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MARITIME FORECAST TO 2050

EXECUTIVE SUMMARY AND HIGHLIGHTS

Energy Transition Outlook 2024

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FOREWORD

Maritime decarbonization is the greatest challenge of our time but our industry's ingenuity and innovation can carry us forward.

The stage is set. Driven by regulations, the IMO's decarbonization goals, pressure from cargo owners, financing terms, and societal trends, shipping's historic voyage towards full decarbonization is underway.

IMO targets are clear: full-scale decarbonization by or around 2050, a 20% emissions reduction by 2030, and a 70% reduction by 2040.

The question now is, how do we get there?

Many in the industry are still waiting to see what happens but now is the time for leaders across the industry to step up. This means making smart decisions now which can accelerate the maritime green transition.

Full decarbonization will require large-scale transition to carbon-neutral fuels and the industry is continuing to embrace diverse fuel technologies like LNG, LPG, methanol, and ammonia. Production of green fuels is also underway but large-scale supply remains elusive and today's reality is that 93% of the world fleet is still running on conventional fossil fuels.

In this latest edition of the Maritime Forecast to 2050, we explore how this can be turned around through pathways involving operational and technological solutions. We examine how shipowners and other stakeholders can ensure that fleets meet emissions targets and regulations, while remaining competitive.

With a range of uncertainties, we accept that this transition will not be rapid, and the challenge must be faced with pragmatism. Simulations in Maritime Forecast to 2050 reinforce how energy-efficiency measures are essential to operating profitably into the 2030s and 2040s until cost and supply of carbon-neutral fuels become more feasible. Indeed, one of the few things which we do know for certain now is that investing in energy saving technologies and reducing fuel consumption creates significant savings for shipowners and should be a central part of any future business strategy.

We estimate that operational and technical energy-efficiency measures can reduce fuel consumption by 4% to 16% by 2030. Some can be achieved quite easily through encouraging operational efficiencies which can minimize fuel consumption and emissions. Achieving

more requires a range of technological solutions: onboard carbon capture and storage, fuel cells, wind-assisted propulsion, air lubrication, and waste-heat recovery systems are among technologies already proven to deliver considerable emissions reductions.

Furthermore, energy efficiency is being significantly enhanced by digitalization. The Maritime Forecast to 2050 shows how this can help to unlock operational efficiencies, while also enabling smooth and reliable emissions reporting and facilitating contractual arrangements.

The estimated range of efficiency gains translates into varying demand for carbon-neutral fuels, and for CO_2 storage for onboard carbon capture, when measured against the IMO's 2030 goals. Depending on efficiency gains, ship demand for carbon-neutral fuels in 2030 is estimated at 7 to 48 million tonnes of oil equivalent, with demand for CO_2 storage between 4 and 76 million tonnes per year.

Two big takeaways result from these estimates. First, the greater predictability and affordability of energy efficiency measures should make this a top priority for shipowners. Second, shipping should work with fuel and carbon capture developers to secure carbon-neutral fuel supply, and with key ports to develop the carbon capture and storage capacity and infrastructure that it needs.

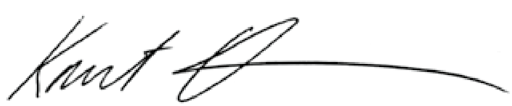
Changes to the technological and regulatory landscape are reflected through significant updates to this year's GHG Pathway Model. Examples include GHG fuel intensity regulation requirements with or without ship pooling, well-to-wake emission factors, FuelEU Maritime, onboard carbon capture, liquid organic hydrogen carriers, and nuclear propulsion.

We explore scenarios for achieving decarbonization (biofuels and onboard carbon capture, methanol, ammonia, and hydrogen), investigating conditions under which uptake of fuel types or technologies will accelerate by 2050. In all scenarios, onboard carbon capture emerges as an important technology after 2030, reducing demand for carbon-neutral fuels. However, no single fuel or technology dominates in any scenario, emphasizing the complexity of choice that the industry will continue to face.

Decarbonizing shipping will come at a cost. Maritime Forecast to 2050 estimates that to achieve the IMO's final and intermediate reduction ambitions in well-to-wake emissions, costs per tonne-mile could increase significantly compared to business-as-usual. Increased freight rates will have to be passed through the value chain, with consumers likely to pick up most of the tab.

In conclusion, the headwinds are strong, and a cloud of uncertainty still obscures how a fully decarbonized global fleet will look in 2050.

Nonetheless, buoyed by a proud tradition of maritime ingenuity, bravery, and innovation, and a spirit of collaboration, both within and beyond the industry, we can steer towards our goals with confidence.



Knut Ørbeck-Nilssen

CEO Maritime, DNV

EXECUTIVE SUMMARY

Maritime Forecast to 2050 is one out of DNV's suite of Energy Transition Outlook reports. This latest edition provides an independent outlook of the technologies and fuels of shipping's energy future. We present an analysis of the future availability of carbon-neutral fuels and carbon storage, as well as estimates on how much shipping can reduce its energy consumption.

