport, both passenger and freight, was responsible both for the majority of the increase in emissions from 2000–2018 and the majority of the expected decline in emissions from 2018 through to 2030. Road transport is also responsible for the majority of current (2018) emissions from transport, as well as anticipated emissions by 2030 (around 75% of total emissions in both years). In comparison, shipping is responsible for around 11% of total emissions, a value that remains unchanged by 2030, and which is almost three time less than for road freight, while representing five times more tonne kilometres moved (OECD and ITF, 2019).

Figure 5: Global freight demand by mode

Source: OECD and ITF [1] and ICAO [4]

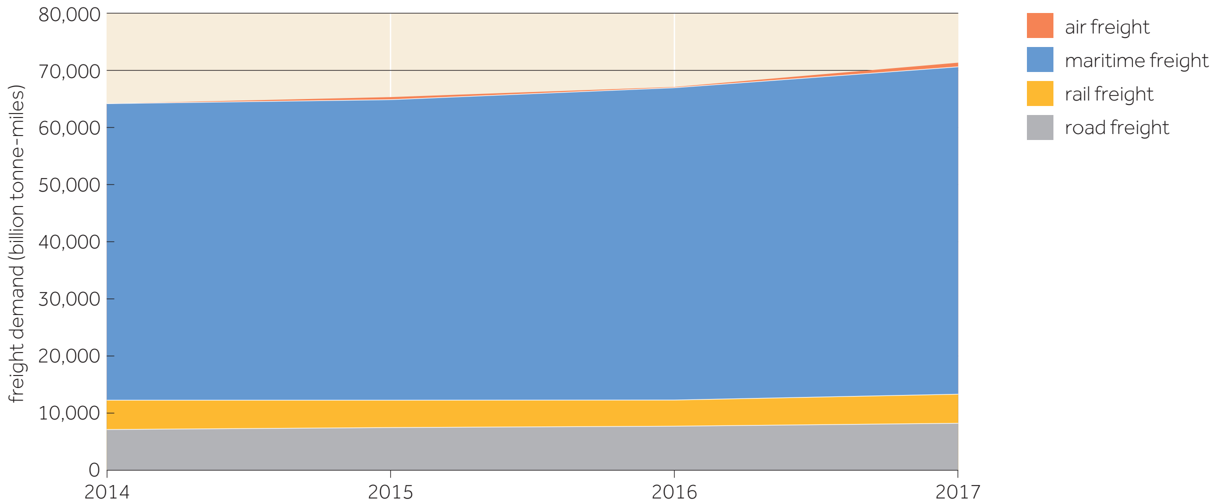


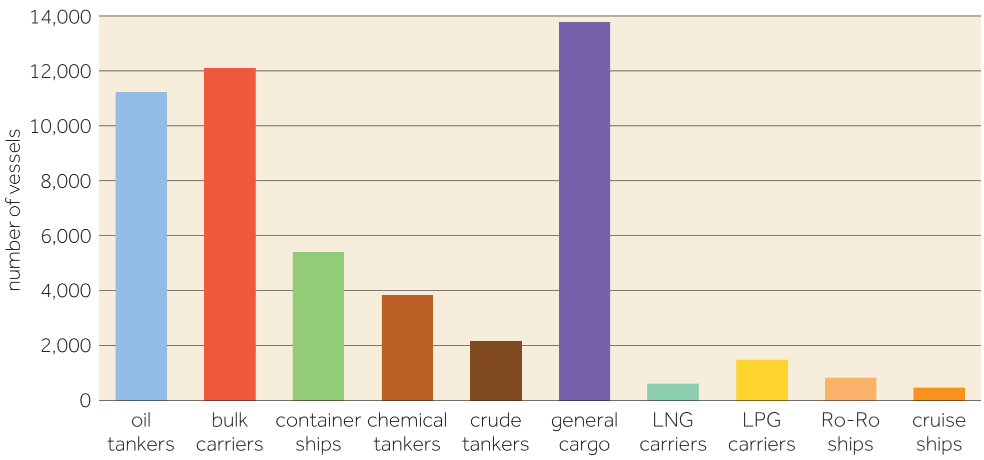
Figure 5 shows that maritime transport meets approximately 81% of global demand for freight transport (in tonne miles), with road and rail providing approximately 12% and 7% respectively. Aviation meets an almost negligible 0.16% of demand.

