

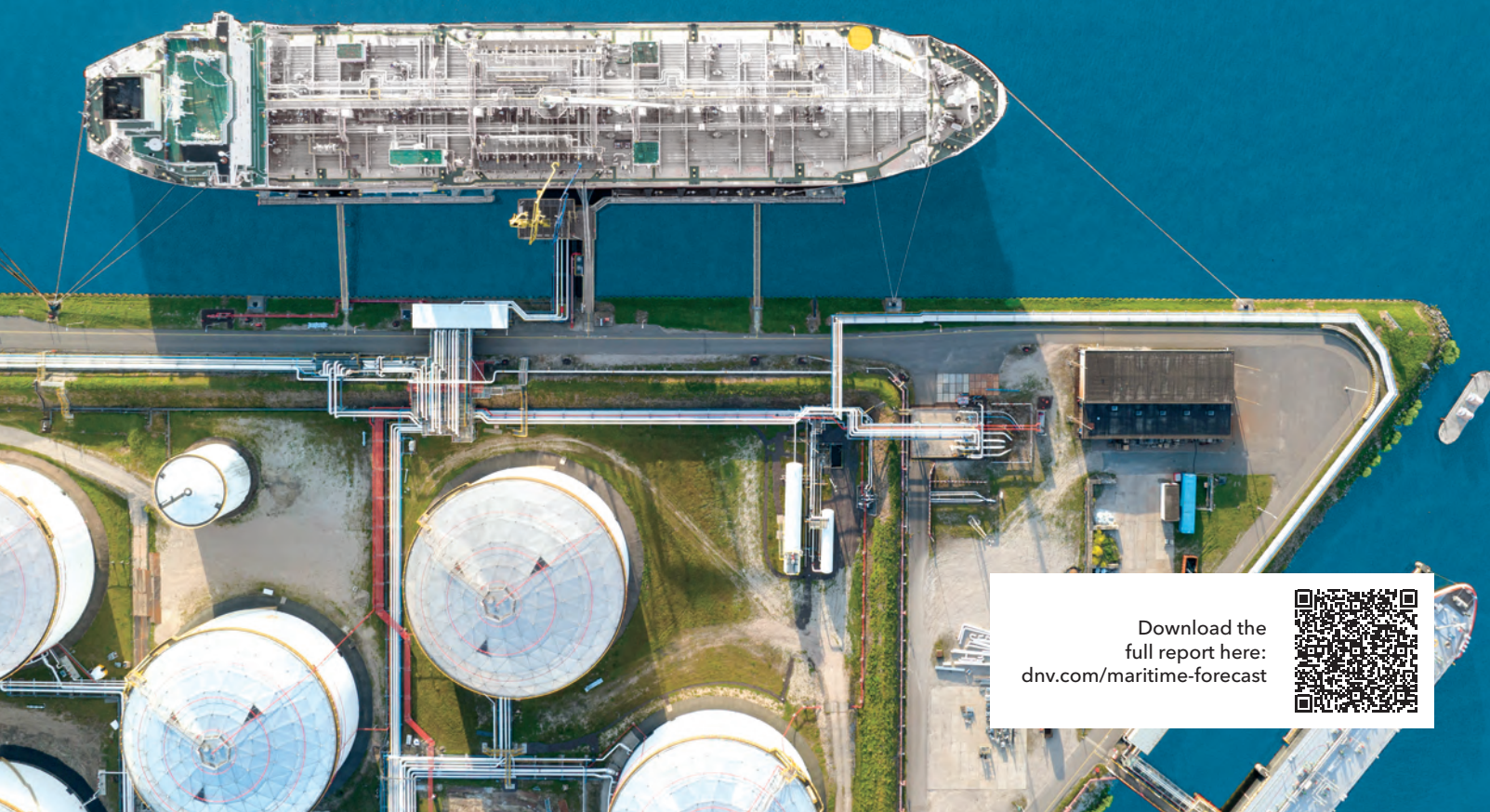


WHEN TRUST MATTERS

MARITIME FORECAST TO 2050

EXECUTIVE SUMMARY AND HIGHLIGHTS

Energy Transition Outlook 2022



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FOREWORD

Let me start with the positive news: newbuild orders and recent industry projects prove that the maritime energy transition is accelerating. The necessary practical considerations are taking shape, and ship-owners have started to future-proof their assets. Applying our Carbon-Risk Framework, launched back in 2020, has also contributed to robust, cost-efficient ship designs.