Spurred by a wave of decarbonization regulations, shipping is in a phase of unprecedented innovation with a wide range of new technologies being developed, tested, and implemented. Overall, the new technologies and fuels necessary for decarbonization increase costs of seaborne transport and these costs must be moved through the value chain to the consumer as an increase in the price of goods.

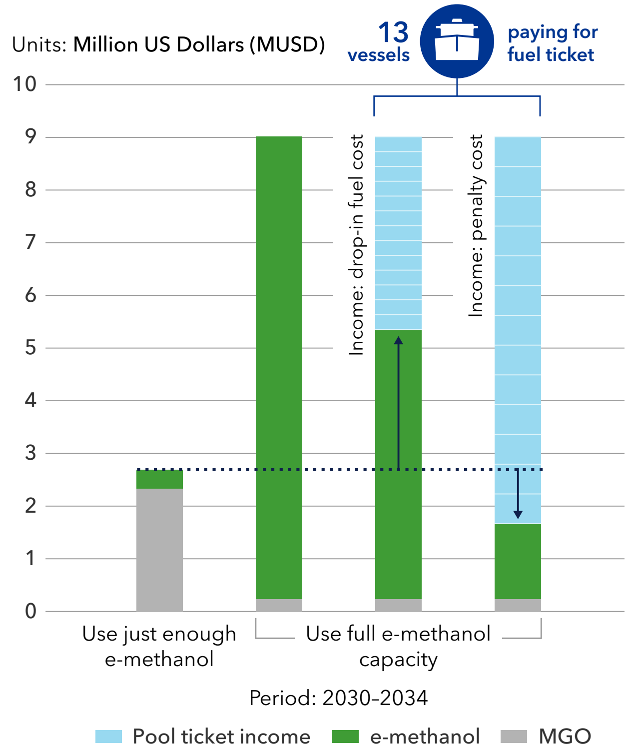
We present ongoing discussions in the IMO and an outlook on the upcoming changes in maritime regulations. This is the first year where ships trading in the EU are subject to the EU Emissions Trading Scheme (EU ETS), which has required a revision of regulatory responsibility and contracts to ensure the allowance costs are passed through the supply chain to the responsible company.

IMO negotiations are ongoing, developing what is called a basket of measures which can consist of two parts: a technical element, which will mandate reduced greenhouse gas (GHG) intensity of marine fuels, and an economic element, which will be a GHG emissions pricing mechanism.

The EU's FuelEU Maritime Regulation (Regulation (EU) 2023/1805) coming in 2025 is imposing a well-to-wake GHG intensity requirement on energy used during a year, effectively forcing the use of qualified low GHG fuels. Another feature of FuelEU Maritime, and something that is under discussion in the IMO, is the option to pool compliance across several ships from the same or different companies. This means that each individual ship

FIGURE 1-1

Annual fuel expenses including pool ticket income for a methanol-capable vessel in a FuelEU Maritime compliance pool



does not need to achieve the required fuel GHG intensity but can rely on other ships to achieve a combined level of fuel GHG intensity that is below the requirement.

Pooling of compliance can incentivize shipowners to invest in technologies to use alternative fuels, as they can receive 'pool ticket income' from ships joining their pool. Measured in total cost per tonne of GHG emission reductions, DNV estimates that including a pooling mechanism can reduce the cost of decarbonization by 6%.

The decarbonization of shipping will also require a transition to carbon-neutral fuels, and hence the construction of vessels that can run on these fuels. The trend of larger ships being ordered with dual-fuel propulsion capabilities is continuing. This does not apply just for liquefied natural gas (LNG). Many methanol and liquefied petroleum gas (LPG) fuel-capable ships are in the order book, while ammonia fuel capability is also emerging.

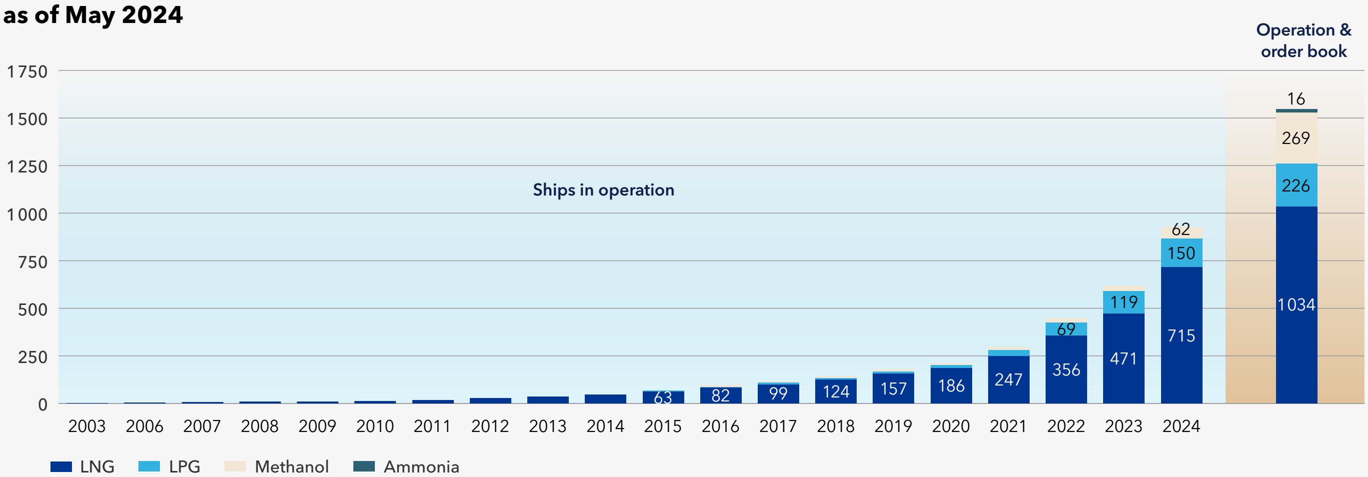
Increasing global carbon-neutral fuel production is necessary to reach the IMO's ambition of a 20% reduction in total CO_2 emissions from shipping by 2030, relative to 2008 levels. We estimate that 44 to 63 million tonnes of oil equivalent (Mtoe) of carbon-neutral fuels will be available by 2030 for all economic sectors, and that shipping will need 10% to 100% of this to reach IMO targets.