Global marine fleet

The current commercial maritime transport fleet consists of more than 51,600 vessels (excluding tugs, fishing boats and other non-transport vessels), with a total deadweight tonnage (DWT) of more than 2.3 billion tonnes. Figure 6 shows the numbers of vessels in the fleet, split into the main categories. The key vessel categories by number are oil tankers, bulk carriers and general cargo vessels.

Figure 6: Global maritime fleet by number of vessels per category

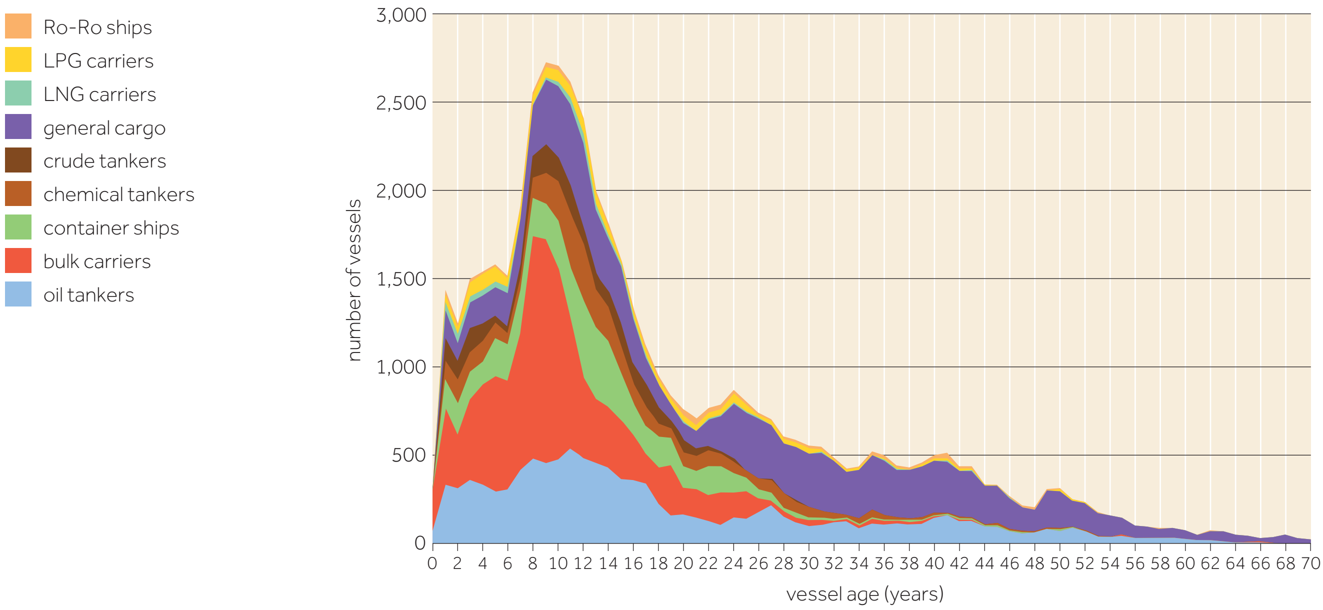
Source: Clarkson Research Services Ltd, World Fleet Register [5]



A key element in the calculation of the future fleet composition is the age profile of the current fleet—see Figure 7.

