MARITIME MAKEOVER

The role for investors in decarbonizing global shipping

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Highlights

- **Maritime shipping is a hard-to-abate sector with significant greenhouse gas emissions.** Decarbonizing shipping, which is responsible for around 3% of global emissions, requires a transition from fossil fuels to a range of solutions, at the center of which are new zero-carbon fuels.
- **The industry is not on track for alignment with the Paris Agreement.** Fully decarbonizing shipping by 2050 is possible but will require that stakeholders take immediate, ambitious steps to reduce fuel usage and accelerate the uptake of non-fossil fuels.
- **Shipping providers are just starting to focus on carbon.** Only 16 of the top ship owners across key industry segments have committed to a net zero target, a first step toward transition planning. In the near term, ship owners and operators should adopt solutions that reduce fuel usage. Integrating zero-carbon fuels and technologies at increasing scale will accelerate the longer-term transition.
- **Shipping customers drive demand for low-carbon shipping.** Cargo owners and charterers should signal a willingness to pay for low-carbon supply chain services by prioritizing the use of low-emissions vessels.
- **Commitments and disclosures for shipping companies.** We identify key "asks" for investors and lenders to make of shipping providers and shipping service users and recommend company-level disclosures.

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Definitions

Carbon-based fuels: Fuels that include carbon as part of their molecular composition e.g., methanol, methane, diesel, and bio-oils.

Electrofuels or e-fuels: Advanced fuels that can be produced using renewable electricity.

International Maritime Organization (IMO): The global standard-setting authority for the safety, security and environmental performance of international shipping. Its main role is to create a global regulatory framework for the shipping industry.

Maritime Shipping Provider (MSP): Companies that provide shipping services, including both ship owners and ship operators.

Maritime Shipping User (MSU): Companies that use shipping services. In container shipping, these are generally known as beneficial cargo owners (BCO). In dry bulk and tanker shipping, these are generally known as charterers.

Well-to-wake pathway: The series of steps that a fuel goes through beginning with production and ending with consumption on a ship.

Tank-to-wake pathway: The steps necessary to combust a fuel in a ship's tank.

Zero-carbon fuels: Fuels that emit no carbon on a lifecycle basis, such as green ammonia, green methanol, and green hydrogen.

CHAPTER 1

Executive Summary

Maritime shipping occupies a central position in the global supply chain: nearly 100,000 commercial vessels move 11 billion tons of goods each year, accounting for about 80% of global trade volume. The associated greenhouse gas emissions add up, and shipping accounts for about 3% of global greenhouse gas emissions. If maritime shipping were a country, only 5 nations would emit more.

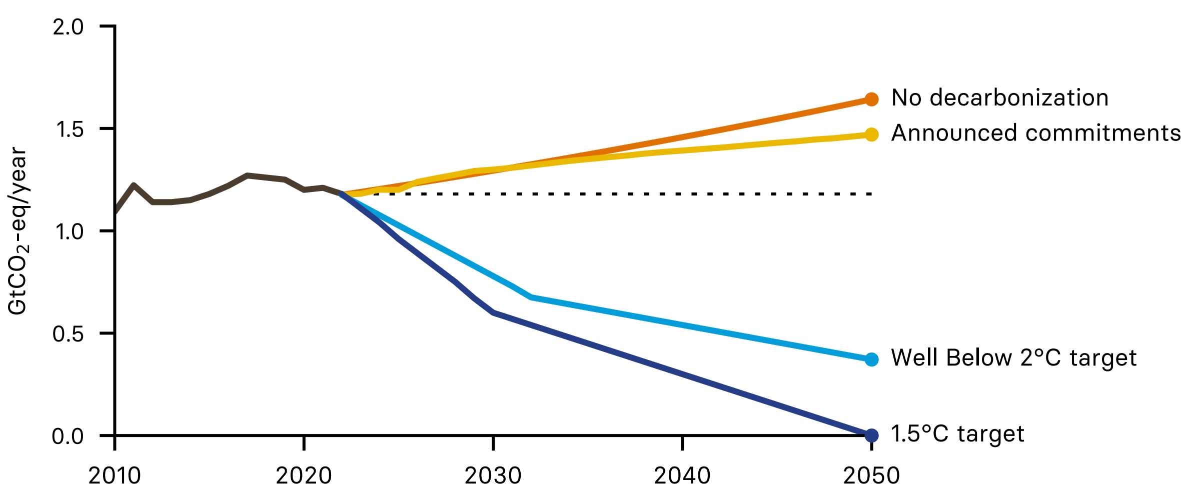
As globalization continues to drive rapid growth in shipping demand, emissions from the sector could increase 40% by 2050 – a trajectory incompatible with pathways that limit global warming to the Paris Agreement targets of 1.5 degrees or well below 2 degrees Celsius (Figure 1). For investors with net zero targets, addressing shipping-related emissions will be necessary to reach them.

In contrast with areas such as electricity generation and passenger vehicles where zero-emissions technologies are commercially available, solutions for maritime shipping are less mature. However, analysis by the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMM Center for Zero Carbon Shipping) shows that there are plausible pathways to fully decarbonize shipping by 2050. The analysis identifies five critical levers that must be activated to reach zero carbon shipping in 2050: energy and fuel advancements on shore; technological advancements on ship; customer demand/pull; finance sector mobilization; and enabling policy and regulation.

The urgency of the transition requires that investors push the industry to take ambitious action now, in order to reduce operational emissions and accelerate the adoption curve for low-carbon fuels by the end of this decade. By taking steps to test and de-risk new fuel pathways, the industry can reduce long-term costs and manage the risk of price or fuel supply shocks in the future.

FIGURE 1

Maritime emissions pathways



Source: MMM Center for Zero Carbon Shipping, forthcoming paper on maritime decarbonization strategy

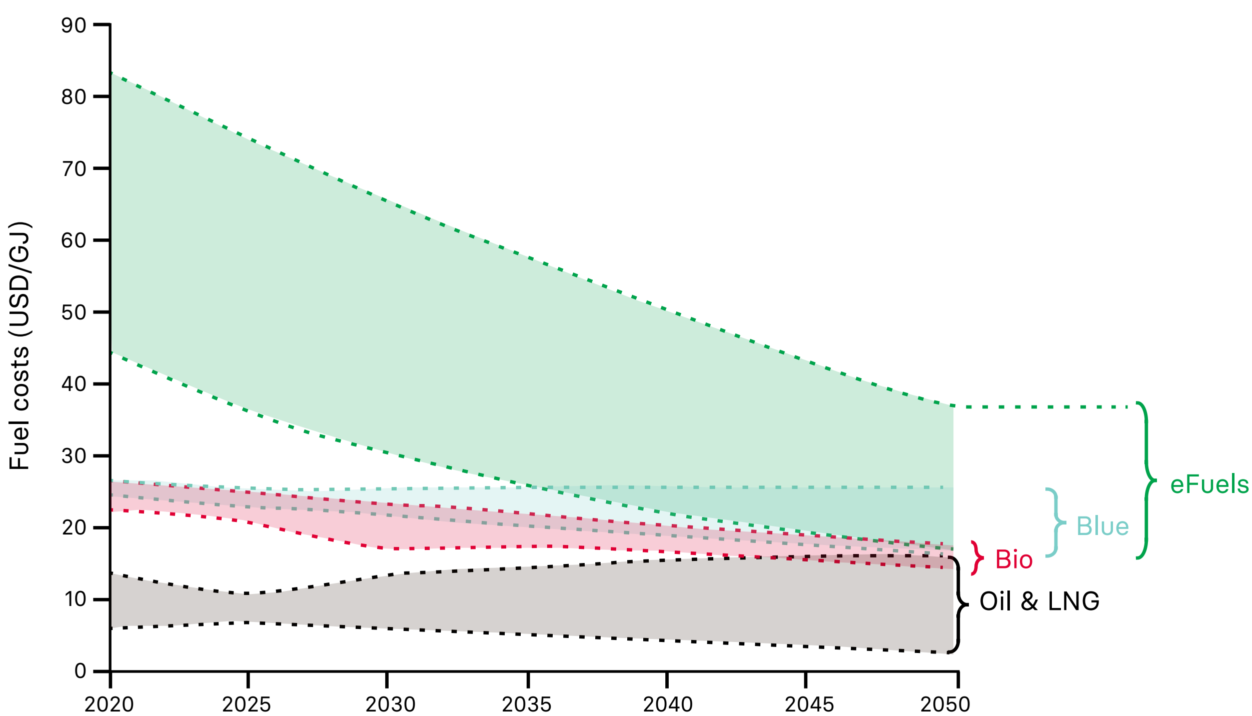
Investors also have an important role to play in calling for more ambitious policies to accelerate the pace of the maritime transition. In the shipping industry, policy authority is diffused among the International Maritime Organization (IMO) - the global standard-setting authority for the international shipping industry - and the many countries across which global shipping companies operate. In its most recent strategy document, IMO calls for emissions to peak "as soon as possible." Next year will provide an opportunity for IMO to raise ambitions as it considers updating industry-wide decarbonization targets.

Shipping companies should adopt measures available today providing cost-effective emissions reductions. However, more dramatic emissions reductions will require significant investments to transition from oil-derived bunker fuel to alternative zero-carbon fuels such as green ammonia or green methanol. Zero-carbon fuels are not yet widely available but are in various stages of readiness. Additionally some are drop-in fuels compatible with existing vessels, but most require engine or vessel modifications.

Alternative fuel costs are expected to fall significantly in the coming years, but current projections suggest they will remain more expensive than fossil-based fuels well into the future (Figure 2). There are differences in the performance, cost, operational capabilities, and scalability of these potential fuel solutions. A single winner may not emerge; more likely is that the industry will rely on a variety of fuels for different applications, adding complexity to the transition.

FIGURE 2

Projected Maritime Shipping Fuel Costs



Source: MMM Center for Zero Carbon Shipping, Industry Transition Strategy (2021)

To lay the groundwork for introducing alternative fuels at scale, stakeholders including shipbuilders, ship owners and operators, ports, fuel providers and shipping customers must work together to address technical, logistical and institutional barriers. Given the many parties involved, close coordination is needed to deploy and expand these solutions, aligning factors such as shipbuilding timeframes, the deployment of new vessels, and cost/willingness to pay.

Some leaders in the maritime shipping industry have committed to a low-carbon transition and begun to chart a path to achieve it. Sixteen of the largest ship owners across key industry segments have set a net zero target, and dozens more have adopted emissions reduction goals. Many more should follow. Waiting too long to begin the transition exposes a company to significant technological, financial and reputational risk.

Investors have an important role to play in pushing companies that provide or use maritime shipping services to set ambitious decarbonization targets and holding them accountable to achieve them. In this report we identify specific commitments that investors should ask of providers and users of maritime shipping services on the path to zero emissions by 2050, and disclosures to measure progress. We explore key factors in the sector's energy transition, including carbon reductions that can be achieved today and the cost and performance drivers behind leading zero-carbon fuels, and we review the steps toward decarbonization taken by major shipping companies.