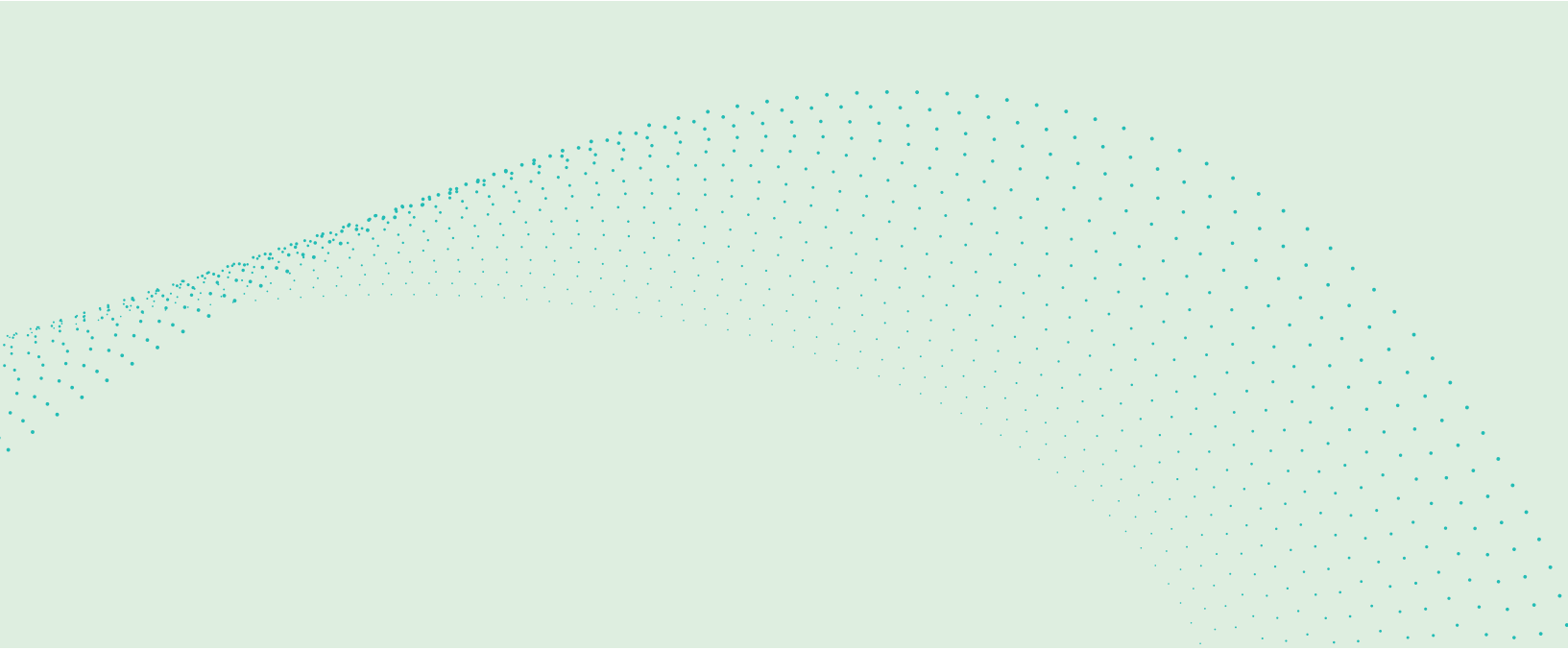
Encouragingly, newbuild vessels are increasingly being ordered ready to run on alternative fuels, with LNG dominant for now. Substantial investment is going into researching safe and economically feasible alternative carbon-neutral fuels and into developing fuel technologies. But this will count for little if the industry and its stakeholders do not collaborate to overcome the ultimate hurdle, fuel availability.

Our 6th Maritime Forecast to 2050 report zeroes in on this key issue and outlines under what conditions each new fuel type will proliferate. Which of them capture



sustainable shares in the 2050 fuel mix – be it biofuels, e-fuels, or fossil fuels with carbon capture and storage – relies on sound global industry decisions and collaboration. The maritime industry must continually seek consensus with other industries to ensure that sustainable energy resources are directed to where they can reduce greenhouse gas emissions most.

Already by 2030, 5% of the energy for shipping should come from carbon-neutral fuels, requiring huge investments in onboard technologies and onshore infrastructure. Navigating the options is complex, not least because there is no single ‘winner-takes-all’ alternative fuel and technology. Our updated model-



ling points to a diverse future energy mix of carbon-neutral and fossil fuels, with the latter gradually phased out by 2050.

We should use all available options to progress towards and reach net zero. Our findings reinforce the need for strong alliances to push the development of supply chains that can ensure fuel availability. The entire maritime value chain – charterers, energy majors, fuel suppliers, governments, financiers, ports, and shipowners – should collaborate to ensure adequate funding and apply it to the right projects. Green shipping corridors can serve as launch pads, also reducing the risk of port infrastructure becoming obsolete as the fuel mix shifts.

En route to decarbonization targets, employing the full power of digital tools for more energy-efficient vessels can deliver up to 15% of GHG emission savings required by 2050. Many such tools are available, and I am confident that even more promising ones will be launched in the coming decades.

If we push towards full decarbonization by 2050, the fuel infrastructure needs to deliver around 270 million tonnes of alternative fuels according to our modellings. A mammoth challenge. However, I am convinced that, together we can build a better, greener maritime future.

I hope that you enjoy reading the report and find value in its research findings for decision-making and strategizing.



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 maritime energy future and examines how the energy transition will affect the industry. The focus is on fuel availability and infrastructure to tackle the shift to carbon-neutral¹ fuels. Our updated scenario analysis provides significant new insights compared with our 2020 analysis.

The maritime industry will go through a period of rapid energy and technology transition that will have a more significant impact on costs, asset values, and earning capacity than many earlier transitions. Shipowners are already experiencing increasing pressure to reduce the greenhouse gas (GHG) footprint of maritime transport. This pressure is being exerted by three fundamental regulatory and commercial drivers: regulations and policies, access to investors and capital, and cargo owner and consumer expectations.