Figure 7: In-service fleet by age and category

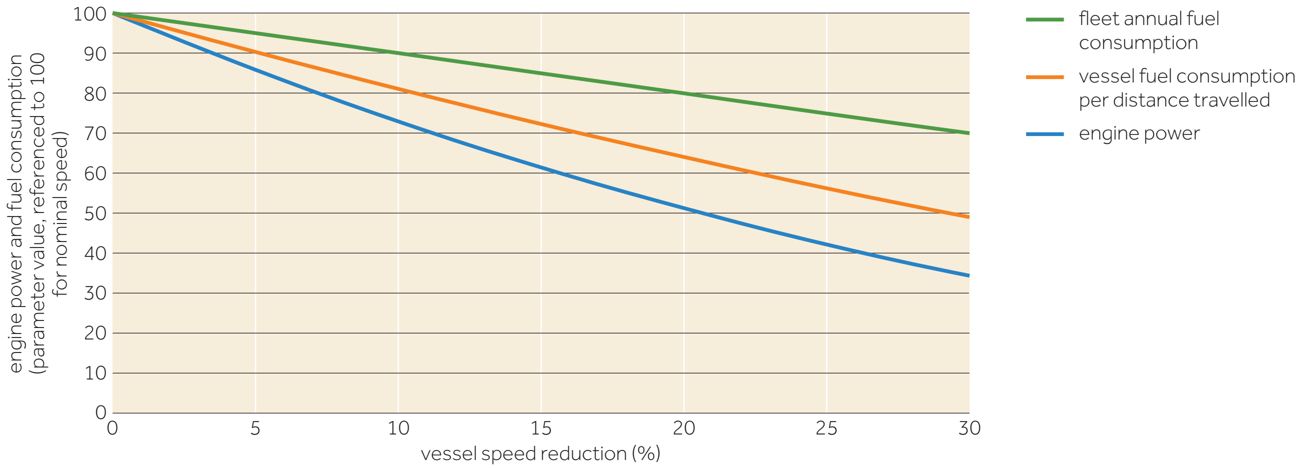
Source: Clarkson Research Services Ltd, World Fleet Register [5]



Speed

The speed of a ship has a significant influence on both earnings and costs for a ship operator. The cubic relationship between speed and fuel consumption is a key factor in determining the optimal speed of a vessel. In numerical terms, a 10% reduction in speed leads to a 27% decrease in power demand. Accounting for the lower distance covered, a 10% speed reduction results in a 19% reduction in fuel consumption per unit of distance.[6] Figure 8 on page 53 illustrates this effect by showing how the required engine power and fuel consumption per unit of distance vary with speed reduction (power and fuel consumption are referenced to a value of 100 at the nominal vessel speed). However, the reduction in speed also results in a reduction in productivity (or utilisation); each vessel will deliver fewer tonne miles in a given period (e.g. a year), therefore more vessels will be required to deliver the original total supply. As a result, the fleet-level fuel consumption required to deliver the same supply forms a linear relationship with speed (-10% fleet annual fuel consumption for a 10% speed reduction).

Figure 8: Effects of slow steaming on the power required, vessel fuel consumption per distance, and overall fleet fuel consumption



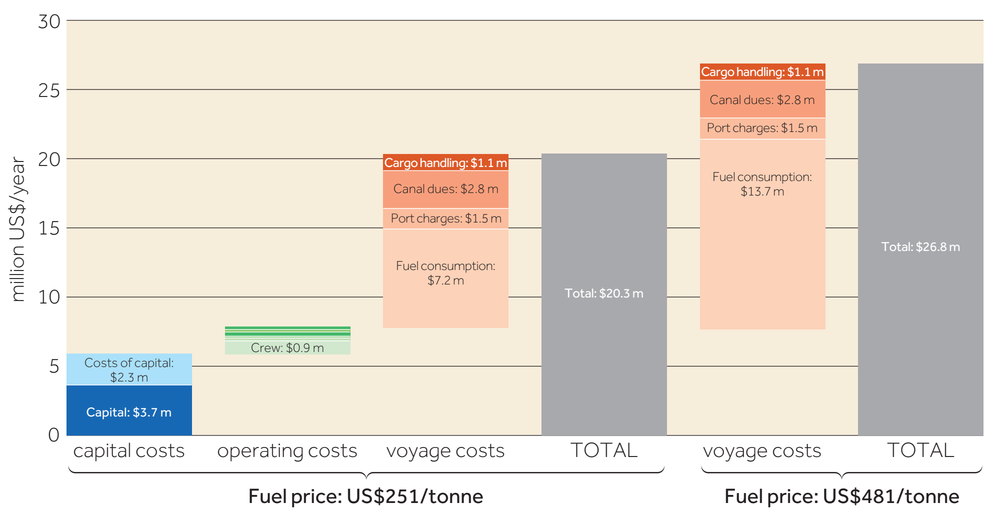
Costs

Fuel price is by far the most important and most volatile determinant of the average vessel costs, being especially pronounced for older and less efficient vessels. The high dependence of vessel operating costs on fuel price provides a strong business driver to reduce the cost of fuels used, and has been the trigger for the universal adoption of heavy fuel oil (HFO, in general the lowest-priced liquid fossil fuel) for maritime transport.