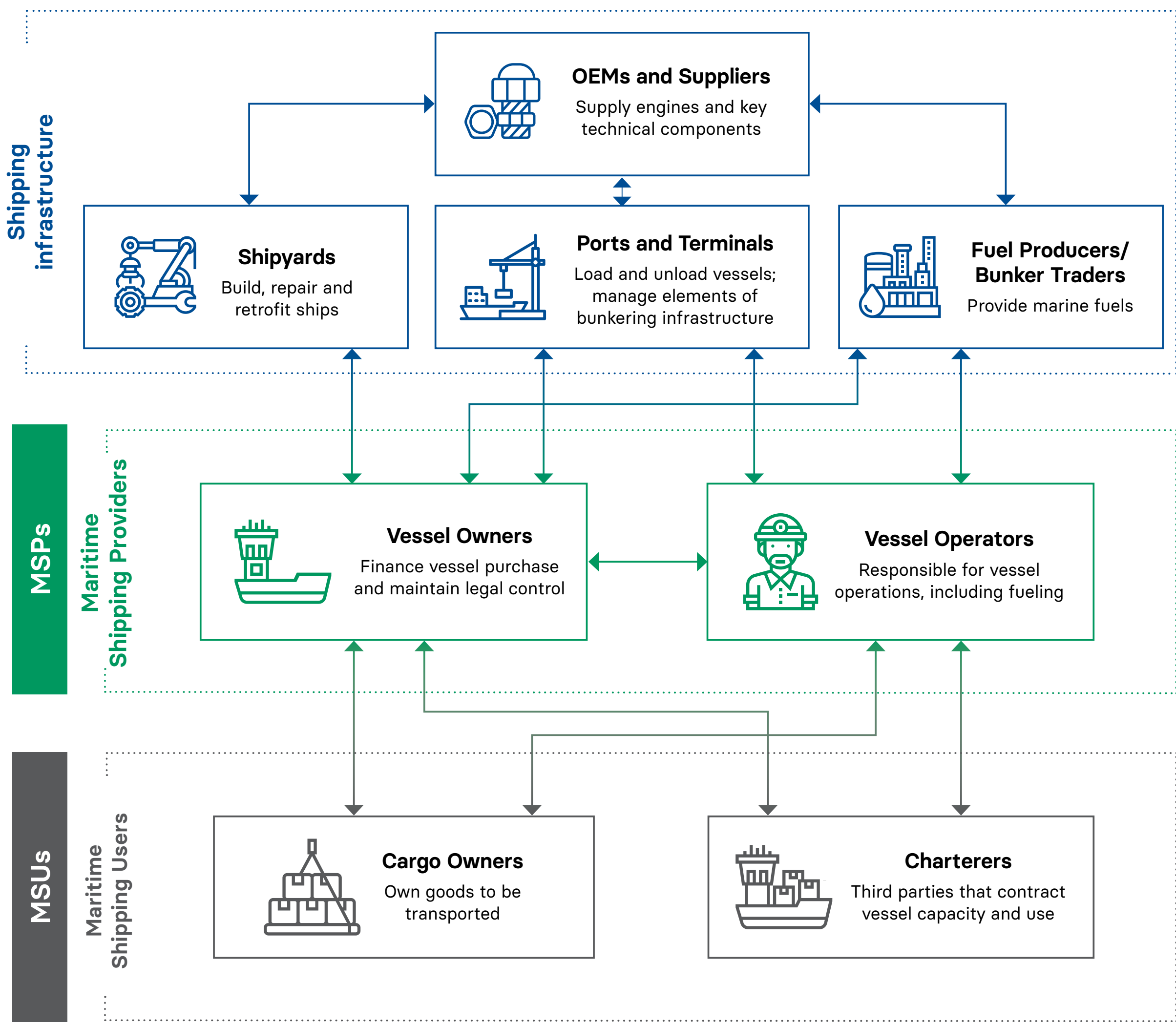
CHAPTER 2

The ask: How key players in shipping can drive emissions reductions

Among the many players with a role in the maritime sector, two types of market participants play a central role influencing the pace of decarbonization. These are: 1) ship owners and operators, referred to in this report as **maritime shipping providers (MSPs)**, and 2) users of shipping such as cargo owners and charterers, referred to as **maritime shipping users (MSUs)**. Each has key leverage over the sector's energy transition due to its central placement in the network of shipping operations and shipping demand, respectively (see Figure 3).

FIGURE 3

The shipping ecosystem



Given the importance of maritime shipping to global supply chains, investors should ask both MSPs and MSUs to make clear commitments to emissions reduction – including concrete short, medium and long-term steps. Companies should also disclose relevant metrics that allow stakeholders to measure progress toward those goals.

Commitments from Maritime Shipping Providers (MSPs)

We identified the following key commitments that investors should ask of MSPs. These will not be equally relevant to all MSPs and will vary depending on company-specific factors such as whether a company owns or operates ships.

1. **Commit to reach zero-emission shipping by 2050.** Companies should set a target to eliminate emissions of carbon dioxide and other greenhouse gases based on a full fuel lifecycle accounting by 2050 or sooner. Some leading companies have set targets to decarbonize by 2040.
2. **Adopt interim emissions reduction targets consistent with long-term goals.** Credible decarbonization plans include immediate reductions in carbon intensity, instead of postponing significant emissions cuts to later years. Interim targets should address:
    a. **Carbon intensity targets.** MSPs should set and disclose targets for declining GHG intensity (in g CO_2/dwt/nm or a similar metric) in the near- and medium-term, i.e., by 2030 and by 2040, and they should report annually on investments and progress towards those goals. MSPs should upgrade their fleets so that by 2024 all vessels achieve a rating of at least "C" in the IMO Carbon Intensity Indicator system that takes effect in 2023; by 2025 all vessels should be on track to achieve an "A" or "B" efficiency rating.
    b. **Fuel strategy.** MSPs should develop and disclose long-term and transitional fuel strategies, addressing factors such as demand projections and infrastructure needs. Companies that have already implemented LNG or biofuel blending as a near-term strategy should address how they will transition fully to zero-carbon fuels, consistent with their target.
    c. **Ship purchase and upgrade strategy.** MSPs should adopt and disclose fleet transition plans encompassing both new-build and vessel retrofits that establish a path to full fleet decarbonization, including short-, medium- and long-term goals and fuel strategies.
    d. **Energy efficiency measures.** Increasing vessels' fuel efficiency is a readily available, cost-effective means to reduce fuel consumption and associated emissions. The options depend on vessel type and operational profile and include technical measures such as hull and propeller optimization; alternative propulsion systems such as wind-assist; and operational efficiency measures such as route optimization and speed reductions. Companies should disclose their fleet efficiency strategy in their transition plans.
3. **Provide cargo-level emissions data.** Companies should disclose emissions per ton (or TEU) of cargo transported per distance carried. They should work toward providing customers with emissions data per cargo unit – including lifecycle CO_2 and non-CO_2 emissions – to support supply chain emissions management.
4. **Support the development of "green" ports and corridors.** Pilot programs and early learning opportunities centered on port electrification and low-carbon shipping corridors are important to accelerate the deployment of new technologies at scale.

5. **Advocate for clean shipping policies at international, regional, national and local levels.** Strong policy support for clean shipping can reduce costs associated with the transition while accelerating decarbonization. MSPs should directly engage in the development and support of ambitious policies to align with the Paris Agreement on Climate Change. Notably, companies should encourage IMO to adopt, in its forthcoming GHG strategy revision, a target of zero carbon emissions by 2050 and a strong 2030 goal.

Commitments from Maritime Shipping Users (MSUs)

We identified the following key commitments that investors should ask of MSUs with respect to their use of maritime freight.

1. **Prioritize climate performance in shipping procurement.** Seek out providers with zero-emission targets, explicit transition plans, ongoing or committed emissions reductions, and other indicators of leadership in the energy transition. This could include committing to ship a minimum share of freight with MSPs that have explicit decarbonization targets. Engage directly with MSPs to understand their transition plans and encourage ambition.
2. **Place cargos on the cleanest, most fuel-efficient vessels possible.** Preferencing ships sailing on alternative fuels or with an IMO rating of "A" or "B" can drive near-term emissions reductions and support corporate scope 3 goals.
3. **Signal a willingness to pay more for zero-carbon shipping services.** In the initial years of the transition, zero-carbon fuels will be more expensive than traditional fossil fuels; MSUs should communicate their willingness to pay a premium for their use.
4. **Support the development of "green" ports and corridors and commit to using them when they become available.** Demand from shipping customers is important to justify early investments in alternative-fuel ships and infrastructure. By participating in such green corridors, MSUs can accelerate their deployment at scale.
5. **Advocate for clean shipping policies at international, regional, national and local levels.** MSUs should directly engage in the development and support of ambitious policies to align the sector's decarbonization with the temperature goals of the Paris Agreement on Climate Change. Companies should encourage IMO to adopt zero-by-2050 emissions reduction targets in the forthcoming revision of its GHG strategy. Policies that lower the expected price gap between scalable zero-carbon fuels and fossil fuels are also of particular importance.

Disclosures

In order to evaluate individual company performance and compare one company to another, investors need consistent and comparable disclosures of emissions performance. The global nature of the maritime shipping industry makes IMO the logical source of such disclosure standards; however, key elements of IMO-required emissions disclosures are not attributed to individual companies. Shipping companies that report emissions do so voluntarily or according to local requirements, leading to a range of disclosure formats.

Disclosures from Maritime Shipping Providers (MSPs)

The Sustainable Accounting Standards Board's Marine Transportation Standard, which has now been included in the International Sustainability Standards Board (ISSB) draft Climate-Related Disclosures, recommends several helpful metrics for MSPs, as do the IMO Data Collection System and EU regulation on monitoring, reporting and verification. However, we believe that companies should go beyond these metrics to provide further disclosures that investors can use to evaluate progress towards climate goals[1]. These are:

1. **GHG emissions.** Companies should disclose scope 1, 2 and 3 emissions and identify which are related to shipping.
2. **Carbon intensity.** This should be expressed at the fleet level in g CO_2/dwt/nm or a similar metric and complemented at the vessel level with the IMO carbon intensity indicator letter grade when those become available in 2024.
3. **Fuel mix.** Disclosure should include the total energy consumed as well as the percent split in energy consumption between heavy fuel oil and other fuels such as natural gas and low- and zero-carbon alternative fuels.
4. **Average Energy Efficiency Design Index for new ships.** This IMO measure, expressed in gCO_2/TNM, is an indicator of whether capex for new ships is being deployed in a way to minimize emissions intensity.
5. **Climate strategy and progress on transition.** MSPs should provide a discussion of their emissions targets and transition plans, as well as an analysis of performance against those targets. This could include, for example, fleet transition strategy, zero-carbon capex plans or the share of cargo-miles shipped on zero-emission vessels.

1 In its submission to the ISSB in response to the IFRS S2 Climate-related Disclosures Exposure Draft, Environmental Defense Fund recommended several enhancements to the Marine Transportation disclosure requirements, consistent with these recommendations.

CHAPTER 3

Background: The shipping industry's emissions challenge

Shipping demand is rising long-term

Maritime shipping plays a central role in global trade and modern supply chains. Nearly 100,000 commercial vessels move 11 billion tons of goods each year. The world's ocean fleet has doubled in capacity since 2005, and today maritime shipping transports about 80% of global trade volumes.

Over the past two decades maritime shipping volumes have grown at an annual rate of 3%, driving growth in the size and number of ships in the water. The OECD forecasts maritime trade will triple by 2050, a 3.6% annual growth rate. This is marginally slower than expected global GDP growth over that period, mainly due to projected declines in the transport of fossil fuels like crude oil, refined fuels, and coal.

Merchant ships are generally grouped into five types: container ships (carrying stacks of intermodal containers on their decks); bulk carriers (carrying unpackaged, raw solid materials such as ores, coal, or grains); tankers (carrying liquids or gases), specialist ships (a highly diverse group including ice breakers, livestock ships, tug boats, drilling ships, etc.); and ferries and cruise ships (see Figure 4).

The focus of this report is on bulk carriers, tankers and container ships, which account for 85% of the global shipping fleet and almost 80% of total CO_2 emissions from maritime shipping. These segments share operational and logistical considerations related to emissions and decarbonization.

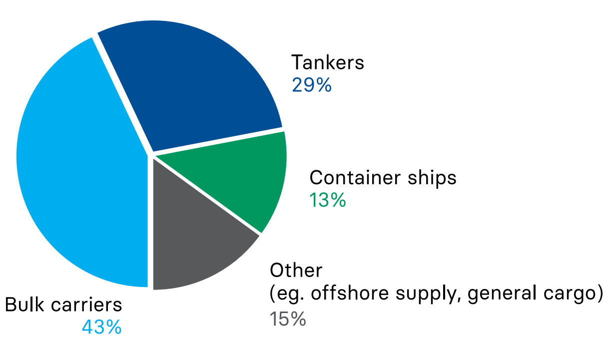
Shipping emissions add up

Compared to other modes of transport, ships are a relatively efficient way to move goods. As Figure 5 indicates, emissions per unit of freight, at around 20 grams of CO_2 per ton-nautical mile for a container ship, are well below most other modes and just a fraction those of long-haul aircraft.