As implied above, shipping has started on a fuel technology transition – in different directions towards LNG, LPG, methanol and ammonia. The production of carbon-neutral fuels, those with low well-to-wake (WtW) emissions, is also underway and being planned. As there are significant uncertainties around several factors influencing the transition, we present exploration scenarios for the development of the world fleet fuel mix where shipping achieves decarbonization. Rather than predicting a future fuel mix, we investigate the conditions under which the uptake of certain fuel types may accelerate. A new addition in this year's Marine Forecast to 2050 is that the scenario results now include fossil fuels with onboard carbon capture, nuclear propulsion, and hydrogen-powered fuel cells.

With limited supply of several carbon-neutral fuels, and the transition to an alternative-fuelled fleet taking time, other decarbonization solutions are required. Energy-

FIGURE 1-2

Growth of the number of ships capable of using selected alternative fuels, excluding LNG carriers, as of May 2024



Energy-efficiency technologies and measures provide cost-efficient and predictable pathways to emissions reduction while also reducing demand for carbon-neutral fuels.

efficiency technologies and measures provide cost-efficient and predictable pathways to emissions reduction while also reducing demand for carbon-neutral fuels. The business case for using energy-saving technologies may now be better when evaluated against the cost of alternative rather than conventional ship fuels.

Technical and operational energy-efficiency measures can be underpinned by growth in the presence and sophistication of digital technologies and systems. Digitalization can add much needed transparency on vessel performance, providing vital data that can measure the impact of energy-saving measures and helping to design and operate the next generation of energy-efficient ships. In a new age of emissions reporting, digital verification tools can help to create an infrastructure of trust, boosting industry-wide collaboration and facilitating new contractual arrangements incentivizing energy-efficiency measures.

Carbon capture and storage (CCS) from continued use of fossil fuels can also contribute significantly to the decarbonization of shipping but infrastructure for handling and storing CO_2 needs to be developed.

FIGURE 1-3

Estimated supply of carbon-neutral fuels to all sectors

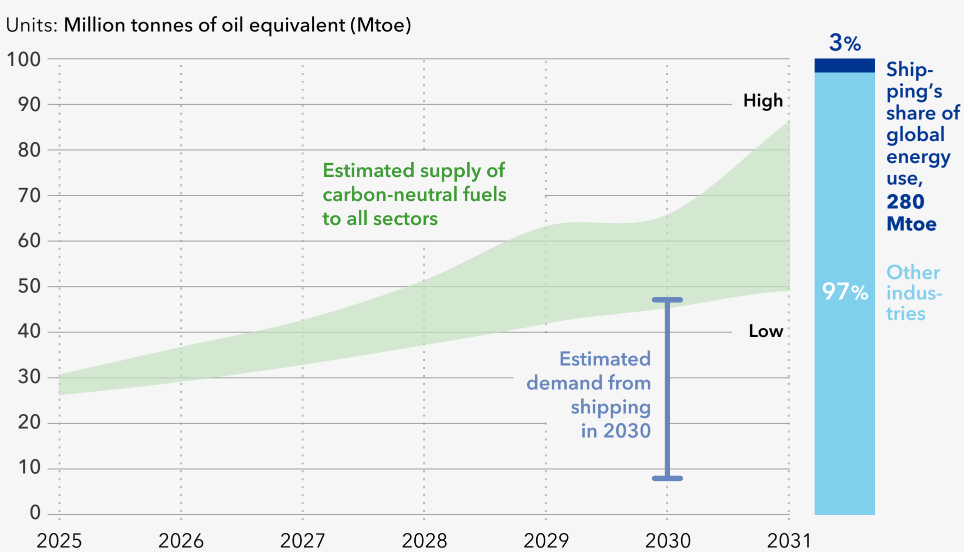
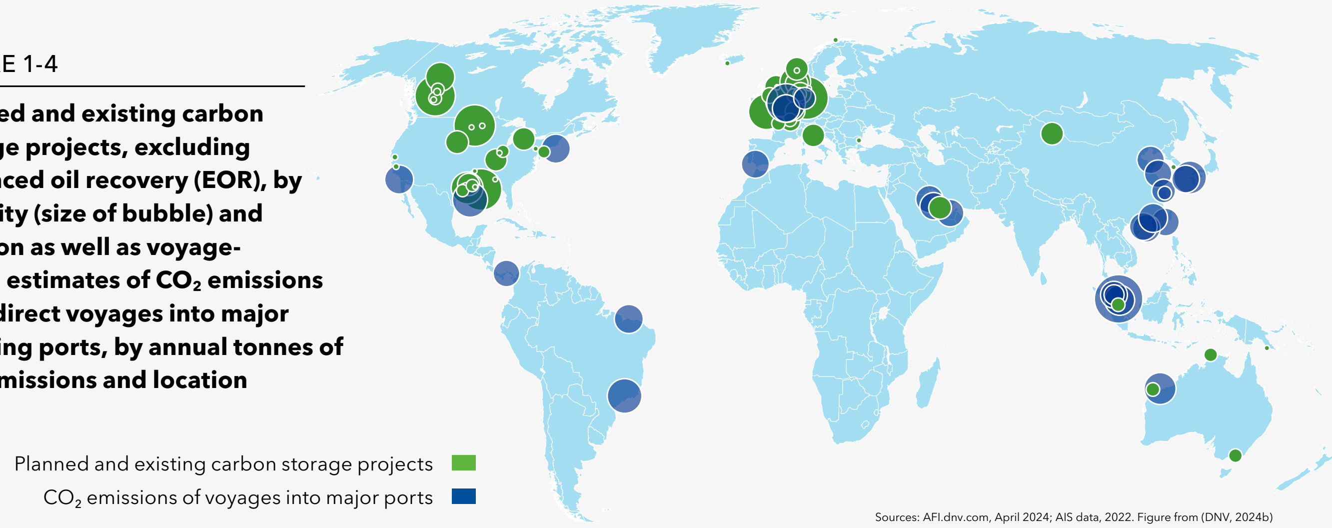