As shown in Figure 9, the ratio of fuel costs versus the total cost structure increases from 35% to 51% when the fuel price increases from US$251/t to US$481/t (2020 economics with Brent at ~US$40/bbl versus 2018 economics with Brent at US$55/bbl, respectively).

Figure 9: Fuel price sensitivities for a 13,000 TEU[a] main liner container, 5 years old

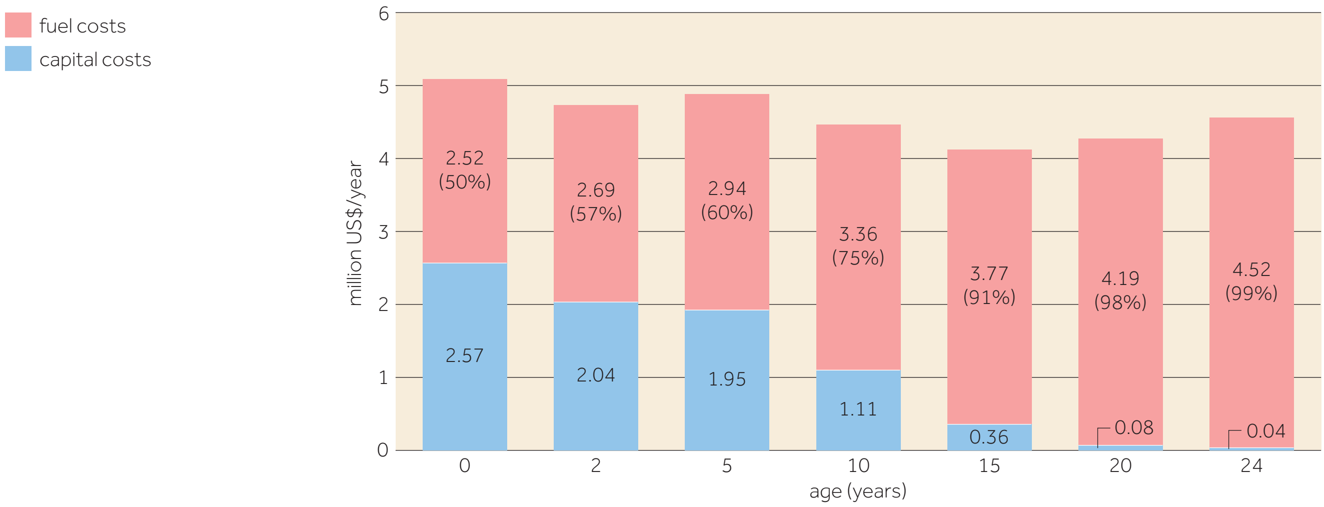
Source: Ricardo literature review and calculations



[a] TEU = twenty-foot equivalent units

The age of a vessel is a key determinant of both capital and fuel costs (Figure 10), because, in general, a vessel depreciates faster at the beginning of its useful life and newer vessels are more efficient. Therefore, applying fuel economy measures will be key in a highly competitive environment for the international shipping sector.

Figure 10: Age sensitivities for a 75,000 dwt bulk carrier — capital and fuel costs (fuel costs of US$481/t)



‘Split incentive’

Because of its structure, the shipping sector is more susceptible to a specific potential barrier to the introduction of new technologies, known as the ‘split incentive’ problem, than other transport sectors. Responsibilities such as fuel charges, operational measures, technological investments and cargo loading can be allocated either to shipowners or ship charterers. Whether there is an incentive for a shipowner to implement energy efficiency measures is often highly dependent on the charter rate that the charterer pays to the ship owner. If the party paying for its implementation does not accrue the benefit of the energy efficiency measure, this can act as a barrier to the adoption of the measure when ordering a new ship.