FIGURE 4

Global fleet vessel share

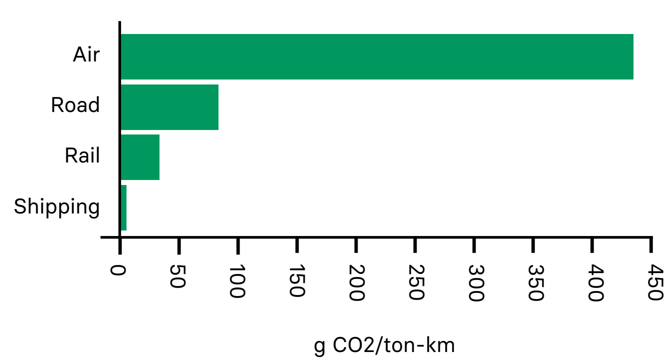
2021



Data: UNCTAD Review of Maritime Transport 2021

FIGURE 5

CO_2 Emissions Intensity by Transport Mode



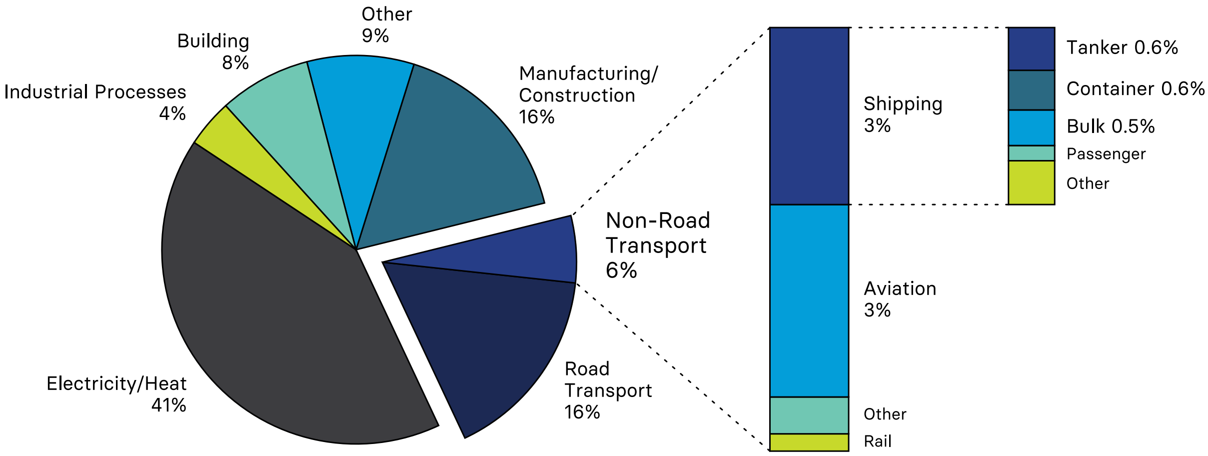
Data: IEA Tracking Transportation 2021

Ships transport the majority of global freight volumes, so despite their relatively lower emissions intensity, the total emissions footprint of shipping is quite high: around [3% of global CO_2 emissions] and rising. Within shipping, the 3 major segments – container ships, tankers and dry bulk carriers – each represent a roughly even share of those emissions.

FIGURE 6

Global CO_2 Emissions

2018



Data: Climate Watch, IEA, ICCT

**Shipping %s estimated from 2015 data.*

In addition to CO_2 emissions, shipping is linked with pollution from other greenhouse gases, notably methane – which has more than 80 times the warming power of CO_2 over the first 20 years following its release.[2] Carbon dioxide and methane emissions are both on an upwards trajectory. From 2012 to 2018, carbon dioxide emissions rose by 9.6% and methane emissions by 87% - with rising methane emissions driven largely by increased use of LNG as a fuel.[3] Increasing LNG shipping is likely to drive further methane emissions growth, the precise extent of which is not yet clear.

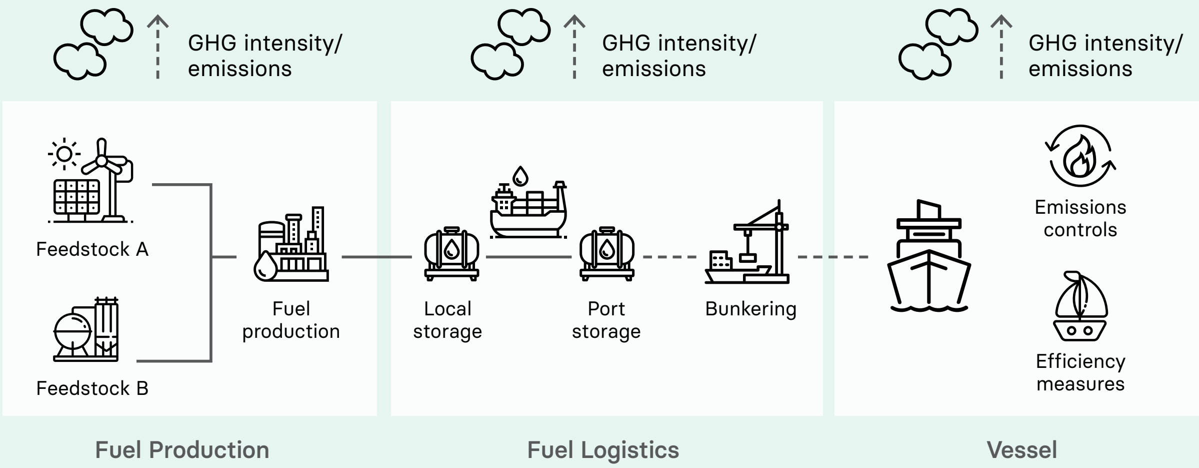
There is, however, significant potential to reduce energy demand from maritime shipping through technologies such as air lubrication, wind-assisted propulsion, waste heat recovery, and speed reductions.

2 Shipping is also associated with numerous other types of pollution with impacts on human health and the environment. Such emissions can include nitrogen oxides, sulphur oxides, hydrocarbons, carbon monoxide, particulate matter, and polycyclic aromatic hydrocarbons. This report focuses primarily on climate pollutants and their impacts.

3 Fourth IMO Greenhouse Gas Study, 2020, pg 11. IMO attributes the significant increase in methane emissions s driven to both an increase in consumption of LNG and by a shift toward dual-fuel equipment that has higher methane emissions.

FIGURE 7

Well-to-wake emissions sources



Source: MMM Center for Zero Carbon Shipping, Fuel Options Study (2022)

Assessing the climate impact of the shipping industry requires accounting for the lifecycle emissions of the fuels used, including upstream emissions associated with fuel production. A well-to-wake GHG accounting methodology takes these into account, including both CO_2 and non-CO_2 emissions such as methane and nitrous oxide (N_2O) (Figure 7). These combined impacts are typically expressed by converting to CO_2 equivalence, CO_2e. Since some shipping-related GHGs, most notably methane, have significant near-term warming impacts, analysis should consider not only the 100-year global warming potential of pollutants but also their 20-year global warming potential.[4]

In its emissions accounting for the maritime sector, IMO only considers tank-to-wake emissions of CO_2, omitting the impact of fuel production and transport.

4 For more recommendations on lifecycle assessment for maritime fuels, see Exploring the relevance of ICAO SAF for the IMO.

Future emissions paths are unclear

There is considerable uncertainty about the future trajectory of shipping emissions. The timing of decarbonization is important to limiting global temperature rise: as more time passes before emissions start to fall, more and more drastic transition measures – at higher cost to the industry – will be required to correct course.

Decarbonization will likely occur unevenly across the shipping sector, beginning with the applications that are easiest to address. Liner shipping, which operates between a set number of ports according to a regular timetable and encompasses most container shipping, is an early target for the introduction of new, zero-emissions infrastructure. Tramp shipping, in which operations respond to operator needs without a fixed schedule or published ports of call, encompasses much of the bulk and tanker trade and will likely transition later due to the higher complexity of fueling.

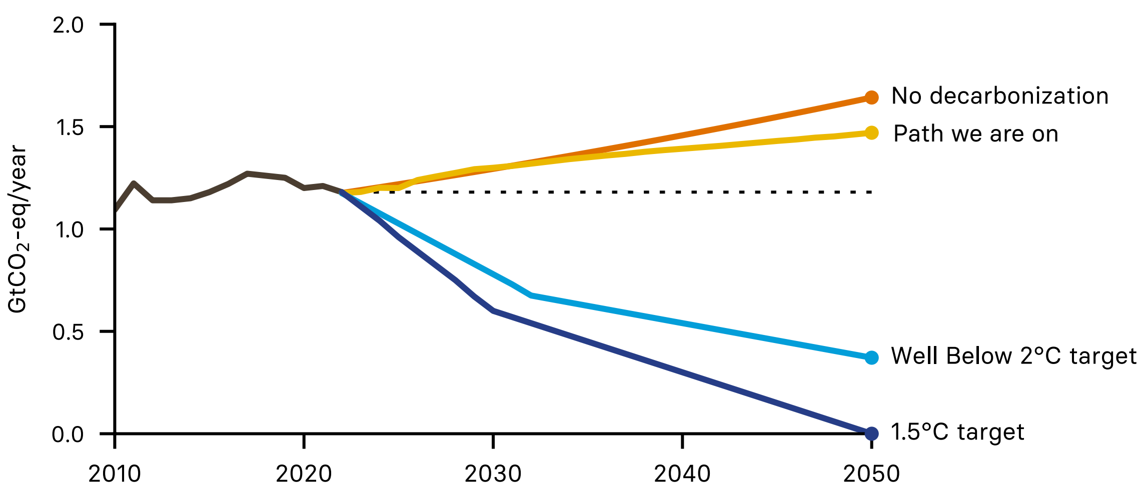
> **“The timing of decarbonization is important to limiting global temperature rise: as more time passes before emissions start to fall, more and more drastic transition measures – at higher cost to the industry – will be required to correct course.”**

Figure 8 illustrates 4 possible emissions pathways for maritime shipping – more detail on these is available in the MMM Center for Zero Carbon Shipping report, Industry Transition Strategy 2021 and will be published in an upcoming report on maritime decarbonization strategy. These scenarios reflect “well-to-wake” emissions estimates (see Box above).

- “No Decarbonization” scenario, assuming the continuation of current practices, fuel mix and efficiency strategies, would see emissions rise by 40% to 1.5bt CO_2e by 2050
- A “current path” scenario assumes the continuation of 2021 decarbonization efforts but otherwise maintains business as usual. This path reduces the emissions associated with individual vessels, routes, or companies, but as the global maritime trade is forecasted to continue growing by around 1.3% every year, it results in a 9% increase in total emissions by 2050.
- A scenario that limits global average temperature rise to well below 2°C (WB2°C) above pre-industrial levels by targeting one third of emissions reduction by 2030 and net zero carbon emissions by 2070
- A scenario that limits global average temperature rise to 1.5°C by reducing emissions ~45% by 2030 and reaching net zero by 2050

FIGURE 8

Maritime emissions pathways



Source: MMM Center for Zero Carbon Shipping, forthcoming paper on maritime decarbonization strategy

According to the MMM Center for Zero Carbon Shipping's techno-economic modelling tool, decarbonizing shipping by 2050 is possible.

Introduced in 2021, the model was developed to support maritime decarbonization by facilitating analysis of the well-to-wake energy value chain. The model incorporates data on vessel type, fuel choice, operational efficiency and other factors to generate insights into total cost of ownership (TCO) and transition planning. Users can modify key assumptions such as the cost of renewable electricity for fuel production, regulated efficiency requirements, or future emissions surcharges, to examine alternative scenarios.

Drawing on the model, the Center for Zero Carbon Shipping found five critical levers that must be activated to reach zero carbon shipping in 2050:[5]

- Energy and fuel advancements onshore, to scale production and drive down costs for alternative fuels
- Technological advancements on vessels including energy efficiency measures and preparing existing and new-build ships for future fuels
- Evidence of customer demand and willingness to pay for green shipping options
- Mobilizing finance for fleet and infrastructure investments
- Policy and regulation to level the global playing field and close the cost gap between fossil and alternative fuels

Maritime decarbonization has implications for the entire business ecosystem. In order to reach zero emissions by 2050, key actions must begin immediately, and real progress must be made within this decade.

An opportunity for leadership from IMO

As the lead regulator for global shipping, IMO plays a critical role in guiding the pace and ambition of sector-wide decarbonization. In 2018, IMO adopted an initial strategy for GHG reductions to peak "as soon as possible."

The strategy includes the following non-binding objectives:

- **Improve the design efficiency of existing and new-build ships.** Ships should meet specific targets for fuel consumption based on their cargo capacity.
- **Reduce GHG emissions by 50% by 2050 and fully decarbonize "as soon as possible in this century."** The target addresses total global shipping emissions from a 2008 baseline.
- **Reduce emissions intensity by 2030.** Reduce carbon intensity industry-wide by at least 40% by 2030 from 2008 levels, and by 70% by 2050.