Our updated outlook for these drivers shows that:

- The Initial IMO Greenhouse Gas Strategy ('the IMO Strategy') currently drives policy development within international shipping, and the next wave of regulations will take effect from 1 January 2023. They are the CII, EEXI, and SEEMP Part III.² We expect them to have a significant impact on design and operations of all ships.
- The IMO Strategy will be revised in 2023, possibly strengthening its emission-reduction ambitions. This

will be followed by developing the next wave of regulations including market-based measures setting a price on CO₂ and a requirement to account for well-to-wake GHG emission intensity of fuels.³

- The EU has proposed to include shipping in the EU Emissions Trading System (EU ETS) and the FuelEU Maritime regulation which aims to increase the use of carbon-neutral fuels through an increasingly stringent well-to-wake GHG intensity requirement. These proposals may be finally adopted later in 2022 and take effect from 2024 and 2025, respectively.
- The regulatory and commercial drivers are enabled by supporting frameworks and standards specifying, for example, the setting of science-based, net-zero GHG emissions targets; taxonomies for sustainable activities; sustainability evaluation criteria and calculation methods for the well-to-wake GHG emissions of fuels; and supply-chain emission reporting requirements.

Figure 1 shows an overview of adopted and proposed regulations from the IMO and the EU.

Responding to the drivers for decarbonization, shipowners will need to apply new technologies and fuels to reduce emissions. This report provides an updated **outlook on ship technologies and fuels**, with an updated timeline for the technology readiness levels of selected alternative fuel technologies, including onboard carbon capture and storage (CCS).

¹ Fuels that have no net GHG emissions; see Intergovernmental Panel on Climate Change (IPCC) definition of carbon-neutral at <https://www.ipcc.ch/sr15/chapter/glossary>

² Carbon Intensity Indicator (CII); Energy Efficiency eXisting ship Index (EEXI); Ship Energy Efficiency Management Plan (SEEMP)

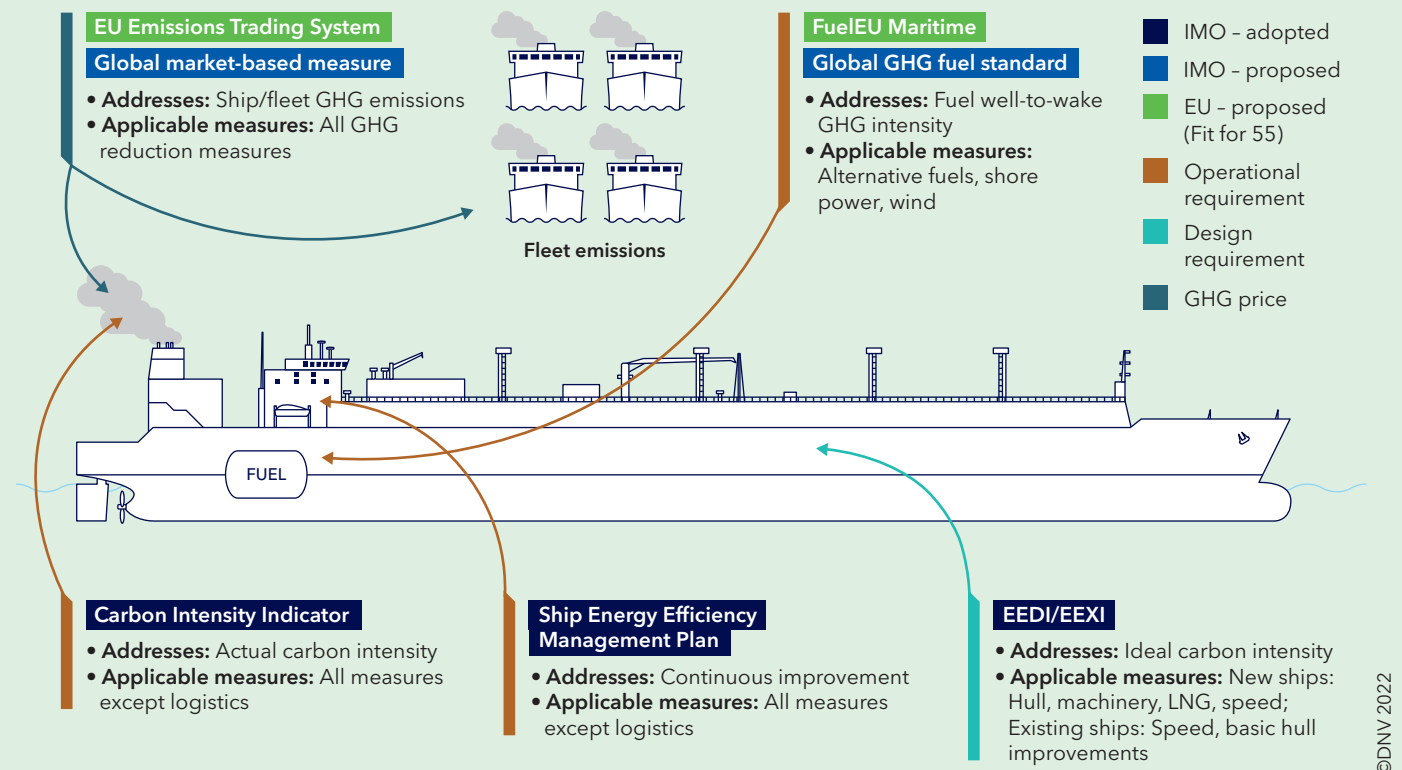
³ Well-to-wake refers to the assessment of GHG emissions from primary production to carriage of the fuel in a ship's tank (well-to-tank, or 'upstream emissions') and from the ship's fuel tank to the exhaust (tank-to-propeller or tank-to-wake, or 'downstream emissions'). See <https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx>