FIGURE 1-4

Planned and existing carbon storage projects, excluding enhanced oil recovery (EOR), by capacity (size of bubble) and location as well as voyage-based estimates of CO_2 emissions from direct voyages into major shipping ports, by annual tonnes of CO_2 emissions and location



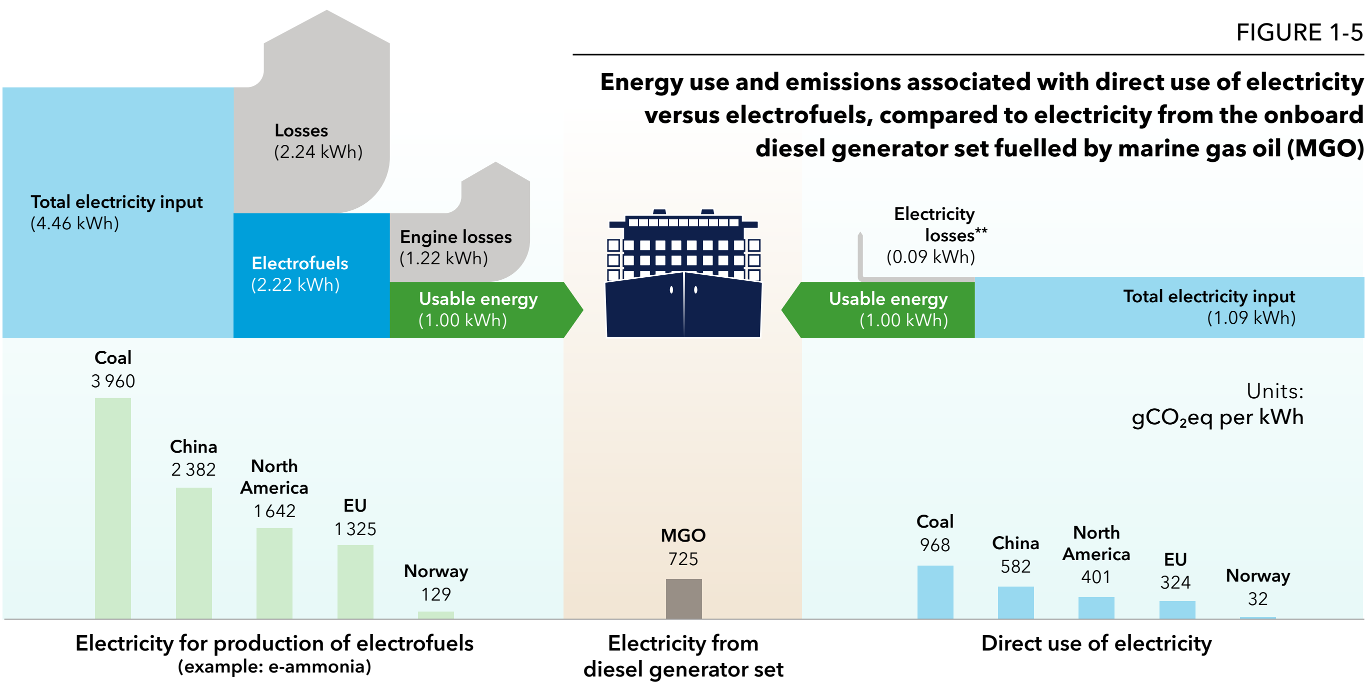
Sources: AFI.dnv.com, April 2024; AIS data, 2022. Figure from (DNV, 2024b)

The estimated demand for carbon storage from shipping in 2030 is 4 to 76 $MtCO_2$, while the estimated global carbon-storage capacity in 2030 is 47 to 67 $MtCO_2$.