IMO is planning to update its GHG strategy in 2023, which presents an opportunity to align its guidance more closely with the Paris 1.5°C target (see Chapter 6 for more on the regulatory environment).

5 For more on this analysis, see the Center's Industry Transition Strategy.

Just Transition

Decarbonizing shipping is a systemic change that will have consequences for people and communities across global energy and maritime value chains. A just transition seeks to ensure that the substantial benefits of a green economy transition are shared widely, while also supporting those who stand to lose economically – be they countries, regions, industries, communities, workers or consumers.[6]

The importance of a just transition in maritime shipping is gaining recognition, as evidenced by two significant announcements last year. In November during COP26, the international Climate Vulnerable Forum issued the Dhaka-Glasgow Declaration, in which 55 of the world's most climate-vulnerable countries called for a GHG levy on international shipping, with revenues to go toward urgent climate actions, particularly in vulnerable developing countries. Also during COP26, the International Chamber of Shipping, the International Transport Workers' Federation and the United Nations Global Compact jointly launched the Just Transition Maritime Task Force to pursue a holistic, people-centered and equitable approach to shipping decarbonization.

Workers and affected communities must be centrally involved in order to manage disruptions that come with this change. The Just Transition Maritime Task Force has set a goal of enabling "a safe, well-communicated, well-managed and just transition for all seafarers, the maritime workforce and their communities to a zero-emission shipping industry by 2050, ensuring skill distribution, decent work, training opportunities, health and safety on board, and equal opportunity for all."[7]

According to the Task Force, a non-exhaustive list of priorities for the just transition includes skills development, "decent work," gender and diversity, occupational health and safety, social dialogue, social protection, equity, supply chains, communities, and climate justice. From May 2022-2023, the Task Force is focused on green jobs, skills, and supply chains across the zero-emission vehicle lifecycle and decarbonized maritime fuel chain, engaging with port communities, assessing national economic development perspectives, and researching safe and decent work on board ships and in green jobs.

As MSPs and MSUs develop and implement their own plans to support a just transition, investors should look for evidence that they are informed by input from affected workers and communities.

6 Definition courtesy of the European Bank for Reconstruction and Development.

7 Unpublished JTMTF presentation, Feb 17 2022.

CHAPTER 4

Decarbonizing shipping: Fuels, efficiency, ports, and green corridors

Over the past decade, growing recognition of the shipping industry's climate impacts has spurred industry and government interest in measures to limit ship emissions. Reducing ship energy use through technologies such as wind-assisted propulsion and air lubrication can significantly cut emissions; combining these with operational measures such as speed optimization can further reduce emissions.[8]

The shipping sector also requires a transition in its fuel use. Zero-emission fuels such as green ammonia and bio-methanol, as well as associated vessels and infrastructure, will be needed for full decarbonization. Measures to reduce ship energy use through higher efficiency will play an important role by offsetting the expected higher costs of these alternative fuels.

Below, we examine key elements of the transition pathway: alternative fuels; efficiency and energy demand reduction; port infrastructure; and the growth of green corridors.

Zero-carbon fuels

It is unlikely that any one zero-emission fuel will meet the needs of all major shipping uses. Going forward, fuel selection will likely vary with the type of shipping, route, vessel and other factors. Each potential fuel solution has advantages as well as important technical, commercial and regulatory considerations, as noted below. These challenges are in addition to cost, which can be expected to fall for most fuels with the achievement of economies of scale. For a deeper look at the technical and regulatory factors associated with particular fuel pathways, see the MMM Center for Zero Carbon Shipping's Fuel Pathway Maturity Map.

In general, there are three primary pathways to produce low- and zero-carbon shipping fuels (Figure 9):

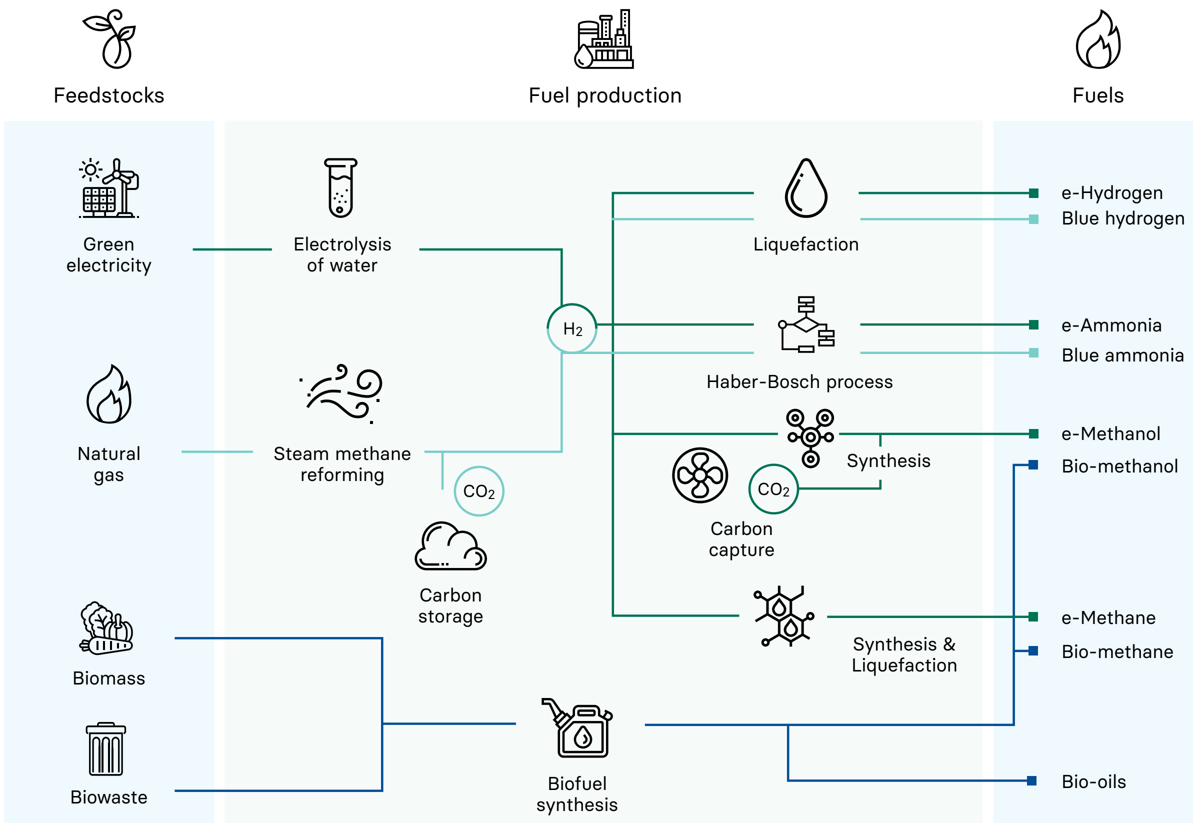
1. Using renewable energy and zero-emissions chemical components to make zero-carbon fuels.
2. Using conventional fuels with carbon capture and measures to reduce other climate-warming emissions.
3. Using different fuel compounds that have lower associated emissions than conventional options.

These three process pathways can produce a range of zero- and low-carbon fuels that hold promise for broad commercialization. All of these fuels continue to face challenges linked to their specific supply path or properties, but some have cleared more technological and regulatory hurdles than others (Figure 10).

8 Bouman, E. A., Lindstad, E., Rialland, A. I., & Strømman, A. H. (2017). State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping–A review. *Transportation Research Part D: Transport and Environment*, 52, 408-421.

FIGURE 9

Shipping fuels and their production pathways



Source: MMM Center for Zero Carbon Shipping, Industry Transition Strategy (2021)

FIGURE 10

Shipping fuel readiness

	Feedstock availability	Fuel production	Fuel storage, logistics and bunkering	Onboard energy storage & fuel conversion	Onboard safety and fuel management	Vessel emissions	Regulation & certification
E-ammonia	MATURE	SOLUTIONS IDENTIFIED	MAJOR CHALLENGES	MAJOR CHALLENGES	MAJOR CHALLENGES	MAJOR CHALLENGES	MAJOR CHALLENGES
Blue ammonia	SOLUTIONS IDENTIFIED	SOLUTIONS IDENTIFIED	MAJOR CHALLENGES	MAJOR CHALLENGES	MAJOR CHALLENGES	MAJOR CHALLENGES	MAJOR CHALLENGES
E-methanol	SOLUTIONS IDENTIFIED	SOLUTIONS IDENTIFIED	SOLUTIONS IDENTIFIED	MATURE	MATURE	MATURE	SOLUTIONS IDENTIFIED
Bio-methanol	SOLUTIONS IDENTIFIED	SOLUTIONS IDENTIFIED	SOLUTIONS IDENTIFIED	MATURE	MATURE	MATURE	SOLUTIONS IDENTIFIED
E-methane	SOLUTIONS IDENTIFIED	SOLUTIONS IDENTIFIED	MATURE	MATURE	MATURE	SOLUTIONS IDENTIFIED	SOLUTIONS IDENTIFIED
Bio-methane	SOLUTIONS IDENTIFIED	SOLUTIONS IDENTIFIED	MATURE	MATURE	MATURE	SOLUTIONS IDENTIFIED	SOLUTIONS IDENTIFIED
Bio-oils	SOLUTIONS IDENTIFIED	MAJOR CHALLENGES	SOLUTIONS IDENTIFIED	SOLUTIONS IDENTIFIED	MATURE	SOLUTIONS IDENTIFIED	SOLUTIONS IDENTIFIED

MATURE
Solutions are available, none or marginal barriers identified

SOLUTIONS IDENTIFIED
Solutions exist, but some challenges on e.g., maturity and availability

MAJOR CHALLENGES
Solutions are not developed or lack specification

Source: MMM Center for Zero Carbon Shipping

Ammonia

Ammonia is composed of hydrogen and nitrogen and has potential shipping application for use with fuel cells or via combustion. As a fuel, ammonia's key strengths include well-established handling guidelines related to its use as a fertilizer and chemical feedstock, mild storage temperature and pressure requirements, and a robust pre-existing network of production and distribution infrastructure.

Key considerations

- **Technical:** Combustion of ammonia does not produce CO_2 emissions, as no carbon is contained in the fuel, though ammonia engine designs require the limited use of a "pilot fuel" that could emit carbon. Ammonia is highly toxic, requiring special attention to vessel design and operational factors. Ammonia can produce health- and climate-damaging emissions of NOx and N_2O during combustion. Engineering work on ammonia-fueled vessels that burn the fuel or use it to power a fuel cell is ongoing, but neither is yet commercially available.

- **Commercial:** There is a robust global market for ammonia and existing infrastructure for the use of fossil fuel-derived ammonia for agricultural and industrial use.

- **Regulatory:** Widely recognized standards do not yet exist for the production of zero-emissions ammonia or for well-to-wake greenhouse gas accounting. In light of its high toxicity to humans and ecosystems, robust frameworks are needed to support safe handling.

Types of ammonia fuel

- E-ammonia or "green ammonia": Fuel produced without carbon emissions by using hydrogen produced with zero-carbon electricity (i.e. renewables) as a feedstock, and zero-carbon electricity for process energy.

- "Blue ammonia": Fuel produced from natural gas with carbon capture and sequestration. Actual emissions depend on variables including the emissions associated with the production and transport of source natural gas, and the CCS process. Mass production of blue ammonia would require new levels of commercial availability for carbon capture and sequestration.

Methanol

Methanol is composed of carbon, hydrogen and oxygen, and is widely used as an industrial solvent and in chemicals manufacturing. Its strengths as a fuel include favorable storage and handling requirements and the existence of global infrastructure and associated regulations.

Key considerations

- **Technical:** There are several pathways for carbon-neutral methanol synthesis with differing levels of technical maturity. Methanol engines for maritime shipping have been tested over the past decade, and some are commercially available today. These engines require a small amount of pilot fuel, which might or might not be carbon neutral. While carbon-free electricity is increasingly available and cost-effective, dedicating large amounts of clean power to maritime fuel production would require diverting it from other high-demand sectors.

- **Commercial:** Thanks to its uses in manufacturing, large quantities of methanol are transported globally and handling protocols already exist. Port infrastructure for methanol, including terminals and bunkering facilities, would need to be drastically expanded if methanol were to be widely adopted as a shipping fuel.