Short-term technology measures to reduce emissions

Most short-term technology measures identified to decarbonise international shipping will prove to be useful. Many offer significant efficiency gains (above 40%) at an affordable cost-effectiveness (US$/t CO_2 avoided), with the range being on average US$5–50/t CO_2. Some of these technologies are already implemented in the existing fleet, but there is further reduction potential for some of these technologies, especially where the technological readiness level (TRL) is high, but uptake is limited.

The short-term measures considered are:

- **Ship and propeller design** measures can reduce GHG emissions by reducing resistance. Measures were identified that can each provide a GHG reduction potential ranging from 0.5–10%.
- **Alternative power-assistance technologies**, such as Flettner rotors, towing kites, sails, solar panels and shoreside power can reduce future direct fuel requirements and provide additional auxiliary power, reducing GHG emissions (ranging from 0.5–15% and up to 100% for shoreside power in port only).
- There are several **operational and voyage optimisation measures** that offer GHG savings (ranging from 0–38%). These measures includes slow steaming, advanced port logistics, automation and IT tools development.
- **Engine design** — conventional engine designs already include the best available technology.

Longer-term shifts to alternative fuels will be needed

To achieve the IMO's ambition to reduce carbon emissions from international shipping by at least 50% in 2050 compared to 2008 levels, the fundamental change will be a switch to alternative zero GHG-emission fuels. There are uncertainties in terms of whether one fuel or two fuels (i.e. one for short-sea shipping and one for deep-sea shipping) should be adopted, or whether multiple fuels will be required. However, there are some emerging trends and some agreement that the transition will first apply to short-sea shipping and later to long-distance shipping.

Each of the fuels investigated are summarised below. These have been categorised into two main groups: 'drop-in fuels' which can be used in the existing fleet largely without engine modifications up to certain blend limits, and other alternative fuels which require significant engine/fuel system modifications, alternative engines and/or infrastructure.

'Drop-in fuels'

- **FAME (fatty acid methyl ester):** To date, the use of FAME blended with conventional marine fuels such as HFO has proven to be compatible in blends containing up to 20% FAME,[7] although the current fuel standard for distillate fuels (ISO 8217 2017) limits FAME content to 7%.[8] The main barriers to future uptake include ensuring sustainability of feedstocks, and competition with other transport sectors.
- **HVO (hydrotreated vegetable oil):** HVO is compatible with existing infrastructure and engine systems, subject to approval by the manufacturer, although minor modifications may sometimes be required.[9] There is no upper limit for blending HVO. The main barriers to future uptake include ensuring sustainability of feedstocks, and competition with other transport sectors.
- **DME (dimethyl ether):** Although DME has been a known substitute for diesel for more than 20 years, it has not been widely used as an alternative maritime fuel. DME can be used with marine diesel oil in blends of ≤40%. The use of neat DME requires engine retrofits or specific engine design. The main barrier to future uptake is a need for green DME production and supply.