We find that:

- The trend of larger ships being ordered with alternative fuel propulsion is continuing, with fossil LNG as the dominant fuel (see Figure 2). Around 5.5% of the total gross tonnage of ships operating today, and a third (33%) of the gross tonnage on order, can or will be able to operate on alternative fuels. This includes liquefied natural gas (LNG) carriers. The uptake of methanol and liquefied petroleum gas (LPG), and the first hydrogen-fuelled newbuilds, are starting to show in the statistics.
- The strong interest in ammonia as fuel, as reflected in concepts and pilot studies, is currently restricted by immature converter technologies.
- Ammonia and hydrogen onboard fuel technologies will be available in three to eight years, according to our estimates. For ammonia, we see development of 2-stroke and 4-stroke engine technologies on parallel paths, enabling uptake in deep-sea and regional short-sea shipping.
- Short-sea shipping is expected to be instrumental for maturing hydrogen technology. Consequently, the development of fuel cells and 4-stroke engines is ahead of other hydrogen energy converters.

Figure 1

IMO and EU regulatory framework for GHG emissions reduction from international shipping



- The current technology readiness levels of methanol fuel technologies are higher than for ammonia and hydrogen.
- Using new fuels and fuel technologies will require all maritime industry stakeholders to focus increasingly on safety, including the development and implementation of safety regulations. The toxicity of methanol and ammonia, and extreme flammability of hydrogen, brings new safety challenges.
- There is increased interest in using onboard CCS with conventional fossil fuels because of significant barriers to the uptake of carbon-neutral fuels. Onboard CCS may be applicable for some ship

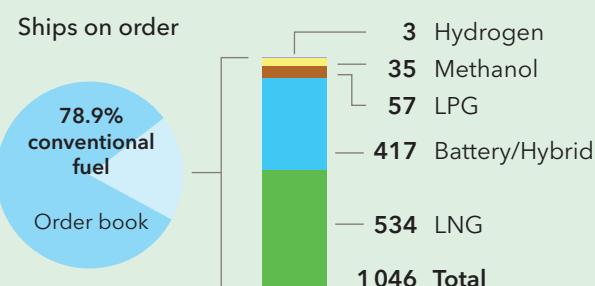
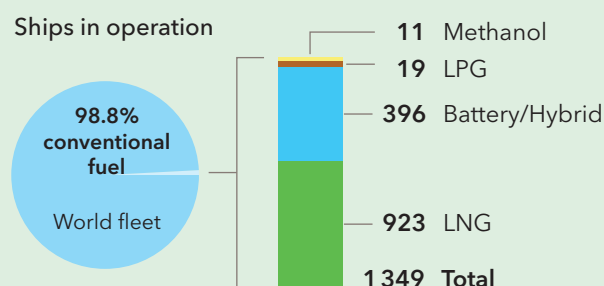
segments depending on regulatory and land-based infrastructure developments. More demonstration and pilot projects will be needed to enhance the technology readiness of onboard CCS. Several ongoing R&D projects address barriers to implementation.

This report also provides an **outlook on alternative fuel production and infrastructure**. Decarbonizing shipping will result in a profound transition in the way future marine fuels are produced and made available to the shipping fleet.

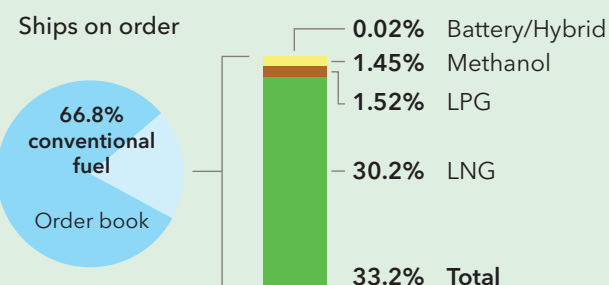
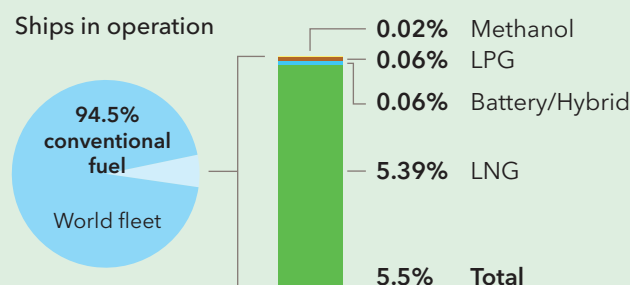
Figure 2

Alternative fuel uptake in the world fleet by number of ships and gross tonnage

NUMBER OF SHIPS



IN % OF GROSS TONNAGE



Key: Liquefied natural gas (LNG); liquefied petroleum gas (LPG)

Sources: IHSMarkit (ihsmarkit.com) and DNV's Alternative Fuels Insights for the shipping industry – AFI platform (afi.dnv.com)

Future fuel supply for shipping will rely on availability and price of the energy sources: renewable electricity, sustainable biomass, or fossil energy with CCS.