- **Regulatory:** IMO has issued interim guidelines for the use of methanol as a shipping fuel and is working on a full fuel specification, which would support infrastructure expansion. Guidance is needed to clarify acceptable methodologies for assessing methanol's lifecycle emissions and for the sources of CO_2 and biomass that can be considered renewable.

Types of methanol fuel

- E-methanol or "green methanol": The main feedstocks for producing e-methanol are water and CO_2. Since burning methanol releases CO_2 into the atmosphere, the fuel can only be considered carbon neutral if the feedstock CO_2 is captured from the environment, as in direct air capture. Using CO_2 captured via the exhaust gas of another process, such as captured CO_2 from a fossil fuel power plant, is also possible but in that case the process would not be considered zero-emissions. Process energy must also come from renewables.

- Bio-methanol: Carbon neutral bio-methanol is made from biogenic waste streams such as manure, agricultural waste and food waste, which are converted into bio-methane and further upgraded to bio-methanol. According to current estimates, total feedstock potential for bio-methanol could prove insufficient for maritime shipping use due to high potential demand across multiple industries. Existing infrastructure, practices, and regulatory frameworks do not support large-scale collection of suitable waste streams.

Methane

Methane is composed of carbon and hydrogen, and it is the primary component in natural gas. Unlike methanol, methane is a gas at ambient temperatures and pressure, leading to more complex handling requirements. Its strengths as a fuel include the existence of global infrastructure and regulatory frameworks developed for fossil fuel-derived methane.

The use of liquefied natural gas (LNG) - consisting almost entirely of methane – in shipping is relatively new, however there are now hundreds of vessels using fossil-based LNG in commercial operation. There are no major operational hurdles to scaling up methane as a shipping fuel; the biggest challenges lie in the availability and cost of emissions-free methane, and open questions about the degree of leakage during shipping.

Key considerations

- **Technical:** Liquid storage of methane requires specialized equipment to keep the fuel chilled to below -163°C. A variety of engines compatible with methane are in use, including dual-fuel, high- and low-pressure, and two-stroke and four-stroke models with varying cost, efficiency, and emissions profiles. Growing evidence suggests that significant amounts of uncombusted methane may be leaked from LNG-powered ships.[9]

- **Commercial:** Fuel supply logistics are well established for LNG as a traded commodity, much of which carries over to methane fueling.

- **Regulatory:** The well-to-wake emissions of methane fuel are driven by the natural gas supply chain: there are significant regulatory gaps throughout production, transport and delivery of methane. The extent of methane leaks onboard vessels is unknown due to a lack of monitoring. Well-to-wake greenhouse gas quantification for methane (or LNG) have not been adopted by regulatory bodies such as the EU or IMO.

Types of methane

- E-methane: The main feedstocks for producing e-methane are water and CO_2. To create carbon-neutral fuel, feedstock CO_2 must be captured from the environment, as in direct air capture. As with e-methanol and e-ammonia, obtaining sufficient zero-carbon electricity to produce e-methane is also problematic considering the immense scale required and anticipated demand from other sectors.

- Bio-methane: Carbon-neutral bio-methane is made from biogenic waste streams such as manure, agricultural waste and food waste. As in the case of bio-methanol, anticipated competing demand for sustainable streams of such feedstocks is high, suggesting likely cost and supply constraints. Another challenge is that existing infrastructure, practices, and regulatory frameworks do not support large-scale collection of suitable waste streams.

9 One study found a methane slip rate of 3.8% from a new-build LNG carrier. Methane is a powerful greenhouse gas that is 80 times more potent than CO2 over the first 20 years following its release, so methane slip can significantly impact the overall emissions impact of the fuel as measured in CO2 equivalence. See P Balcombe et al (2022) Total Methane and CO2 Emissions from Liquefied Natural Gas Carrier Ships: The First Primary Measurements, Env Sci Technol 2002, 56, 13, 9632-9640.

Hydrogen

Hydrogen is both a precursor to all e-fuels and a fuel in its own right, and it can be used either in combustion engines or with fuel cells. Hydrogen poses challenges in storage, transportation and bunkering, largely because, as the smallest element on the periodic table, it is prone to escaping from many types of infrastructure[10]. It has a significantly lower energy density compared to other candidate shipping fuels, so its use would require shorter trips, more frequent bunkering stops, or a reduction in cargo capacity in order to store more fuel on board. These difficulties make hydrogen an unlikely choice for long-distance shipping, but it is being tested for use in fuel cells on inland waterways and may have applications in short sea shipping.

Key considerations

- **Technical:** In combustion engines hydrogen requires use of a pilot fuel, as is the case with ammonia or methanol. Storage as a liquid requires specialized equipment to maintain -253°C. Equipment to detect hydrogen leaks at climate-relevant levels is not commercially available. Low volumetric energy density makes hydrogen challenging for long routes.

- **Commercial:** Only a tiny share (<1%) of hydrogen production is carbon neutral today; demand is expected to expand significantly, driving up costs.

- **Regulatory:** Widely accepted standards for the production, handling, transport, etc. of hydrogen fuel have not been established. Standards that address hydrogen safety may be insufficient to avoid leaks at smaller levels that have climate impacts.

Types of hydrogen

- "Green hydrogen": This zero-carbon fuel is produced using renewable sources for production energy.

- "Blue hydrogen": This potentially low-carbon hydrogen is produced from natural gas using CCS. The associated GHG emissions depend on emissions associated with the source natural gas and the CCS process.

10 Ocko, I. B. and Hamburg, S. P.: Climate consequences of hydrogen emissions, Atmos. Chem. Phys., 22, 9349–9368, https://doi.org/10.5194/acp-22-9349-2022, 2022.

Bio-oils and e-diesel

The vast majority of the global fleet today uses various types of fuel oil, and drop-in replacements for those fossil-based fuels are highly desirable. There is also a long-term potential market for these fuels for use as carbon-neutral pilot fuels, for co-firing with the low- and zero-emission alternative fuels to enable proper combustion in vessel engines, as described above.

There are two main classes of drop-in fuel oil replacements with high relevance: bio-oils and e-diesel. There are several different kinds of bio-oils that are produced from biomass streams such as agricultural waste, wet waste, or manure. Carbon-neutral e-diesel, like e-methane and e-methanol, is produced from reacting e-hydrogen with CO_2 from renewable sources.

Key considerations

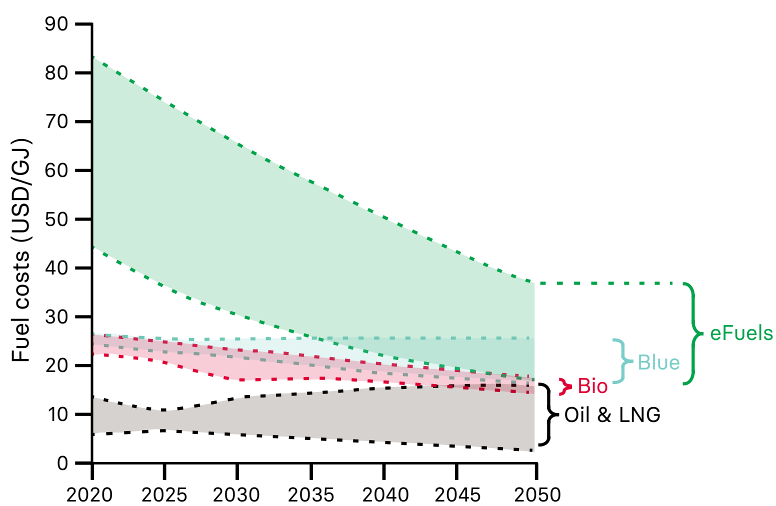
- **Technical:** The conversion of shipping engines for bio-oil compatibility is simpler than the conversions required for other sectors, potentially making shipping an early use case. Challenges remain in refining and mixing bio-oils derived from different types of waste.
- **Commercial:** Limited availability of bio-oils makes them unlikely to be viable for broad use. Bio-oils face supply chain challenges because existing infrastructure, practices, and regulatory frameworks do not support large-scale biomass collection. E-diesel is challenged by high projected demand for renewable electricity and the availability of large quantities of carbon-neutral CO_2.
- **Regulatory:** Standardized life-cycle emissions assessment methods do not exist for the full range of bio-oils and e-diesel.

Fuel costs

Fuel cost is a major part of overall cost of ownership in the maritime industry, ranging from 20% in dry bulk to 35% in container. Today, alternative fuels are roughly 2 to 8 times more costly to produce than fossil fuels. Figure X7 shows estimated production costs of select zero-carbon fuels under different modes of production.[11] The price gap between fossil and alternative zero-carbon fuels is projected to narrow over time but is not likely to close through market forces alone before 2050.

FIGURE 11

Projected Maritime Shipping Fuel Costs



Source: MMM Center for Zero Carbon Shipping, Industry Transition Strategy (2021)

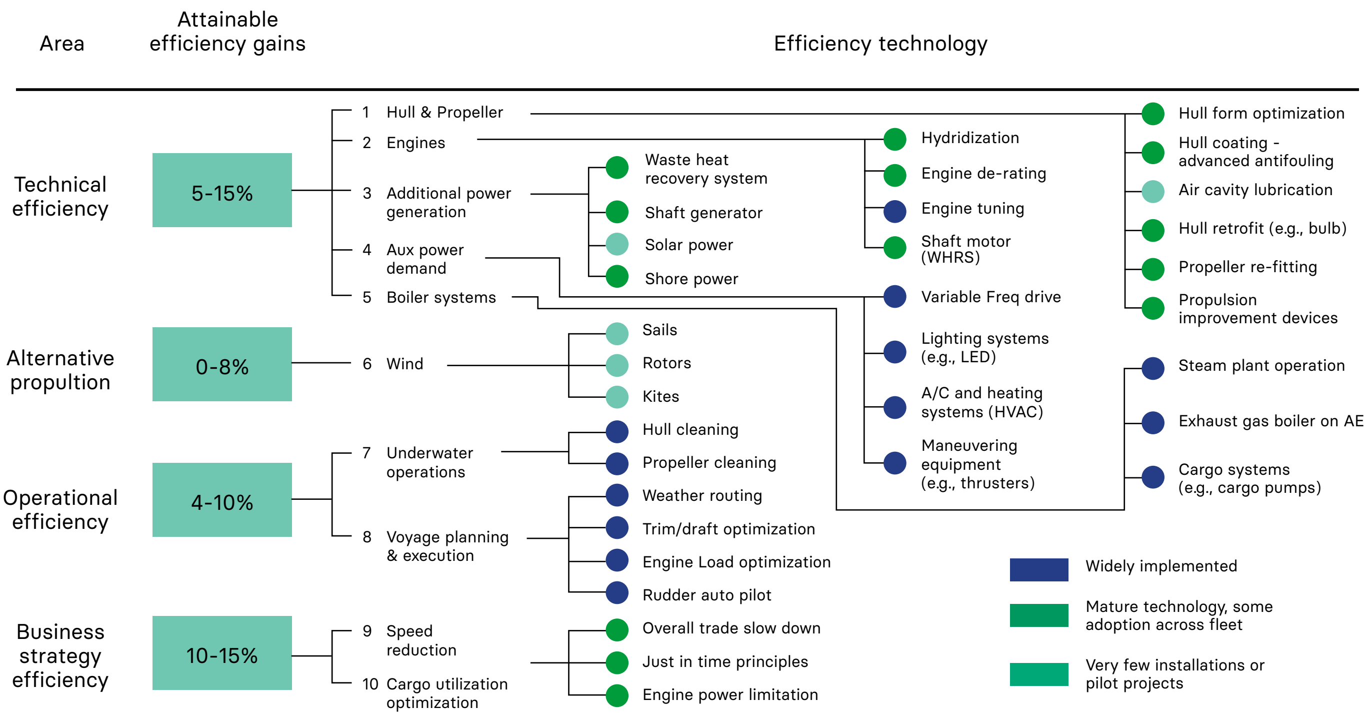
11 For a comprehensive fuel cost analysis, see https://cms.zerocarbonshipping.com/media/uploads/documents/Fuel-Options-Position-Paper_Oct-2021_final.pdf

Energy efficiency and demand reduction technologies

In the near term, technical and operational means of reducing the energy intensity of shipping provide a clear, "no regrets" path to reducing overall emissions while contributing to the success of longer-run strategies like fuel switching (Figure 12).