The accumulated volumes of CO_2 emissions in the busiest shipping locations are large, with combined annual emissions on the last voyage of vessels entering the ports of Singapore and Rotterdam amounting

FIGURE 1-5

Energy use and emissions associated with direct use of electricity versus electrofuels, compared to electricity from the onboard diesel generator set fuelled by marine gas oil (MGO)

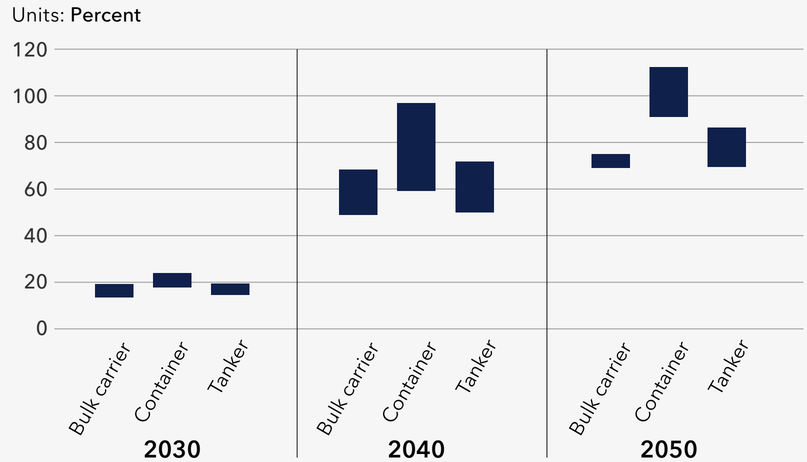


Key assumptions – Energy efficiencies: electric grid (92%); electrolysis (68%); H-B synthesis (69%*); onboard generator (45%); **Electric grid GHG intensity in gCO_2eq per kWh:** North America (368); EU (297); China (534); Norway (29); coal power (888); **MGO WtW GHG intensity in gCO_2eq per kWh:** WtT GHG (52); TtW GHG (274), based on FuelEU Maritime default emission factors

*includes loss of hydrogen and electrical energy; **excludes any losses related to battery charging

FIGURE 1-6

Range of increase in total costs per transport work (USD/DWT-nm for bulk and tank, USD/TEU-nm for containers) from decarbonization in 2030, 2040, and 2050, relative to a business-as-usual scenario



to 24 and 13 $MtCO_2$, respectively. The 10 largest announced projects for dedicated CO_2 storage, intended for use with other industries, have a planned capacity of 7.5 to 20 $MtCO_2$/year. For the largest ports, dedicated CCS infrastructure for shipping could be built and could contribute significantly to decarbonizing shipping.

Emissions reductions can also be obtained through using shore power. Up to 7% of the total energy consumption of ships could be covered this way while they are in port, if shore power capacity was sufficient and all ships had shore power capability. The well-to-wake emissions from producing electricity from onboard diesel generators are higher than the average GHG intensity from the grid in many countries, while electrofuels should only be produced from very low GHG intensity electricity.

For a large set of scenarios for the IMO assessing the impact of coming GHG regulations on the world fleet, DNV simulations estimate that shipping could reduce fuel consumption in 2030 by 4% to 16% from operational and technical energy-efficiency measures, compared to a business-as-usual scenario. This results in a large variation in the estimated demand in 2030 from shipping for both carbon-neutral fuels and for CO_2 storage from onboard carbon capture. The estimated demand for carbon-neutral fuels is between 7 and 48 Mtoe in 2030, while the demand for CO_2 storage from using fossil fuels with onboard carbon capture is between 4 and 76 $MtCO_2$.

Decarbonizing shipping will come at a cost. In this year's report, we present four scenarios where the increase in US dollar-denominated cost (capital expenditure, fuel cost, CO_2 price) per transport work (measured in deadweight tonne-miles, DWT-nm; or as twenty-foot equivalent unit nautical miles, TEU-nm) in a decarbonized 2050, compared to a business-as-usual scenario, was 69% to 75% for bulk carriers, 70% to 86% for tankers, and 91% to 112% for container vessels. With such a significant increase in costs for owning and operating ships, strategic fleet management is even more important, and the increased costs will have to be compensated for through an increase in freight rates, in order to move the increased costs through the value chain to consumers.

The decarbonization of shipping is a complex puzzle with many different solutions. Meeting the IMO's goal of zero-emission shipping by 2050 requires smart decision-making and strategic investments today to lay the foundations for significant emissions reductions in the future.