We find that:

- Shipping's future fuel market will be more diverse, reliant on multiple energy sources, and more interconnected and integrated with regional energy markets, regional energy production, and regional industry.
- Future fuel supply for shipping will rely on availability and price of the energy sources: renewable electricity, sustainable biomass, or fossil energy with CCS (see Figure 3). Availability may constrain the coming energy transition in shipping.
- Because no industry can decarbonize in isolation, global industries need to make the right choices together, and sustainable energy should be directed to where it has the biggest impact on reducing emissions. To maximize the GHG reduction potential of sustainable biomass – potentially an important source for carbon-neutral drop-in fuels for conventional machinery – this should be reserved for hard-to-abate sectors like shipping and aviation, rather than for electricity production.
- Provided that energy can be made available, production capacity will be a barrier and must be scaled up to meet shipping's coming demand for carbon-neutral fuels. This will require massive investment, though some existing production facilities can be reused. For the various fuel production and supply paths, the focus should be on reducing energy losses in production, distribution, and conversion on board. Developing the necessary infrastructure and production capacity will take time, be costly, and involve many stakeholders in the supply chain.
- Co-operation with major energy and fuel providers will be important to supply the future fuels. Ports will play key roles in the green maritime transition by serving as energy hubs providing both shore-side electricity and

infrastructure for storing and fuelling ships with future fuels, as well as supporting the first movers and establishing green energy corridors.

This year we present an **updated portfolio of scenarios, built with an enhanced version of our GHG Pathway Model** to explore the fuel transition that shipping is facing. We investigate how the future fuel mix and uptake of carbon-neutral fuels are impacted by the availability of energy sources and other key inputs for fuel production, and by price assumptions on emerging fuels, technologies, and retrofits. We also assess fuel costs regionally, and how the build-up of regional fuel production and infrastructure impact the development of the fuel mix.

Significant uncertainties around several factors influence our projected energy transition from conventional to carbon-neutral fuels. Considering these uncertainties, which preclude developing a single 'most likely' projection, we have developed and provide a set of scenarios. Each describes a possible development of the future fleet composition, energy use and fuel mix, and emissions to 2050, under a particular set of framing conditions, and without prejudging the likelihood of these conditions.

We have developed 24 scenarios to explore:

- **two decarbonization pathways**, one in which shipping achieves the ambitions set in the current IMO GHG Strategy, including a 50% reduction of total GHG emissions in 2050; and a second, in which the ambition is to decarbonize the fleet by 2050.
- **variations on three fuel families**, in which we simulate the availability of sustainable biomass to produce

