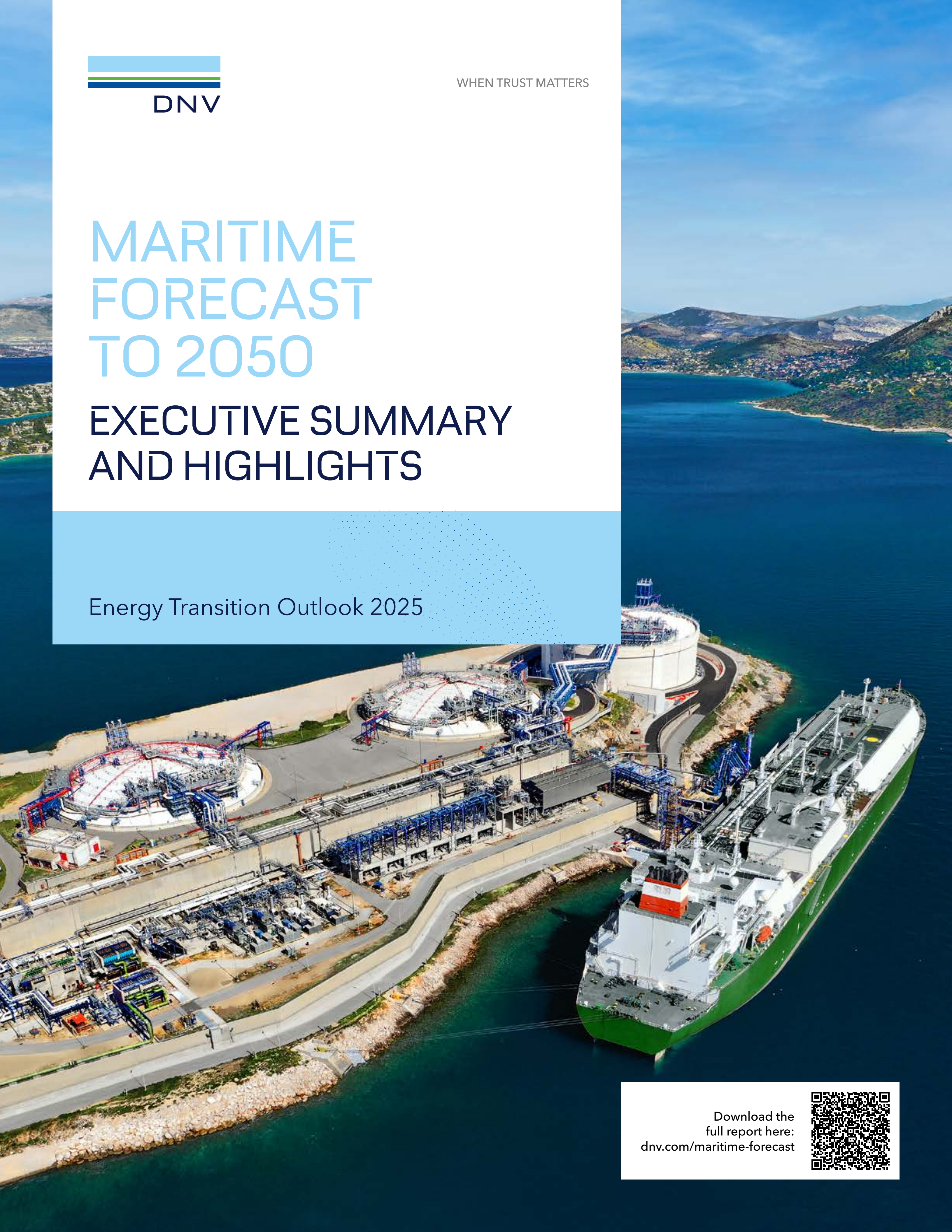
WHEN TRUST MATTERS

MARITIME FORECAST TO 2050

EXECUTIVE SUMMARY AND HIGHLIGHTS

Energy Transition Outlook 2025



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FOREWORD

Shipping's transformation is underway, powered by innovation, collaboration, and purpose

Maritime decarbonization continues to define our time. With global regulations gaining momentum and industry commitment accelerating, the pathway to net zero is no longer theoretical, it's unfolding in real time. The challenges are complex, but the direction is clear, and the pace of innovation, investment, and collaboration is picking up across certain parts of the value chain.