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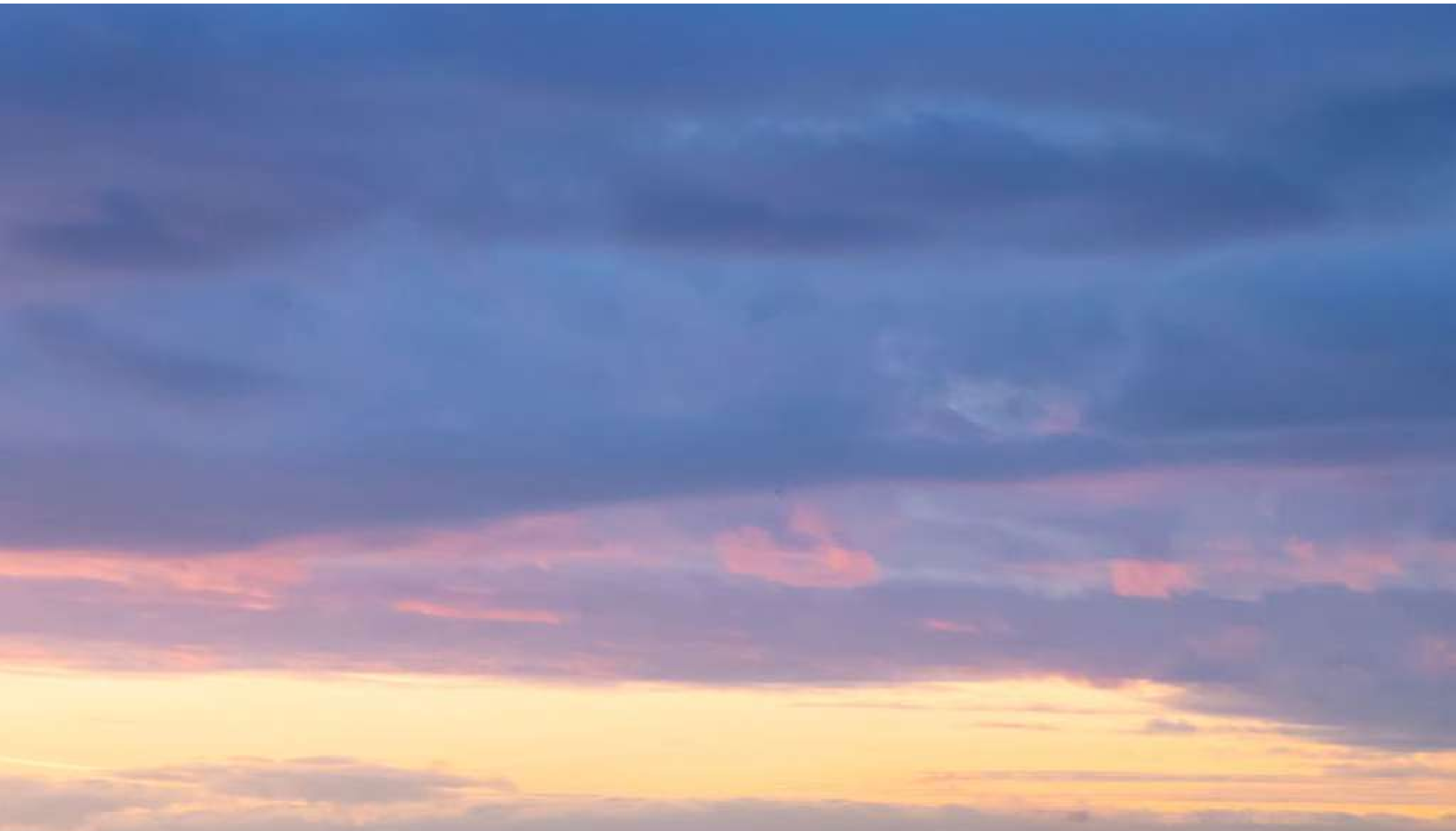