Other alternative fuels

- **LNG (liquefied natural gas):** As a fossil fuel, albeit with a lower carbon content than HFO, it is recognised that LNG cannot be the final solution for decarbonising shipping. LNG as a marine fuel has already reached market maturity and is in use by vessels currently in operation. Another emerging consideration for LNG is that bio-LNG (liquefied bio-methane) and liquefied synthetic methane (LSM) could be compatible with LNG-fuelled ships. The main barriers to future uptake include methane slip and life-cycle emissions, and suitable bunkering infrastructure.
- **Methanol:** Currently, methanol is produced mainly from natural gas, but can be produced from a number of different feedstock resources including renewable sources such as black liquor from pulp and paper mills, agricultural waste or forest thinning, and even CO_2 that is directly captured from power plants.[9] The main barriers to future uptake include green methanol production and supply, and adequate infrastructure.
- **Ammonia:** Until recently, there has been little motivation to explore ammonia as a maritime fuel. However, if synthesised from renewable resources, 'green ammonia' as a fuel is carbon free. Green ammonia production uses the renewable electrolysis process to separate hydrogen atoms from oxygen atoms within water using electrolysers which are already in extensive commercial use. In this process, the GHG reduction potential of ammonia depends on the percentage of electricity generated by renewable sources. The main barriers to future uptake include green ammonia production and supply, price parity, and the availability of solid oxide fuel cell technology for future use in fuel cells.
- **Hydrogen:** When hydrogen is combusted, the process is carbon free, and if the hydrogen is synthesised using renewable power, it is a completely carbon-neutral fuel with zero CO_2 emissions. Hydrogen has a very low volumetric density which was previously a limiting factor to its use. The main barriers to future uptake include green hydrogen production and supply, cost and price parity.
- **Batteries:** Batteries have been used as an energy carrier for short-sea shipping since 2015. They can provide vessel power through an electrochemical reaction, whereby energy is absorbed and released in the lithium-ion cell within the battery. Compared to using conventional fuels, emissions of CO_2, NO_x and SO_x are reduced when using full electric (battery) and hybrid (battery and diesel) configurations. The energy efficiency of electric propulsion systems can even exceed 90%, compared to about 40% for conventional propulsion with diesel engines.[10] Stakeholders in the sector do not foresee batteries as a realistic energy carrier option for deep-sea shipping. The main barriers to future uptake include fire risk, limited range, cost, weight/size and end-of-life disposal.
- **Fuel cells:** Using fuel cells rather than internal combustion engines can reduce emissions. If the fuel used is hydrogen, the only products produced in the fuel cell reactions are water, electricity and excess heat. If powered by a fuel produced using renewable energy the carbon reduction potential of fuel cells is 100%. Fuel cells require their own storage systems and equipment, and continue to function as long as they have a fuel source. The main barriers to future uptake include capital and maintenance costs, proving the feasibility of scale-up, bunkering availability, and the longevity of fuel cells.

Table 1 provides a summary of the maximum potential reductions in net emissions available from the different alternative fuels described, with the costs and cost-effectiveness calculated for each fuel based on the production technologies described. The costs are based on estimates available from the literature and do not reflect projections to 2050.

Table 1: Maximum potential reductions in net emissions, plus costs, cost-effectiveness and compatibility notes for the alternative fuels described (results and figures may evolve as the study has not yet been finalised)

	MAXIMUM GHG REDUCTION POTENTIAL (%)	TRL FOR TRANS-OCEANIC	CURRENT COST (US$/GJ)	CURRENT COST-EFFECTIVENESS (INCLUDING FUEL COSTS) (US$/t CO_2)	COMPATIBILITY
LNG *Global average pathway*	10%	9	7.1	340.1	Requires gas/dual-fuel engine and associated cryogenic storage.
Bio LNG *Liquid manure pathway*	169%	9	11.3	49.5	Same requirements as for LNG.
Methanol *Synthetic methanol pathway*	92%	8/9	28.7	305.3	Not drop-in. Compatible with internal combustion engines.
Ammonia *Municipal waste pathway*	79%*	3/4/5	31.9	400.5	Compatible with internal combustion engines (spark ignition with a hydrogen blend to promote combustion, and dual-fuel with pilot diesel).
Hydrogen *Biomass gasification pathway*	95%*	3/4/5	89.2	1,028.7	Compatible with internal combustion engines (spark ignition and dual-fuel) but requires development and a supporting fuel).
FAME *Waste cooking oil pathway*	84%	9	17.0	174.0	Drop-in (blended only <20% FAME). May face competition for feedstock availability from other sectors.
HVO *Waste cooking oil pathway*	91%	9	17.2	163.3	Drop-in (blended and neat). May face competition for feedstock availability from other sectors.
Batteries *(Lithium-ion)*	66%	4/5/6	-	-	Not compatible with internal combustion engines as part of a prime mover. Have a role in coastal or short-sea shipping. May have a role in reducing emissions from auxiliary power in deep-sea shipping. Require their own storage systems and equipment.

Notes: Maximum potentials are shown, with the exception of ammonia, hydrogen and battery electric. In theory, 100% reduction (or higher) may be achievable with 100% renewable electricity for these fuels; however, the time frame and costs for these production pathways are not clear at present, therefore data for the pathways with the next highest reduction potential are shown.