Earlier in 2025, the IMO took a momentous step by approving in principle what may become the most impactful global regulation in any industry – the Net-Zero Framework (NZF) for shipping. Building on the ambitions laid out in the 2023 IMO GHG Strategy, the NZF introduces the first global pricing mechanism for greenhouse gas emissions, alongside technical requirements for well-to-wake GHG intensity.

If adopted in October, this regulation will reshape investment decisions, operational strategies, and fuel choices across the industry, and this year's Maritime Forecast to 2050 highlights and analyses its potentially transformative impact.

The framework, while groundbreaking, is not without its imperfections, and urgently needs clarity across several key areas to ensure that all pathways to decarbonization are properly recognized and rewarded. The coming year will be pivotal as the IMO starts laying the groundwork for the supporting guidelines which will determine how effectively the framework can be implemented.

Crucially, the calculation method for the greenhouse gas fuel intensity (GFI) must be finalized to avoid inconsistencies and ensure comparability across fuel types. Life Cycle Assessment (LCA) guidelines, including well-to-tank (WtT) values for fossil LNG and other fuels, are essential to ensure that those who are making real strides towards emissions reductions today are rewarded and not penalized.

The emergence of low-GHG fuels can also be facilitated by practical and sensible guidelines around the sustainable fuels certification framework. Without a harmonized and credible system, the market for low- and zero-emission fuels will struggle to scale. The adoption of flexible Chain of Custody models can allow for the distribution of green fuels together with fossil fuels, removing the need for extra pipelines and infrastructure, potentially saving millions in CAPEX investments while reducing emissions.

More broadly, the reward mechanism for zero and near-zero (ZNZ) fuels, and for emission- and energy-saving technologies, should be clarified to incentivize innovation and early adoption. Governance and spending mechanisms must be defined to build trust in how revenues from the

IMO Net-Zero Fund are managed and reinvested back into the industry to accelerate the transition.

As shown in this year's Maritime Forecast to 2050, there is no silver bullet for decarbonization, and a wide and diverse number of technological and operational pathways lie in front of us. While our natural instincts may compel us to seek the best singular solution, it is crucial that we embrace this diversity.

These solutions are not in competition – they are complementary. Maritime decarbonization demands a portfolio approach, where low-GHG fuels, energy efficiency, onboard carbon capture, and digital optimization work together to reduce emissions.

Significant progress has already been made and there is much to celebrate, particularly on the technology transition.

Drawing on insights from DNV's Alternative Fuels Insight database, this year's report shows how the number of vessels on order with alternative fuel capability is set to more than double by 2028, leading us to conclude that the old 'chicken-and-egg' dilemma – whether ships or fuels should come first – no longer applies.

By 2030, the alternative-fuelled fleet will be capable of consuming around 50 million tonnes of oil equivalent (Mtoe) of non-oil fuels annually. While this is still short of the total fleet consumption of 280 Mtoe per year, it is a remarkable achievement in a short time.

This progress shifts the spotlight to fuel producers. To meet the IMO's 2030 target of a 20% emissions reduction, shipping will need access to around 25 Mtoe of low-GHG fuels annually. This represents roughly a quarter to a third of the total projected global supply of 70–100 Mtoe of low-GHG fuels by 2030, highlighting the intense competition shipping will face from other sectors also racing to decarbonize.

The fuel transition will take time and while we hope that green versions of fuels such as methanol, LNG, hydrogen, and ammonia will eventually power a carbon-neutral fleet in the future, other avenues to emissions reductions must be explored in the meantime. This includes energy-efficiency measures, where a wide range of solutions can already be applied to ships, at relatively low cost, delivering emissions reductions today.

Great strides are being made in wind-assisted propulsion systems, and several pilot and third-party verification projects are already underway in 2025 to quantify their benefits. If successful, we could see a surge in their uptake, representing a breakthrough for sustainable shipping.

Onboard carbon capture is also growing in prominence. Research from this year's report shows that retrofitting this technology to the largest containers, bulkers, and tankers in the global fleet is feasible, with space requirements similar to a standard LNG fuel tank. If this is allayed with the development of CO_2 offloading infrastructure at 20 of the world's largest ports, emissions from these vessels could be reduced by 19%, equivalent to a 9% reduction in total fleet emissions.

We are still putting the pieces of this puzzle together. Progress isn't linear. It's built on innovation, lessons learned, collaboration, and relentless improvement. We each have a role to play and engagement and collaboration across all fronts are critical.

Let's keep working together and continue to move forward.