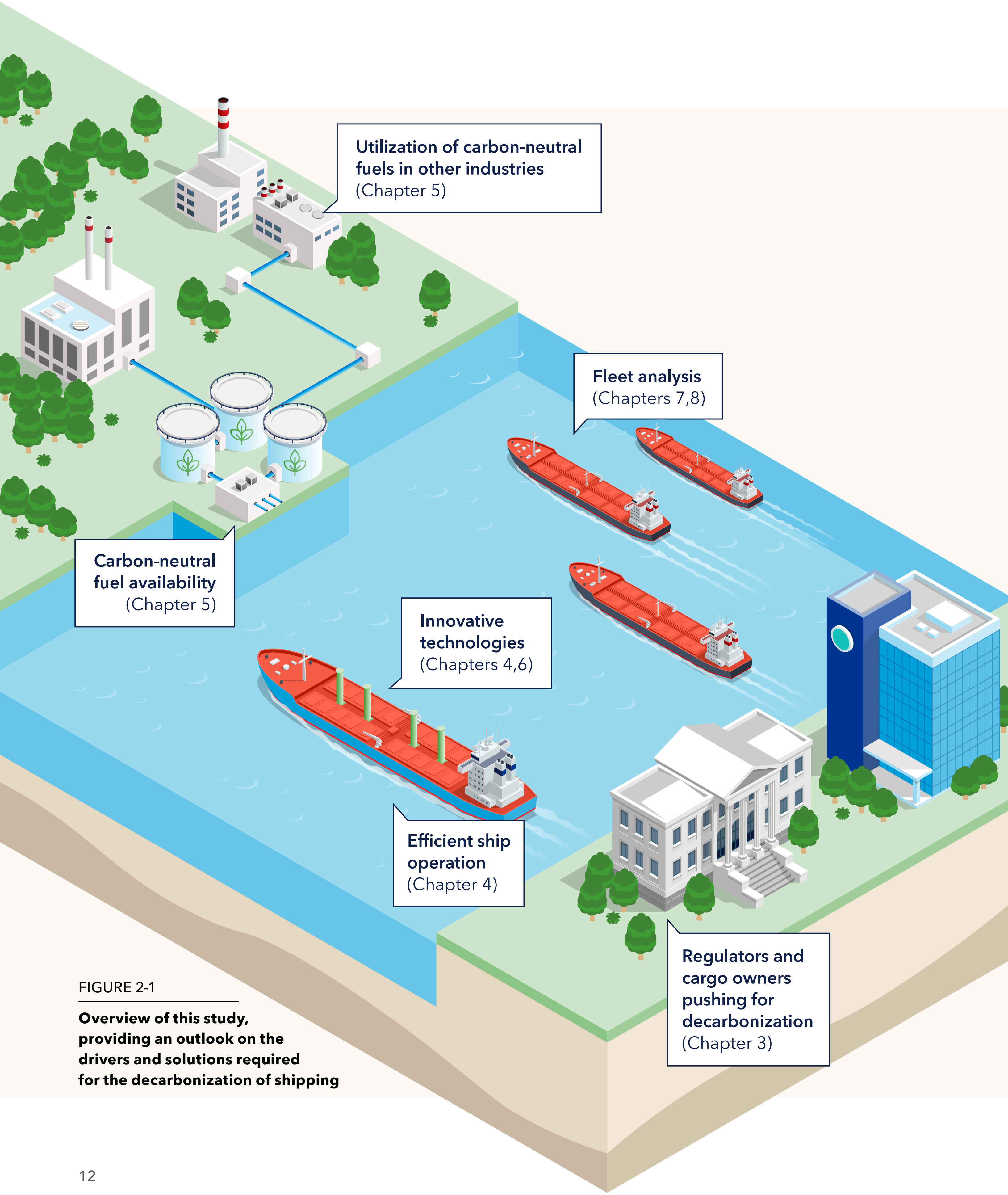


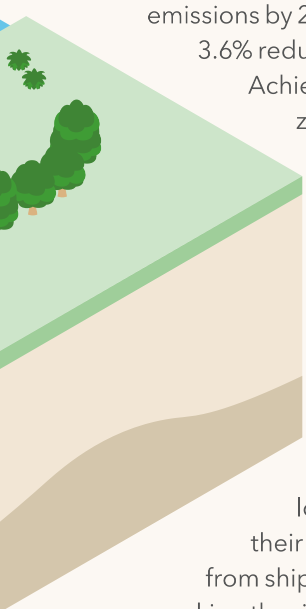
FIGURE 2-1

Overview of this study, providing an outlook on the drivers and solutions required for the decarbonization of shipping

INTRODUCTION

This publication is part of DNV's 2024 suite of Energy Transition Outlook (ETO) reports. Our latest Maritime Forecast to 2050 provides an independent outlook of shipping's energy future and examines how the technology and energy transition will affect the industry.

The course and speed are set for the maritime decarbonization transition, where compliance becomes tougher and ship emissions will cost. In this year's report we aim to provide understanding of the maritime transition driven by regulations and drivers, leading to technology changes and development in the world fleet and land-based industry providing energy for ships. The IMO aims to have reduced well-to-wake greenhouse gas (GHG) emissions by 20% in 2030 relative to 2008, far beyond the 3.6% reduction achieved by 2023 (DNV, 2024a). Achieving the IMO's updated ambition of zero-emission shipping by 2050 will require shipowners to identify, evaluate, and use technologies, fuels, and solutions that help minimize energy consumption and decarbonize ships. Many ships contracted in the coming years may still be in operation in 2050, and to retain their commercial attractiveness, asset value, and profitability for the following decades, new ships need to consider future demands for lowering energy use and GHG emissions in their design and operation. Net-zero emissions from shipping will not be reached in 2050 without making the right decisions and investments today.



Shipping is indeed facing an unprecedented wave of decarbonization regulations (Chapter 3) that not only affect technology choices and operation of ships (Chapter 4), but also impact the development of shoreside infrastructure and energy industries by creating demand from shipping for increased production of renewable or nuclear electricity, sustainable biomass, carbon storage and various alternative 'energy carriers', and fuels (Chapter 5).

The increasingly complex interplay between shipping, energy, and fuel production on land, impacts the strategies of shipowners and fuel producers, as well as society as a whole as it plans for broader decarbonization goals. With the ramping-up of production and competition from other sectors, the amounts of carbon-neutral fuels – from renewable electricity, sustainable biomass, and fossil sources with carbon capture and storage – that will be available for shipping are still uncertain. Therefore, it is crucial to not only focus on such alternative[1] fuels, but also to make increasing use of emerging technologies that can reduce emissions without using the limited carbon-neutral[2] fuels (Chapter 6).