Different alternative fuels have been identified, together with their GHG reduction potential, respective costs and current TRLs. Given the uncertainties around the future development of the different fuels and the different production pathways associated with them, it is not possible at present to identify the specific fuels that are most likely to be developed and adopted in the future. However, it is possible to identify criteria that may be used when assessing fuels for potential commercial production and widespread use by the fleet. These criteria include:

- the price relative to conventional fuels;
- certainty of the GHG reduction potential and well-to-propeller (WTP) emissions;
- adequate fuel availability; and
- low competition from other sectors in the timing of deployment, e.g. aviation.

Conclusion

The shipping industry is entering a challenging decade, as the sector will have to reduce its overall emissions while the demand for transport continues to increase, i.e. by decoupling emissions from growth. There will not be a unique path, and the timing for deployment of the cheapest measures from the CO_2 cost abatement curve will be crucial. Improvements in ship technology and operational measures are the most financially attractive options for reducing CO_2 emissions (with costs ranging from US$5–50/t CO_2). Alternative fuels and energy carriers will also be necessary, and the uncertainty is higher with regard to the timing and identification of the specific fuel/energy supply that will need to be developed.

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Next steps in the study

Phase 1 of this study considered the background to the development of the maritime sector, and a range of technologies and fuels that can contribute to the future decarbonisation of the sector. It has also identified three scenarios for the future growth of demand for maritime transport, and three packages of measures (technologies/operational measures/alternative fuels).

Phase 2 of the study (due to be published in Q1 2021) will perform a 'deep-dive' investigation of those packages, exploring their potential uptake and impact on the emissions from the different ship categories (and ship sizes, where appropriate). For each scenario, a model will be developed of the evolution of the maritime fleet, including the introduction of newly built ships as driven by the demand for trade (and taking account of the retirement, or demolition, of older ships). The technology developments for new ships and fuels, and the evolution of the fleet, will be combined into a set of pathways showing how decarbonisation of the sector can develop through to 2050.

References

1. OECD and ITF (2019). *ITF Transport Outlook 2019*. Published by the OECD and the International Transport Forum. https://www.oecd-ilibrary.org/transport/itf-transport-outlook-2019_transp_outlook-en-2019-en
2. IEA (2019). 'Transport sector CO_2 emissions by mode in the Sustainable Development Scenario, 2000–2030' (website). Last updated 22 November 2019. https://www.iea.org/data-and-statistics/charts/transport-sector-co2-emissions-by-mode-in-the-sustainable-development-scenario-2000-2030
3. ICAO (2019). 'Trends in Emissions that affect Climate Change' (website). International Civil Aviation Organization. https://www.icao.int/environmental-protection/Pages/ClimateChange_Trends.aspx
4. ICAO (2018). *Annual Report of the Council, 2018*. International Civil Aviation Authority. https://www.icao.int/annual-report-2018/Pages/default.aspx
5. Clarkson Research Services Ltd (2020). 'World Fleet Register' (website). https://www.clarksons.net/wfr/
6. CE Delft (2017). *Regulating speed: a short-term measure to reduce maritime GHG emissions*. https://www.cleanshipping.org/download/Slow-steaming-CE-Delft-final.pdf
7. ECOFYS (2012). *Potential of biofuels for shipping. Final Report*. Prepared by ECOFYS Netherlands B.V. for the European Maritime Safety Agency (EMSA). http://www.emsa.europa.eu/fc-default-view/download/1626/1376/23.html
8. ISO (2017). *ISO 8217 2017 Fuel Standard for marine distillate fuels*. https://www.wfscorp.com/sites/default/files/ISO-8217-2017-Tables-1-and-2-1-1.pdf
9. DNV GL (2019). *Comparison of Alternative Marine Fuels*. Produced by DNV GL for SEA\LNG Ltd. https://safety4sea.com/wp-content/uploads/2019/09/SEA-LNG-DNV-GL-Comparison-of-Alternative-Marine-Fuels-2019_09.pdf
10. American Bureau of Shipping (2019). *Setting the Course to Low Carbon Shipping: Pathways to Sustainable Shipping*. https://absinfo.eagle.org/acton/fs/blocks/showLandingPage/a/16130/p/p-01c1/t/page/fm/0