FIGURE 12

Gains from energy efficiency and demand reduction



Source: MMM Center for Zero Carbon Shipping, Industry Transition Strategy (2021)

The Getting to Zero Coalition, a partnership between the Global Maritime Forum and the World Economic Forum, estimates the potential energy and carbon savings from such measures at 25% - 30% across the global fleet. However, the emissions reductions possible for a particular vessel or MSP fleet could be higher or lower than that global average, depending on factors such as vessel age, engine type and maintenance. The Retrofit Project, a case study of 3 ship retrofit projects documented by the Danish consortium Green Ship of the Future, identified dozens of measures with combined potential energy savings ranging from 11% to 27%.[12] Another recent study suggests emissions reductions could range as high as 78% for some vessels.[13]

12 The Retrofit Project addressed retrofits that were cost-effective over a 3-year payback period at prevailing fuel prices, and its conclusions do not represent a technological limit on efficiency measures. A longer payback period or higher fuel prices would increase the emissions reductions available through vessel retrofitting.

13 Bouman, E. A., Lindstad, E., Rialland, A. I., & Strømman, A. H. (2017). State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping – A review. Transportation Research Part D: Transport and Environment, 52, 408–421. https://doi.org/10.1016/j.trd.2017.03.022

One demand reduction measure merits special note: slow steaming. This refers to sailing at a reduced speed to reduce fuel consumption. Slow steaming has been widely used during periods of high oil prices, most notably during the 2009 global financial crisis, and can generate fuel gains in the range of 20% - 40% while reducing emissions.

Other efficiency measures, including promising options such as wind-assisted propulsion and weather and route optimization, have seen more limited uptake. Identifying and addressing barriers, such as misalignment between which parties bear the costs and benefits of upgrades, will be central to their adoption.

Port infrastructure

Ports can and will play a pivotal role in decarbonizing the shipping industry - not only by decarbonizing their own operations but also by accommodating the specific requirements of ships running on zero-carbon fuels. Moreover, they can incentivize the transition by implementing rules and policies that favor clean ships. A 2020 study by University Maritime Advisory Services and Energy Transition Commission found that about 85% of total investment in the maritime shipping energy transition will target land-based infrastructure.

Some large ports have adopted commitments to zero-carbon operations by 2050, encompassing the decarbonization of operations such as tugboats and workboats as well as support for their customers' zero-emissions shipping needs (Figure 13).

FIGURE 13

Major ports that have committed to supporting zero-carbon shipping

1 Singapore
2 Hamburg
3 Algeciras (Spain)
4 Valencia (Spain)
5 Antwerp
6 Rotterdam
7 New York
8 Long Beach LA
9 Vancouver
10 Houston

Many more ports have taken steps to provide Onshore Power Supply (OPS). The use of OPS offers benefits for the climate and local community by delivering electric grid power to ships as a replacement for the use of on-ship fossil fuel-based power generation. This can significantly reduce carbon, air and noise pollution. The initial deployment of OPS requires significant capital investment by the port authority, and OPS is so far mostly limited to the U.S. and northern Europe. The European Commission has proposed that most vessels and major container ports use Onshore Power Supply by 2030.

An additional area where ports can play a critical role in the shipping transition is in offering services for affected maritime workers and communities. MSPs can engage with port authorities to support such services.[14] Climate-resilient port infrastructure can help safeguard coastal communities living nearby.

Green Corridors

In this decade, "green corridors" could create pockets of predictable demand for zero-carbon fuels at specific ports and accelerate operational learning on zero-carbon fuel production and bunkering. Green corridors are currently being designed to enable low-carbon shipping, encompassing the full value chain including vessels, fuels, regulators and finance providers, and secured by demand from customers. Bringing together essential stakeholders, green corridors can serve as large-scale opportunities for learning and demonstration of the availability, operational factors, and financial feasibility of technology transition.

The Clydebank Declaration for green shipping corridors, launched in 2021, sets a target of at least 6 such routes to be operational by 2025. Significant green corridor initiatives announced to date include the European Green Corridors Network established with the port authorities of Hamburg, Gdynia, Roenne, Rotterdam, and Tallinn; a Rotterdam-Singapore green corridor; a green corridor that would connect the ports of Shanghai and Los Angeles; a green corridor to transport iron ore between Australia and East Asia; and consideration of a Chilean Green Corridor. These corridors will offer valuable real-world experience with zero-carbon fuels for participating MSPs and MSUs.[15]

14 For more on the role of ports in the shipping sector energy transition, see Browne, A. & O'Leary, A. (2022). Ports Playbook for Zero-Emission Shipping. Pacific Environment and Opportunity Green.

15 For more information see the MMM Center for Zero Carbon Shipping's Green Corridors: Feasibility Phase Blueprint (2022).

CHAPTER 5

Regulatory frameworks: IMO and the EU drive the industry

Despite increasing attention to the need for shipping decarbonisation among policymakers, businesses and industry, sufficient enabling policies are not in place at a global level. The year 2023 will be decisive as IMO considers more ambitious decarbonization targets and the possible adoption of market-based measures to help reach them.

The International Maritime Organization

Founded in 1948, IMO is the United Nations' specialized agency with responsibility for international maritime shipping, addressing everything from safety and security to the prevention of marine and air pollution by ships. As the global regulator, IMO has an important role to play in setting expectations for the pace and ambition of sector-wide decarbonization. IMO's 175 member states look to it for leadership and harmonization in adopting policies that will be binding in their own jurisdictions.

In 2018, IMO published an "Initial strategy on the reduction of GHG emissions from ships" which targeted reductions in shipping emissions by at least 50% by 2050, compared with 2008 levels, and aimed for the sector to fully decarbonize "as soon as possible during this century." The strategy also sets levels of ambition to reduce carbon intensity by at least 40% by 2030, with a goal of 70% by 2050, compared to 2008 levels. Although this initial climate framework was seen as a major step forward for the industry, it falls short of full decarbonization and achieving it would leave the industry considerably short of the Paris Agreement goals.

One criticism made of IMO's 2030 GHG ambitions is that they commit the industry to little beyond the efficiency levels that have already been reached. As of 2015, the carbon intensity of international shipping had dropped by more than 30% from 2008 levels through the introduction of ship efficiency improvements. According to the International Council on Clean Transportation, shipping's carbon intensity is likely to fall by another 10 percentage points or more by 2030 without further policy interventions.

In late 2021, nearly 50 countries – including the US, the UK, the EU27 and several developing countries – signalled support for an overarching IMO commitment to zero shipping emissions by 2050. The demonstrated support is a clear indicator of renewed political and industry focus on decarbonization, but there is still significant work to make meaningful progress at IMO and ensure an equitable transition.

IMO is planning to revise its GHG strategy in 2023, which provides an opportunity to raise its policy ambition. By using the opportunity to strengthen IMO's 2030 goal and adopt a zero-emissions-by-2050 goal, IMO member states can provide stronger direction to MSPs, MSUs, and other stakeholders and facilitate a more organized and cost-effective transition.

Among its implementation strategies, IMO is considering adoption of a carbon price on shipping fuel that would make it more expensive to operate ships without climate mitigation. This would immediately incentivise operational improvements, while beginning to narrow the competitiveness gap between traditional fossil fuels and alternative fuels. Revenue from this price could go toward building out ship- and land-based infrastructure, with special priority for small island developing states and least-developed countries.

In support of this Paris-aligned shipping decarbonisation goal, EDF and the MMM Center for Zero Carbon Shipping recommend the following policy measures:

- **Set standards for zero- and low-carbon fuels.** The shipping industry needs robust science- and equity-based standards and criteria based on well-to-wake assessment for the production and use of key alternative fuels to ensure high performance on environmental, equity, and climate metrics and to provide certainty for investors in green shipping.

- **Adopt a market-based measure to price carbon industry-wide.** IMO should adopt a carbon pricing scheme designed to reduce shipping emissions and to help alternative fuels become price-competitive with conventional fuels. Revenues should be directed to ship- and land-based infrastructure needs, including those required to achieve an equitable transition for disadvantaged communities.

- **Strengthen efficiency requirements.** IMO should increase the stringency of efficiency requirements including its Carbon Intensity Indicator, used to assign ship-level efficiency grades.

- **Adopt a technical measure supporting alternative fuels.** This could take the form of a global fuels standard.

IMO metrics

IMO publishes limited fuel consumption data as part of its Data Collection System: ships with a capacity of over 5,000 gross tons must submit fuel consumption data, which is anonymized and aggregated before it is converted to GHG emissions and released to the public. The European Union's MRV system collects and publishes fuel consumption, distance and cargo data for ships over 5,000 gross tons calling at EU ports.

IMO has several emissions and efficiency metrics, some of which are already in use while others will be reported starting in January 2023:

- **Annual Efficiency Ratio (AER):** Efficiency indicator in emissions per ton-mile, reported according to ship capacity.
- **Energy Efficiency Operational Index (EEOI):** Efficiency indicator in emissions per mile based on actual cargo carried.
- **Energy Efficiency Design Index (EEDI):** A measure of the design efficiency of new-build ships.
- **Energy Efficiency eXisting ship Index (EEXI):** A measure of the technical efficiency of existing ships, to be reported beginning in 2023.
- **Carbon Intensity Indicator (CII):** An efficiency indicator with associated ship-level ratings of A (highest) to E (lowest), to be reported beginning in 2023. Shipowners and charterers can improve a vessel's CII rating by investing in technical upgrades or by operating more efficiently, for example through slower speeds.

Because IMO ship-level data is reported only on an anonymized and aggregated basis, it offers limited value to investors. EDF and the MMM Center for Zero Carbon Shipping recommend that IMO follow the lead of the EU in its monitoring, reporting and verification database, to increase the transparency of data collection and reporting related to ships' carbon footprint.

Key regional/national governments

Europe – an opportunity to lead

The EU is preparing legislation to decarbonise its share of global shipping. As part of its "Fit for 55" legislative package aiming to reduce emissions by 55% relative to 1990 levels by 2030, the European Commission has proposed to extend is Emissions Trading System (ETS) to the maritime sector. The maritime ETS rule would require ship owners or charterers to pay for emissions allowances to cover fuel consumption for domestic (intra-EU) journeys, as well as 50% of international journeys. This would put a price on shipping GHG emissions and be the first such measure globally.

The EU will complement carbon pricing with a fuel standard, which aims to increase the use of sustainable alternative fuels in European shipping and ports by addressing market barriers that hamper their use. Through the proposed Fuel EU standard, the EU would require the GHG intensity of marine fuels to gradually decrease over time, reaching a 75% reduction from the baseline in 2050. Rather than mandating the blending of specific fuels, Fuel EU is goal-based, reflecting uncertainty about which technical options are market-ready.

EU policy by itself will expedite, but cannot substitute for, global policy. EDF-commissioned analysis by the maritime consultancy UMAS shows that a carbon price affecting only maritime voyages that begin or end within the EU is not sufficient to decarbonize the sector by 2050.

The US – New funding for ports

In 2021, the Biden administration committed to working with other nations to adopt a goal of achieving zero emissions from international shipping by 2050. This year, the US Congress passed the Inflation Reduction Act (IRA), hailed as "the biggest package of climate investments in U.S. history," which includes $3 billion in grants and rebates for port authorities and marine terminals to spend on zero-emission port equipment and technology and to address air pollution in port communities. Detailed spending plans for those funds have yet to emerge.

National-level data reporting

Governments around the world are increasingly requiring MSUs and MSPs to publicly report on relevant data. In the EU, shipping companies disclose CO_2 emissions from maritime fuel consumption into the EU-MRV system, which makes it publicly available. Certain other sustainability data is reported by publicly traded companies with more than 500 employees under the Non-Financial Reporting Directive. A proposed amendment to the NRFD, the Corporate Sustainability Reporting Directive, would extend reporting requirements to all companies listed on regulated markets and would require audited GHG emissions and life cycle assessments.

Outside the EU, several governments where shipping companies are headquartered are considering mandatory GHG reporting schemes, including Korea, the UK, Japan, and the US. Publicly traded US companies would be required to increase their disclosures on climate impacts and risks under a draft policy under consideration by the Securities and Exchange Commission. Mandatory disclosure requirements for some companies were adopted in Japan in 2021 and South Korea.

CHAPTER 6

The role of finance in the transition

Shipping is a capital-intensive industry, and most MSPs rely on external capital obtained via loans, equity or bonds.[16] In each major segment of the industry, more than half of capacity of the top 10 largest players is held by companies with listed equity, and many of the other players have issued bonds. All shipping companies rely on bank debt to varying degrees. This provides investors and lenders with an opportunity to encourage action towards a transition.