The coming regulations allowing pooling of compliance between ships (Chapter 7) can drive uptake of high capital expenditure (CAPEX) solutions to decarbonization in the short to medium term. The driving force of regulations, the development of ship technologies, and the build-up of fuel infrastructure/production will impact and change the future fuel mix of shipping (Chapter 8). In these early stages of the transition, there is still uncertainty over exactly which technologies shipping will use in the future, but the first steps are being taken in several different directions.

[1]Alternative fuels are non-conventional fuels, e.g. LNG, LPG, methanol, ammonia and hydrogen.
[2]Fuels that have no net GHG emissions, ref. IPCC's definition of carbon-neutral (https://www.ipcc.ch/sr15/chapter/glossary).

CHAPTER HIGHLIGHTS

3 – Outlook on regulations for decarbonization

We review the status and outlook for regulations impacting ship decarbonization, including:

- The EU Emissions Trading Scheme being implemented and the advanced preparations for FuelEU Maritime.
- The need for bunker suppliers to provide certified low-emission fuels when delivering to ships trading in the EU.
- FuelEU Maritime introducing the option to pool compliance across a fleet of ships.
- The IMO considering a GHG fuel intensity requirement and a GHG emission pricing mechanism.
- Ongoing negotiations on future IMO requirements, expected to conclude in 2025.

4 – Outlook on ship technologies and fuels

Our tracking of technology uptake for reducing ship energy consumption and using new fuels finds:

- 92.6% of tonnage in operation can only use fuel oils, but half the tonnage on order will have alternative fuel capability.
- The number of ships that can run on LNG keeps rising and orders include many methanol and LPG-fuelled ships and the first ammonia-powered vessels.
- Nearly 1,000 ships today use batteries alone or in hybrid systems, with 400 more on order.
- By sharing costs and gains among parties, data sharing and verification in new contracts can unlock low-cost operational measures for emission reduction.

5 – Outlook on alternative fuel production and demand

We investigate carbon-neutral fuel production and alternative fuel infrastructure for shipping, finding that:

- Requiring between 10% and 100% of the world's carbon-neutral fuel production, the shipping industry must significantly cut its energy use to reduce fuel demand, to stand a chance of meeting the 2030 targets.
- In all potential fuel pathways, maritime will compete with other decarbonizing sectors for carbon-neutral fuels.
- Robust and trusted chain of custody models such as Mass Balance and Book and Claim are needed to certify the sustainability and GHG intensity of fuels.
- A book and claim model can reduce the need for separate infrastructure and transport of carbon-neutral fuels and increase their availability.

6 – Emerging technologies to reduce demand for carbon-neutral fuels

We investigate emerging technologies that can reduce demand for limited carbon-neutral fuels, concluding that:

- Shore power usually emits less GHGs than ship generators and should be promoted by incentives and regulations across regions.
- Up to 7% of the total energy consumption of ships can be covered by use of shore power while ships are in port.
- Existing ships' share of energy used on short voyages shows the potential for electrification with batteries (plug-in hybridization).
- Development of a logistics system for battery swapping in different ports can reduce shipowner investment needs and risk.
- The estimated carbon dioxide storage demand from shipping to achieve emission-reduction goals in 2030 is 6% to 160% of the estimated total global CO_2 storage capacity.

7 – FuelEU maritime compliance pooling case study

We investigate if the pooling mechanism in FuelEU Maritime, effective 2025[1], could trigger a sustainable business case for methanol-capable vessels utilizing full green-methanol capacity over a 10-year period, showing that:

- In a pool, an over-compliant vessel (i.e. with compliance surplus) can cover several vessels with compliance deficits and could, under some circumstances, help to justify the extra costs associated with investing and running an over-compliant vessel on costly low GHG intensity fuels.
- With time, due to stricter GHG intensity targets in FuelEU Maritime, the window of opportunity to use compliance pooling as a business opportunity for a green vessel will close.

8 – Pathways for decarbonization of shipping

Building on our previous modelling, we investigate the conditions under which uptake of certain fuel types will accelerate with decarbonization towards 2050, finding that:

- Small changes in fuel prices lead to significantly different fuel mixes.
- Decarbonizing shipping will double the cost of transporting goods by containers.
- Onboard carbon capture has the potential to become an important technology for reducing greenhouse gas emissions from shipping.
- While biofuel and electrofuel production grows and carbon capture projects boost the output of blue fuels and the use of onboard carbon capture at scale, shipping should mitigate the potential shortfall of carbon-neutral fuels by maximizing the energy efficiency of ships.

[1]https://eur-lex.europa.eu/eli/reg/2023/1805/oj

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DNV is the world's leading classification society and a recognized advisor for the maritime industry. We enhance safety, quality, energy efficiency and environmental performance of the global shipping industry – across all vessel types and offshore structures. We invest heavily in research and development to find solutions, together with the industry, that address strategic, operational or regulatory challenges.

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