Knut Ørbeck-Nilssen

CEO Maritime, DNV

EXECUTIVE SUMMARY

Maritime Forecast to 2050 is one out of DNV's suite of Energy Transition Outlook reports. With this latest edition we aim to improve our understanding of the International Maritime Organization's (IMO) Net-Zero Framework (NZF) and its implications, and to provide fresh insight into the status of the maritime fuel transition today – onboard and onshore.

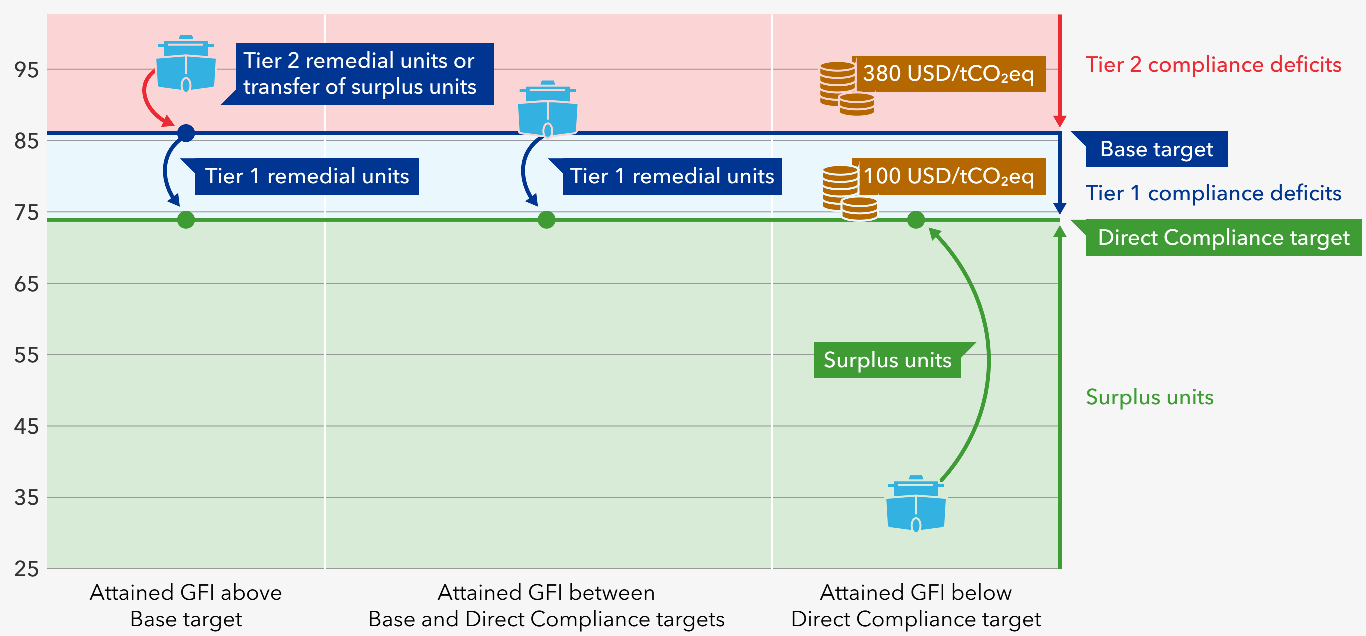
The stage is set. The IMO has approved – but not yet adopted – the NZF and is heading towards implementation of the first ever global pricing mechanism for GHG emissions. Even as projects for the production of low-GHG fuels are facing headwinds, the shipping industry is moving forward. LNG- and methanol-capable ships are crowding the order book, while ammonia as fuel, onboard carbon capture, and modern sails are all being tested and readied to impact on the global shipping industry.

Ships contracted in the coming years need to consider the upcoming stringent requirements to retain their commercial attractiveness, asset value, and profitability in the following decades. As we move beyond 2030, ships in operation may need to consider retrofit options for using low-GHG emission fuels. The NZF regulations not only affect technology choices and operation of

FIGURE 1-1

Illustration of compliance approaches in the NZF exemplified for the 2030 targets

Units: GFI (gCO_2eq/MJ)



ships but also impact the development of shoreside infrastructure and the availability of low-GHG fuels and carbon dioxide (CO_2) storage.