Figure 3

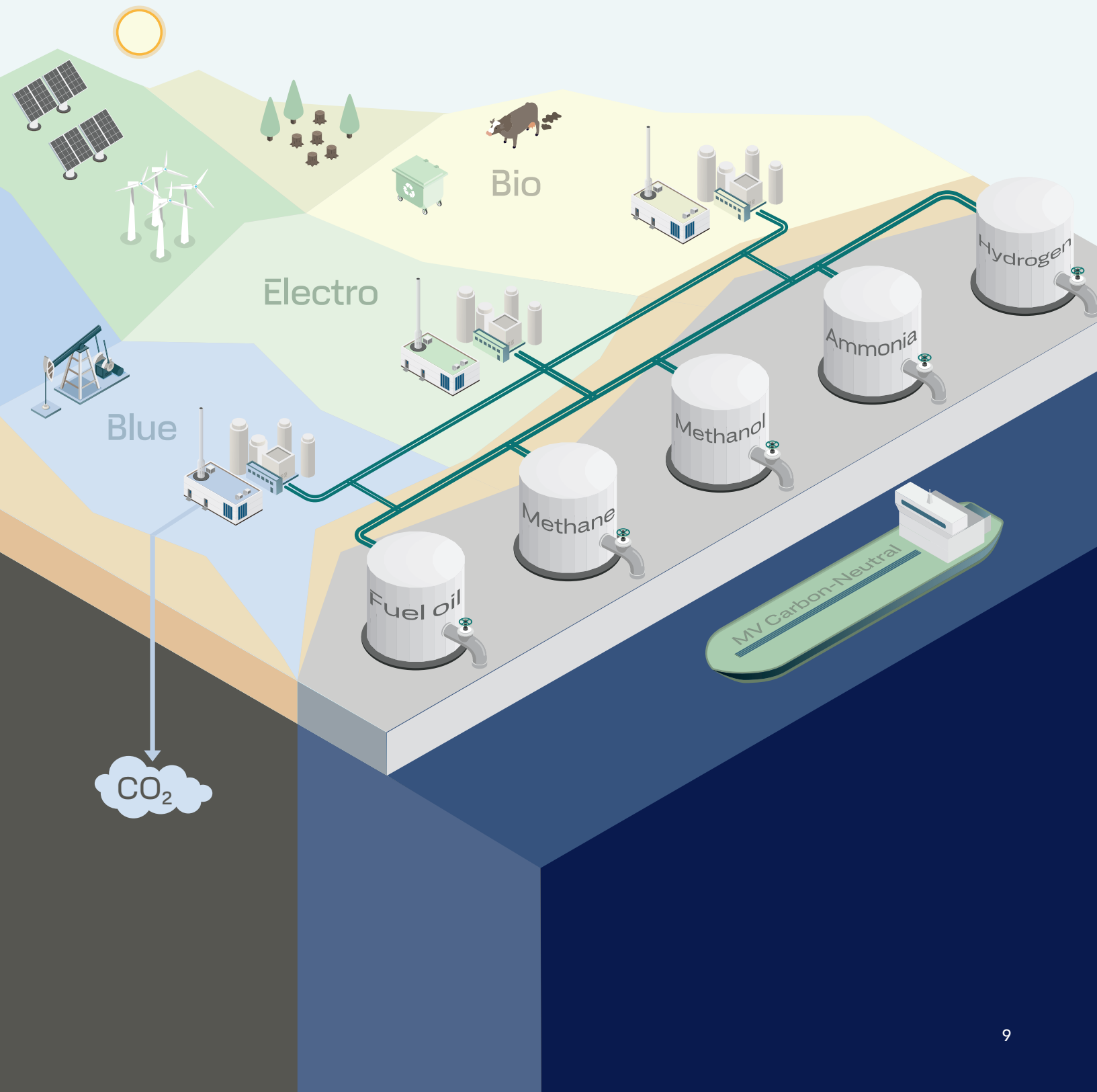
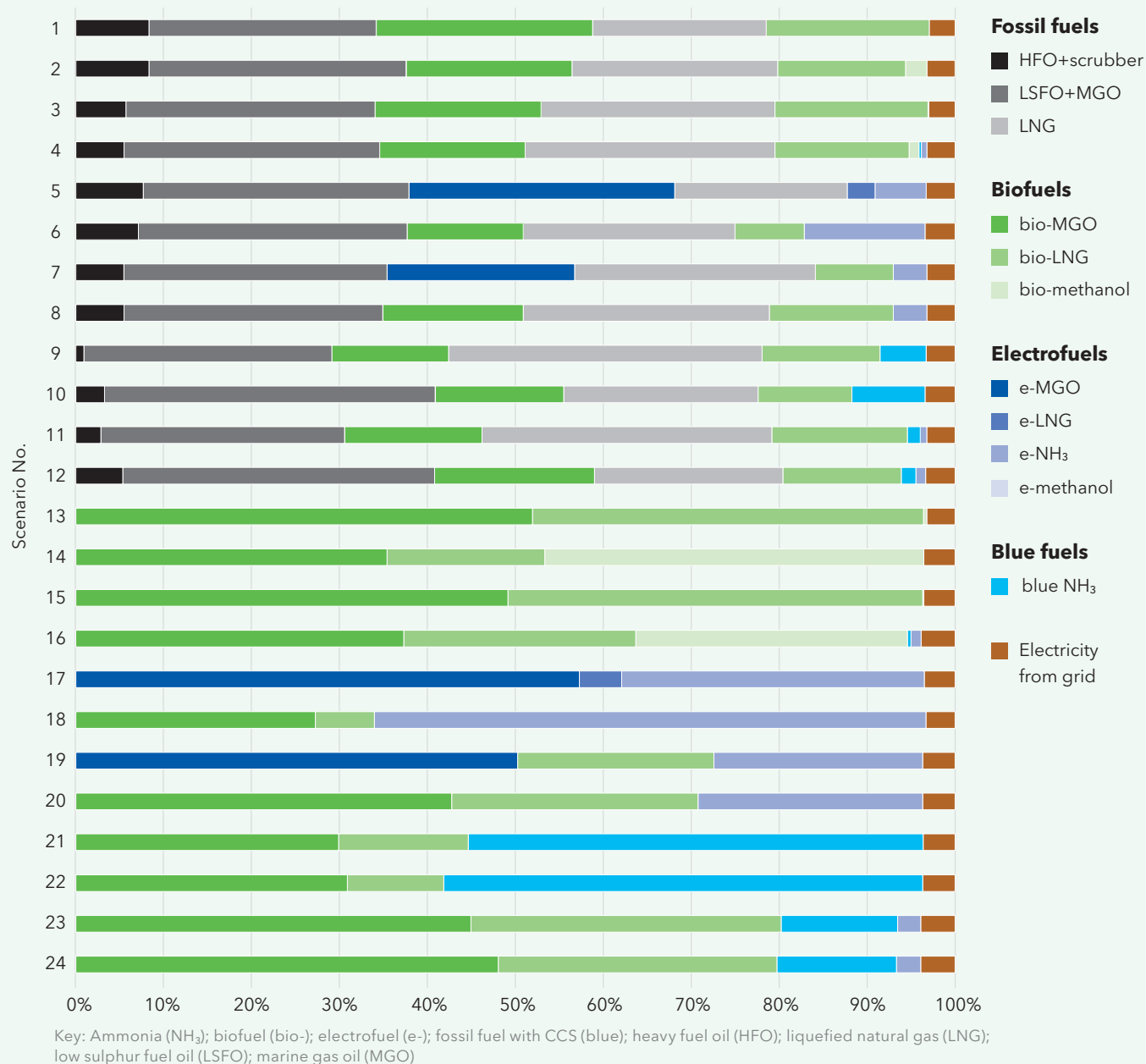
The future carbon-neutral energy supply chain

Figure 4

Our 24 scenarios for the maritime energy mix in 2050



Bio-LNG, bio-MGO and bio-methanol, which are relatively energy-dense hydrocarbons, would be the preferred fuels.

biofuels, renewable electricity to produce e-fuels, and fossil fuels combined with CCS to produce blue fuels.

- **variations for specific fuel types**, in which key input factors impacting the relative cost differences between fuels within each family are examined.