Banks

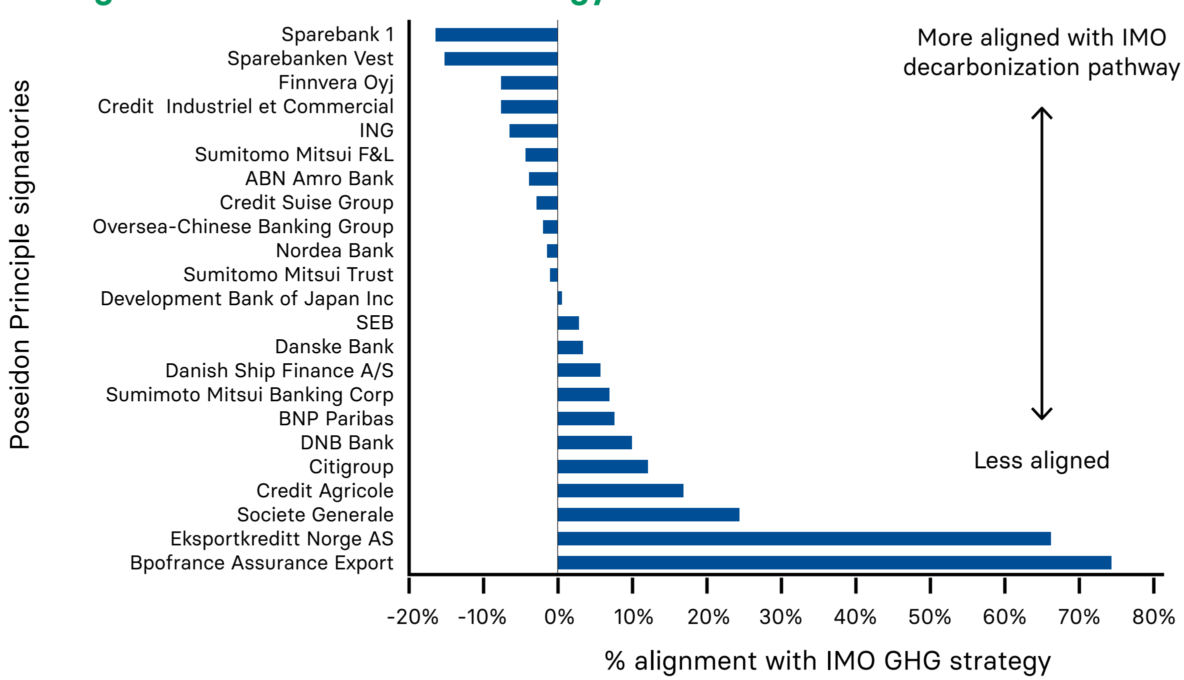
Lenders can have significant influence with shipping companies, given the particular importance of debt financing in shipping. At the end of 2021, the 20 largest shipping companies carried gross debt of $102b and invested nearly $10b in capex. Most shipping companies need regular access to external capital to replace ageing vessels. This will be even more the case in coming years as the industry turns over its fleet to reduce emissions. The banking industry, therefore, can play an important role by providing financial incentives to direct capital to support the transition.

The Poseidon Principles, a framework for assessing and disclosing the climate alignment of ship finance portfolios at commercial banks, has played a role in integrating climate concerns into the lending process. Developed by global shipping banks led by Citi, Societe Generale and DNB, the 26 signatories commit to integrating climate metrics such as emissions intensity into loan terms, with reference to IMO's climate goals.

Signatories of the Poseidon Principles report the alignment of their maritime loan books to efficiency metrics as set out in IMO's Initial GHG Strategy. The 2021 annual disclosure report indicates that 11 signatories reported emissions performance of borrowers that was in-line or better with the IMO benchmark, while 12 reported a higher carbon intensity (Figure 14).

FIGURE 14

Bank alignment with IMO GHG strategy



Data: Poseidon Principles Annual Disclosure Report 2021

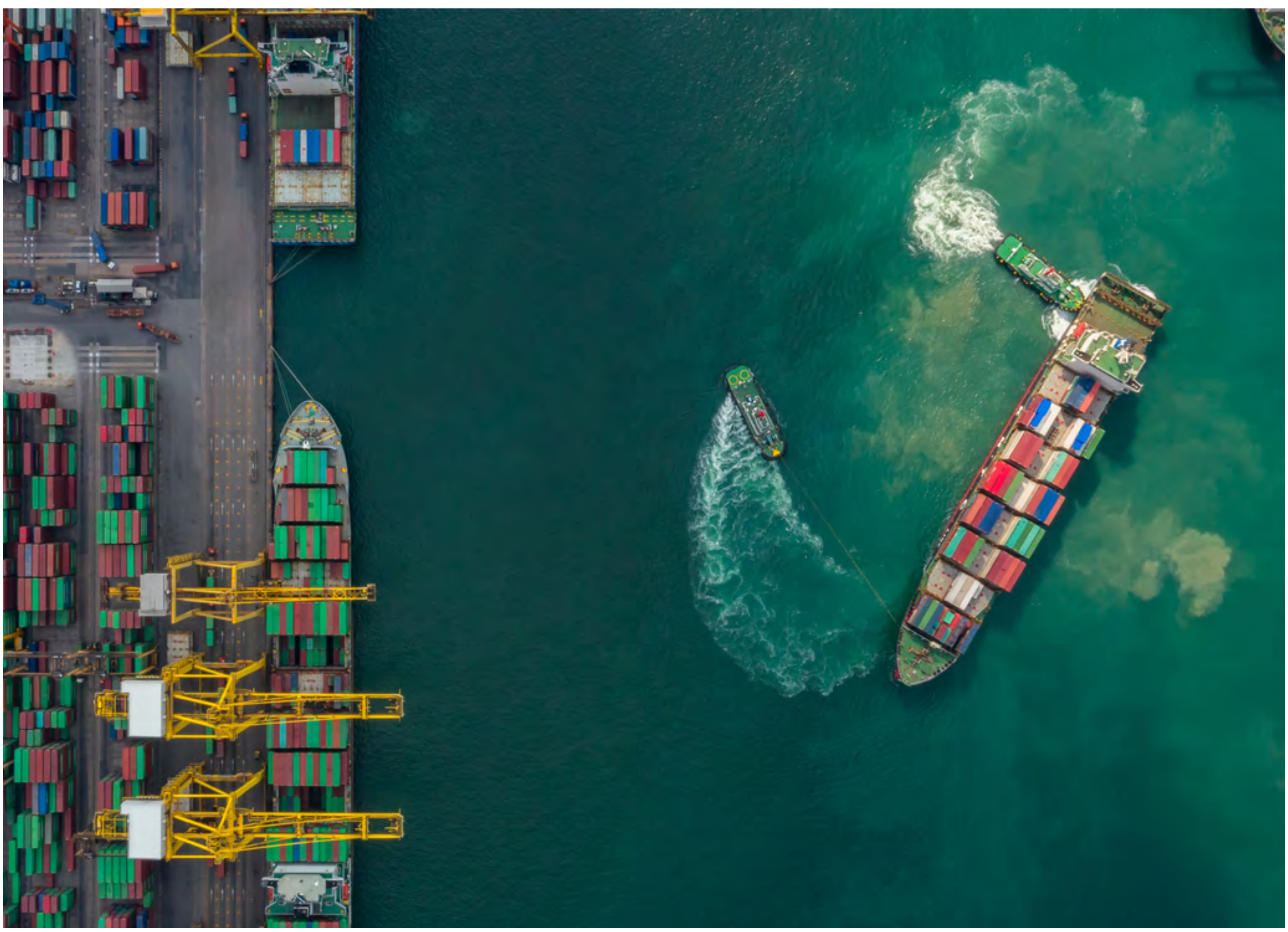
16 Beyond the capital intensity of dedicated shipping infastructure, extensive energy-sector investments are needed to enable a transition to zero-carbon fuels. The Global Maritime Forum estimates that energy could account for as much as 87% of the total decarbonization investment for maritime shipping.

Financial markets

There are numerous ways in which financial markets can incentivize the shipping industry to move more aggressively on the energy transition.

The green bond market is one of these, with the potential to channel finance towards emissions reduction at lower interest rates. The Climate Bonds Initiative (CBI), which develops standards for labelling green investments and certifies bonds against those standards, published a set of criteria specific to the shipping industry in 2020 intended to facilitate maritime green bond issuance. These criteria are starting to be put to use: in late 2021, the New Zealand ferry operator KiwiRail raised the first CBI-certified shipping loan with a $350m loan facility to finance the purchase of 2 low-emission ferries. Given the large capital needs associated with the maritime transition in coming years, there is significant potential to put instruments such as green bonds and sustainability-linked bonds to use in shipping.

Investors can also use their position as shareholders to apply pressure on both MSPs and MSUs. Shareholder resolutions have become an increasingly potent instrument for raising the urgency of climate with company boards and management teams across sectors. Transportation-sector resolutions have been rising in line with the general trend but have yet to be put forward for maritime shipping companies.



Assessment of Shipping Company performance

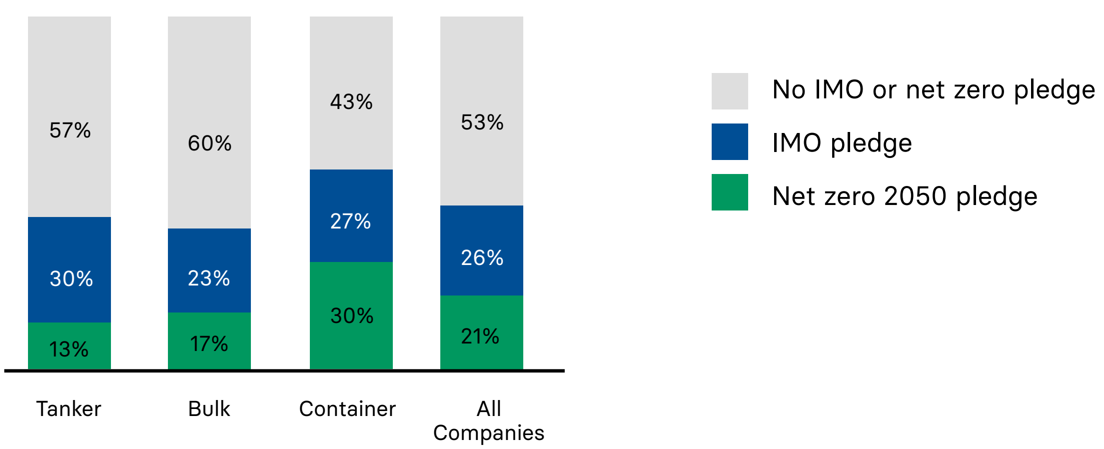
The shipping industry is diverse and fragmented, with some 100,000 commercial ships of 100 gross tons or more spanning hundreds of companies. The industry encompasses companies ranging from large, publicly owned corporations to small, privately held entities with a handful of ships.

Review of top ship owners

The MMM Center for Zero Carbon Shipping reviewed the top 30 ship owners, by capacity in dead weight tonnes (DWT), in container, tanker and bulk shipping, which account for the majority of shipping GHG emissions.[17]

FIGURE 15

Decarbonization pledges amongst the 30 largest owners in each segment



Source: MMM Center for Zero Carbon Shipping

The study, based on information in the public domain in August 2022, reviewed company decarbonization pledges, disclosures, strategies, and actions (Figure 15).

- 16 of the top ship owners across the container, tanker and bulk carrier segments have committed to a net zero target
- 47% of the top ship owners across all three segments have targets in line with IMO ambition or for net zero emissions by 2050.
- The container segment shows the highest levels of ambition with 30% of top ship owners having adopted net zero by 2050 targets.

The analysis also found that 47% of assessed firms had published a sustainability report and that most reporting companies did not publish historical emissions data or data on Scope 2 or Scope 3

17 Since some companies operate in multiple segments, the analysis encompassed a total of 74 companies.

emissions. For eight companies with net zero 2050 ambitions that had disclosed their emissions under the CDP framework, an average of 9 million USD was invested in the previous year on decarbonization, representing an average of 2% of capital expenditures and so far yielding an 8% reduction in emissions.

Case study: Maersk and NYK Line pursue different alternative fuels

The Danish shipper **Maersk** and Japan's **Nippon Yusen Kaisha or NYK Line**, are two leading proponents of shipping decarbonization that are investing in different fuel pathways.

Both companies increased their decarbonization commitments in 2021. Maersk committed to net zero emissions across the business by 2040 and for all ocean operations by 2050. NYK Line upgraded its pre-2021 target of a 50% emissions reduction to adopt a goal of net zero by 2050. Both companies are aligning their emissions planning with the Science-Based Targets Initiative, and report on baseline emissions, targets and performance across scope 1, 2, and 3 emissions, as well as energy consumption and other environmental metrics, according to the guidelines of the Task Force on Climate-related Financial Disclosures.

The two companies differ in their near-term fuel strategies, though. Maersk has centered methanol as its initial strategy towards decarbonization and has invested in 13 methanol-enabled vessels. The first is expected to enter operation by 2023, and the rest are to be in operation by 2025. NYK Line is focused on LNG to achieve its mid-term environmental targets and serve as a bridge to the long-term use of lower-carbon marine fuels such as ammonia or hydrogen. In 2021, the NYK Group launched a concept design for an ammonia-ready LNG-fueled vessel, to facilitate a transition from LNG to ammonia.

Opportunities for leadership among large companies

Assessing the decarbonization commitments of the largest companies in each segment reveals opportunities for leadership. Among the 10 largest MSPs by capacity in each segment, only a minority of companies have committed to net zero by 2050 (Table 1).[18] There is a significant task ahead for the industry to increase the share of the global fleet with a commitment to net zero and improve transparency around environmental performance and GHG emissions.

18 Companies are listed in order of capacity in DWT of their owned fleet, not including vessels operated but not owned by the company. Data was collected in Jan-Feb 2022 through public information sources such as annual reports, sustainability reports, websites, press releases etc. Pledges published after February 2022 are not reflected.

TABLE 1

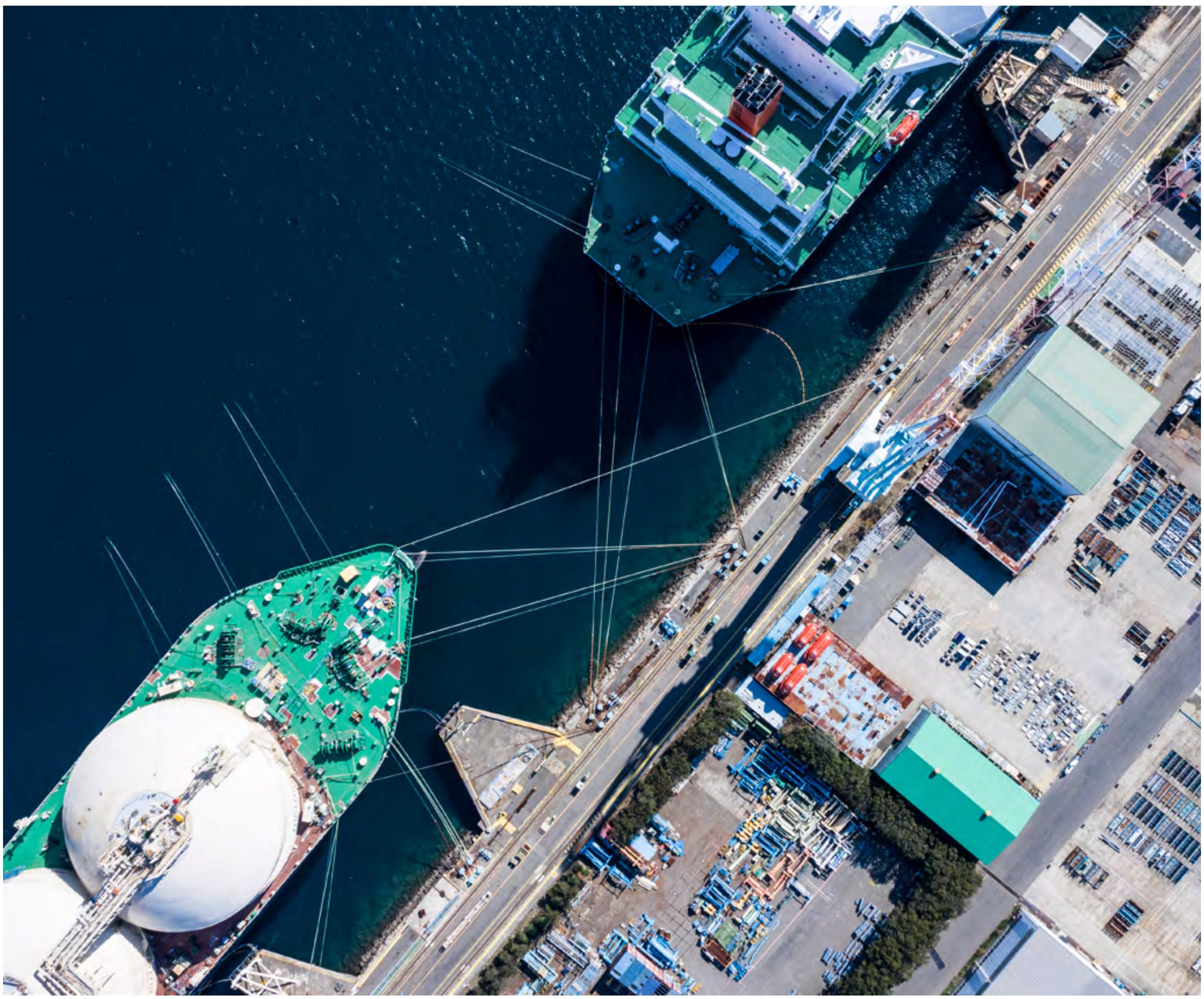
Climate commitments across key shipping segments

Ship owner	Ownership	Fleet size	Issues sustainability report	Has net-zero-by-2050 commitment	Has other net-zero commitment	Has IMO-aligned commitment (50%-by-2050)
Top 10 tanker companies by carrying capacity (DWT)						
China COSCO Shipping	State-owned	174	Y	N	Y	Y
China Merchants	State-owned	123	N	N	N	N
Euronav NV	Public	69	Y	Y	N	Y
Bahri	Public	79	Y	N	N	N
Angelicoussis Group	Private	53	N	N	N	N
Nat Iranian Tanker	Public	55	N	N	N	N
Fredriksen Group	Private	76	N	N	N	N
Dynacom Tankers Mgmt	Private	63	N	N	N	Y
Mitsui OSK Lines	Public	151	Y	Y	N	Y
SCF Group	State-owned	108	Y	N	N	Y
Top 10 bulk companies by carrying capacity (DWT)						
China COSCO Shipping	State-owned	337	Y	N	Y	Y
Golden Ocean Group	Public	109	Y	Y	N	Y
Star Bulk Carriers	Public	129	Y	N	N	Y
Nippon Yusen Kaisha (NYK)	Public	148	Y	Y	N	Y
China Merchants	State-owned	115	N	N	N	N
K-Line	Public	101	Y	Y	N	Y
Berge Bulk	Private	66	Y	Y	N	Y
Oldendorff Carriers	Private	96	N	N	N	Y
ICBC	State-owned	39	N	N	N	N
China Dev Bank	State-owned	104	Y	N	N	Y
Top 10 container companies by carrying capacity (DWT)						
China COSCO Shipping	State-owned	245	Y	N	Y	Y
Mærsk	Public	313	Y	Y	N	Y
MSC	Private	335	Y	Y	N	Y
Atlas Corp (Seaspan)	Private	134	Y	N	Y	Y
CMA CGM	Private	182	Y	Y	N	Y
Hapag-Lloyd	Public	111	Y	Y	N	Y
Evergreen Marine	Public	122	Y	N	N	Y
Imabari Shipbuilding	Public	66	N	N	N	N
HMM	Public	44	Y	Y	N	Y
Zodiac Maritime	Private	48	Y	N	Y	Y

Conclusion

The shipping industry is in the early stages of addressing its climate impact and is not on track to zero out its considerable greenhouse gas emissions by 2050. This presents climate-related transition risk for investors. A range of efficiency, operational and fuel-related strategies are needed to decarbonize the sector. To reduce long-term risk and accelerate the transition timeline, companies need to accelerate pilot programs and early learning for low-carbon fuels, while implementing efficiency and operational changes that can quickly reduce emissions. By advocating before international, regional and national authorities for supportive policies, shipping providers and their customers can manage their transition costs and smooth the industry's path to zero emissions.

As a capital-intensive industry, maritime shipping has reason to be responsive to investors and lenders. To reduce portfolio emissions, investors should call on providers and users of shipping services to adopt transition plans consistent with zeroing out emissions by 2050, and should support enabling policies to increase the speed of the transition and reduce its cost.



Appendix: Key institutions supporting the maritime transition

Below is a partial list of organizations that are particularly active in maritime shipping decarbonization. This list is non-exhaustive, and there are many other organizations that are making important contributions to various aspects of the issue as well.

Cargo Owners for Zero-emission Vessels (coZEV). CoZEV is a cargo owner-led platform for collaboration that enables maritime freight customers to come together and use their brand power and economies of scale to accelerate maritime decarbonization. CoZEV was launched by the Aspen Institute in 2021 and includes as signatories Amazon, Brooks Running, Frog Bikes, IKEA, Inditex, Michelin, Patagonia, Tchibo, and Unilever.

Getting to Zero Coalition. The Getting to Zero Coalition is an alliance of more than 150 companies within the maritime, energy, infrastructure and finance sectors. A partnership between the Global Maritime Forum and World Economic Forum, the Coalition is committed to getting commercially viable deep sea zero-emission vessels powered by zero-emission fuels into operation by 2030

Global Center for Maritime Decarbonisation. The Global Centre for Maritime Decarbonisation (GCMD) is a non-profit formed in 2021 with funding from the Maritime and Port Authority of Singapore, BHP, BW, DNV Foundation, Eastern Pacific Shipping, Ocean Network Express and Sembcorp Marine. Located in Singapore, GCMD supports decarbonization of the maritime industry to meet or exceed the International Maritime Organization's (IMO) goals for 2030 and 2050.

Global Maritime Forum. The Global Maritime Forum is an international non-profit organization committed to shaping the future of global seaborne trade to increase sustainable long-term economic development and human wellbeing. The GMG facilitates the Poseidon Principles, the Sea Cargo Charter and the Getting to Zero Coalition.

International Chamber of Shipping. Representing 80% of the world's merchant tonnage, the ICS is one of the world's leading shipping organizations in advising on maritime regulatory, operational, and legal issues.

International Maritime Organization. Founded in 1948, IMO is the United Nations specialized agency responsible for regulating shipping, including safety and security and the prevention of marine and air pollution.

Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMM Center for Zero Carbon Shipping). The Center is a not-for-profit, independent research and development center looking to accelerate the transition towards a net-zero future for the maritime industry. It seeks to drive the development and implementation of new technologies; build confidence in new concepts, and drive systemic and regulatory change.

Sea Cargo Charter. The Sea Cargo Charter was established under the Global Maritime Forum as a framework for measuring and reporting the alignment of ship charterers' activities with climate goals. It focuses on assessing climate alignment, accountability, enforcement and transparency.

Sustainable Shipping Initiative (SSI). SSI seeks to improve the sustainability of the shipping industry in terms of social, environmental and economic impacts. Founded in September 2010 by Forum for the Future in collaboration with WWF and industry leaders ABN Amro, BP Shipping, Gearbulk, Lloyd's Register, and Maersk Line, SSI has 15 members including charterers, shipowners and operators, shipyards, banks, classification societies and technology companies.

UN Global Compact Ocean Stewardship Coalition. A global and cross-sector initiative that convenes to drive action and determine how the ocean, and ocean industries, can deliver on the Paris Agreement and the Sustainable Development Goals. Transitioning from the Sustainable Ocean Business Action Platform, the coalition achieves targets by defining actions and recommendations, establishing baselines, developing frameworks and supporting maritime industries.

UMAS. A commercial advisory service affiliated with University College London's Energy Institute, delivering applied solutions to businesses with carbon constrained futures within the maritime sector.

World Shipping Council. Founded in 2000, the World Shipping Council is the primary trade association that represents roughly 90% of the international shipping industry. Based in Washington, Brussels and Singapore, the Council have developed standards of vessel air emissions and pollution, improved customs procedures, and worked with members to strive for carbon neutrality.