Regarding the future fuel mix in the modelled scenarios (Figure 4), we find the following:

- Regulatory policies and primary energy prices are key drivers for uptake of carbon-neutral fuel and the future fuel mix. The uptake of carbon-neutral fuel needs to pick up in the mid-2030s, reaching 40% of the fuel mix in 2050 under the current IMO ambitions and 100% to decarbonize shipping fully. Fossil very low sulphur fuel oil (VLSFO)/marine gas oil (MGO) and LNG are in rapid decline by mid-century or are phased out completely in the most ambitious decarbonization scenarios. LNG, however, sees significant uptake to around 20% to 30% of the fuel mix prior to the acceleration of the transition to carbon-neutral fuels. Figure 4 presents the energy mix in 2050 for the 24 modelled scenarios.
- It is hard to identify clear winners among the many different carbon-neutral fuel options given the uncertainties on price and availability, but we can outline under what conditions each will proliferate. Bio-LNG, bio-MGO and bio-methanol, which are relatively energy-dense hydrocarbons, would be the preferred fuels, given sufficient availability of sustainable biomass. The uptake of bio-methanol is very sensitive to the production cost compared with bio-MGO and bio-LNG. With low availability of sustainable biomass, the prices of biofuels will likely be

uncompetitive with those of electrofuels and blue fuels.

- The availability of electrofuels depends firstly on the availability of renewable electricity to produce hydrogen by electrolysis. This requires the phasing out of fossil energy from power generation, which is still a long way off in most regions. Using electricity even partly generated from fossil fuels to produce electrofuels is not energy efficient and could lead to higher net emissions. The second prerequisite for electrofuels is the availability of sustainable carbon from either biogenic sources or direct air capture. This carbon could be combined with the hydrogen produced by electrolysis to produce e-MGO⁴, e-LNG, or e-methanol, again taking advantage of using more energy-dense fuels. Without this carbon being available and affordable, e-ammonia would be the preferred fuel, with bio-MGO or e-MGO being used as pilot fuels.
- The availability of blue fuels depends on the effectiveness of carbon capture, as well as infrastructure for permanent storage of the captured carbon. With high availability, blue ammonia is the preferred fuel, with bio-MGO or e-MGO as pilot fuels. Mature CCS technology and infrastructure could also make onboard CCS a viable alternative where fossil fuels continue to be used on the ship.
- The use of drop-in fuels – such as bio-LNG, e-LNG, bio-MGO and e-MGO – is significant in all scenarios and depends on the pace of decarbonization. With slower decarbonization with moderate operational requirements, fossil fuels combined with just the required amount of drop-in fuels are preferred to switching to ammonia or methanol fuel systems,

⁴ The prefix 'e-' denotes an electrofuel, 'bio-' a biofuel, and 'blue' a fuel produced from fossil energy with CCS

even though these fuels are likely less expensive than the drop-in fuels.

Significant investment is needed in coming decades to enable the transition to carbon-neutral shipping. We find that:

- USD 8 billion (bn) to 28bn is needed annually in additional total investment on ships in a transition phase towards decarbonization in 2050. The largest investments come in scenarios with high uptake of ammonia or methanol.
- Fuel infrastructure investments will outpace onboard investments in almost all scenarios. Decarbonizing shipping completely by 2050 will require about 2.5 times more investment than if pursuing current IMO ambitions. About USD 28bn to 90bn per year is needed onshore to scale up production, fuel distribution, and bunkering infrastructure to supply 100% carbon-neutral fuels by 2050. The largest investments come in scenarios with high uptake of electrofuels.
- The more expensive energy sources and onshore investments could increase the annual fuel costs by more than USD 100bn to 150bn when fully decarbonized, a 70% to 100% increase from today.

Concluding remarks

The initial preparation for decarbonization is well underway with regulatory and commercial drivers and a supporting framework coming into place. Scrutiny is focused on full supply-chain emissions, including from ships and the production and supply of fuel. We see

progress in onboard fuel technology development, and the fleet's uptake of alternative fuels is increasing. However, several fuel technologies that may be needed in 2050 are immature.

More effort is needed to bring down barriers and speed up the progress of next-generation carbon-neutral ships. This will require accelerated technology development, large-scale piloting for deep-sea vessels, and ensuring safe application of new fuels on board and onshore. Stronger emphasis is needed on system-level thinking and integration of all available technologies. This will require time, investment, and combining efforts from all stakeholders in the maritime supply chain. Green energy corridors, a concept taking shape now, could support this effort by pairing commitments on fuel supply and demand, and reducing first-mover risk. The idea is to help start shipping decarbonization by increasing the availability of alternative fuels in connected regions.

Shipowners and other stakeholders – such as governments, charterers, ports and fuel suppliers – can use our 24 scenarios to support decision-making to minimize carbon risk and explore effective policy interventions such as green corridors. Uncertainty over the price and availability of energy sources means that fuel flexibility and Fuel Ready solutions, combined with improved energy efficiency, remain key strategies that could ease the transition and minimize the risk of investing in stranded assets. Digitalization will enable the unlocking of further energy-efficiency potential and will support the necessary collaboration and information sharing needed to accelerate the transition.

Shipowners and other stakeholders can use our 24 scenarios to support decision-making to minimize carbon risk and explore effective policy interventions such as green corridors.



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References



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INTRODUCTION

This publication is part of DNV's 2022 suite of Energy Transition Outlook reports. This latest edition of Maritime Forecast to 2050 gives an independent outlook of the maritime energy future and examines how the transition will affect the industry. It provides valuable insights for decision makers ranging from shipowners, charterers, fuel suppliers, ports, finance and insurance, through to national and regional policymakers.



More specifically, the outlook focuses on fuel availability and infrastructure to tackle the shift to carbon-neutral⁵ fuels. We significantly update our 2020 scenario analysis of the maritime energy future (DNV, 2021c; DNV, 2020) as shipping experiences increasing pressure to decarbonize operations and reduce emissions to air. Regulatory requirements addressing greenhouse gas (GHG) emissions take shape in both the IMO and EU, and are enabled by supporting frameworks and standards. Examples of these enablers are: setting science-based net-zero GHG emissions targets; taxonomies for sustainable activities; sustainability evaluation criteria and well-to-wake GHG emission calculation methods for fuels; and supply chain reporting requirements. Most notably, in April 2018 the IMO adopted an ambitious GHG emissions-reduction strategy for international shipping. 2023 will see the implementation of further regulatory measures to address the decarbonization of shipping. In November 2021, the IMO Marine Environment Protection Committee's 77th session (MEPC 77) also recognized the need to strengthen the ambitions of its GHG strategy when it is revised in 2023. Increasingly, we also see key stakeholders such as banks and cargo owners focusing on decarbonization. All this points to a changing business environment for ships in the near future, shaping the future fleet in important ways, particularly in the choice of fuels and technologies.

In contrast to past environmental requirements, meeting GHG targets requires fundamentally more challenging technological and operational changes for shipping. In previous transitions, the industry moved from wind to coal and steam, and then to oil – and every ship made the same transition. For the transition now underway, there are many options for carbon-neutral fuels (bio, electro, or blue), such as ammonia, diesel, electricity, hydrogen, methane and methanol – all ships will probably not transition to the same fuel. The existence of many transition pathways is driving complexity. The challenges include a transition to new and alternative low or zero-carbon fuels and non-conventional technologies. This requires the simultaneous introduction of new

technologies on ships and low or zero-carbon fuel production and infrastructure onshore, where significant investments are needed during the next decades to enable the transition. While the industry has been discussing emissions reduction for many years, the most likely solutions still face challenges and barriers including – the focus of this year's study – fuel availability. DNV's alternative fuel uptake analysis indicates that the transition has started slowly, with 33% of gross tonnage in the order book able to operate on alternative fuel (heavily dominated by LNG).

In this year's report we have updated our scenario library of regulations, future technologies, and costs, to understand the coming transition so that stakeholders can make informed decisions. We have modelled two different decarbonization pathways: the current IMO ambitions to 2050, and a full decarbonization by 2050. We refer to these henceforth as *IMO ambitions* and *Decarbonization by 2050*. Our decarbonization modelling shows a diverse energy mix comprising both fossil and carbon-neutral fuels, where fossil fuels are gradually phased out by 2050.

This report starts by presenting updated outlooks on drivers and regulations (Chapter 2) then ship technologies and fuels (Chapter 3), with estimated maturation timelines for energy converters, onboard CCS technologies, and corresponding safety regulations for onboard use. We introduce an entirely new outlook on alternative fuel production and infrastructure, including availability and prices from the updated Marine Fuel Price Mapper (Chapter 4). These chapters provide input to our updated world fleet scenario modelling (Chapter 5), including modelling of the impact of measures to increase regional availability, such as green corridors.

⁵ Fuels that have no net GHG emissions; see Intergovernmental Panel on Climate Change (IPCC) definition of carbon-neutral at <https://www.ipcc.ch/sr15/chapter/glossary>

CHAPTER HIGHLIGHTS

2 - Outlook on drivers and regulations for decarbonization

Three key fundamentals are driving ship decarbonization: regulations, cargo owner expectations, and access to capital:

- We provide an updated outlook and timeline for regulatory developments impacting the maritime sector.
- We explore how evaluating well-to-wake GHG emissions and sustainability of fuels becomes important to avoid unintended emission increases from other sectors.
- We assess the need for investments on board and onshore to decarbonize shipping and explore why clear frameworks and standards are needed to accelerate and improve decision-making.

3 - Outlook on ship technologies and fuels

Decarbonization requires new fuels, greater energy efficiency, and better logistics:

- We provide a new snapshot of alternative fuel uptake in the world fleet.
- We assess the current and future technical readiness of onboard fuel technologies.
- We emphasize safety challenges in the transition to new fuels.
- We explore how digitalization can enable maritime decarbonization.

4 – Outlook on alternative fuel production and infrastructure

The maritime industry must reduce barriers for a shore-side transition in fuel production and bunkering infrastructure:

- We identify supply chain and infrastructure constraints on carbon-neutral fuel use in ships.
- We conclude that supply chains will need to change dramatically to supply several such fuel options for ships.
- We analyse what will determine which carbon-neutral fuels will be available for large-scale maritime use.

5 – Pathways for decarbonization of shipping

Our scenario modelling explores the fuel transition facing shipping:

- We update our portfolio of decarbonization scenarios built with an enhanced version of our GHG Pathway Model.
- We investigate what will determine the future fuel mix and uptake of carbon-neutral fuels.
- We assess fuel costs by region, and how regional fuel production and infrastructure impact the future fuel mix.

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DNV is an independent assurance and risk management provider, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry standards, and inspires and invents solutions.

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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