The NZF aims to accelerate the adoption of low-GHG fuels and technologies, thereby supporting the achievement of the revised 2023 IMO GHG Strategy, namely a 20% reduction in emissions by 2030, a 40% reduction by 2040 (compared to 2008 levels), and net-zero emissions 'by or around' 2050. It is based on the GHG fuel intensity (GFI) metric expressed in gCO_2eq/MJ of all energy used on board in a calendar year on a well-to-wake (WtW) basis. Gradually stricter GFI targets are to be set every year from 2028. In effect, the NZF penalizes vessels with a GFI higher than the targets and incentivizes the use of low-GHG fuels and other technologies that can reduce the GFI.

TABLE 1-1

Fuel transition status August 2025

Progress status

Very high | High | Medium | Low

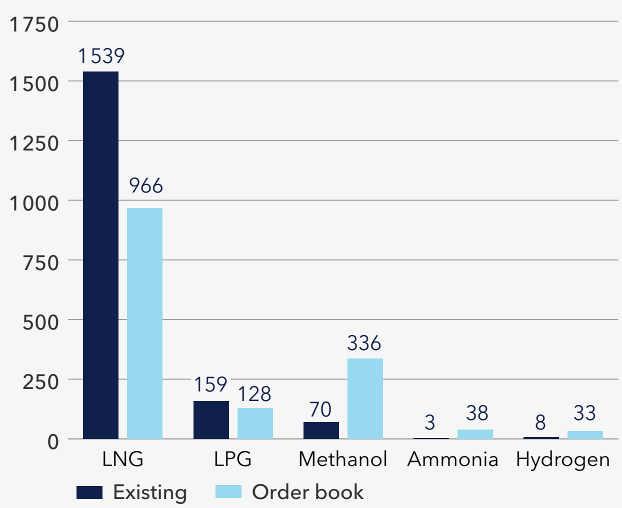
		Low GHG fuels				
		Bio-based diesel / e-diesel (mono-fuel vessels)	Bio-LNG/ e-LNG	Bio-methanol/ e-methanol	Blue ammonia / e-ammonia	Blue H_2/ e-H_2
Ship technol-ogies	Technical maturity	Conventional (mature)	Mature	Limited engine models available	Under development	Under development
	Safety regulations	Conventional (mature)	Mature	Interim IMO guidelines	Interim IMO guidelines (high-level)	Alternative design approval process
	Vessels in operation* (number of vessels)	Majority of vessels in operation	1 539	70	3	8
	Order book* (number of vessels)	Majority of newbuild order book	966	336	38	33
	Potential annual fuel consumption (Mtoe)*,**	Majority of potential annual fuel consumption	~40	~6	~0.2	~0.04
Fuel supply	Global fuel production (Mtoe)	~20***	~9	~1	~0.1	~3
	Supply to shipping (Mtoe)	~0.7	~0.1	~0.1	0	0
Infra-structure	Bunkering facilities (dedicated infrastructure only)	>670	106	3	1	1

*values include vessels using cargo as fuel, e.g., Liquefied Natural Gas (LNG) carriers, methanol tankers, and ammonia tankers; **includes vessels in operation and order book; ***only accounting for bio-based diesel produced from non-food and non-feed sources

FIGURE 1-2

Number of ships with alternative fuel capabilities in the order book compared to the existing fleet (incl. LNGC).

Units: Number of vessel



Source: Alternative Fuels Insight (AFI) - afi.dnv.com, as of August 2025

A ship that has a higher GFI than the targets can buy remedial units (RU) to make up for compliance deficits, with the initial RU prices for the reporting periods 2028 to 2030 being set as follows:

- **Tier 1 RU**: 100 USD per tonne of CO_2eq
- **Tier 2 RU:** 380 USD per tonne of CO_2eq

The proceeds from the sale of RUs to shipping companies – estimated to reach 10 to 15 BUSD/year – will go directly into the Net-Zero Fund, which will be set up and managed by the IMO. While the legal framework of the NZF has been established through the approved amendments to MARPOL Annex VI, much work remains to develop the necessary guidelines ahead of its entry into force.

We present a case study ship operating under the NZF, a chemical tanker of 18,000 DWT, and find that with present biofuel prices it will be a better business case to use biofuel rather than pay Tier 2 penalties. To reach the Base target from 2028 to 2040 by increasingly blending in biofuels, the case study ship starts with 6% of biofuel in its energy mix in 2028, increasing to 78% in 2040.

We find that a strategy of selling surplus units through maximal use of bio-LNG for the LNG version of the case study ship is not economically viable with our case study assumptions after 2031, without extra income from premium transport or rewards from the IMO Net-Zero Fund.

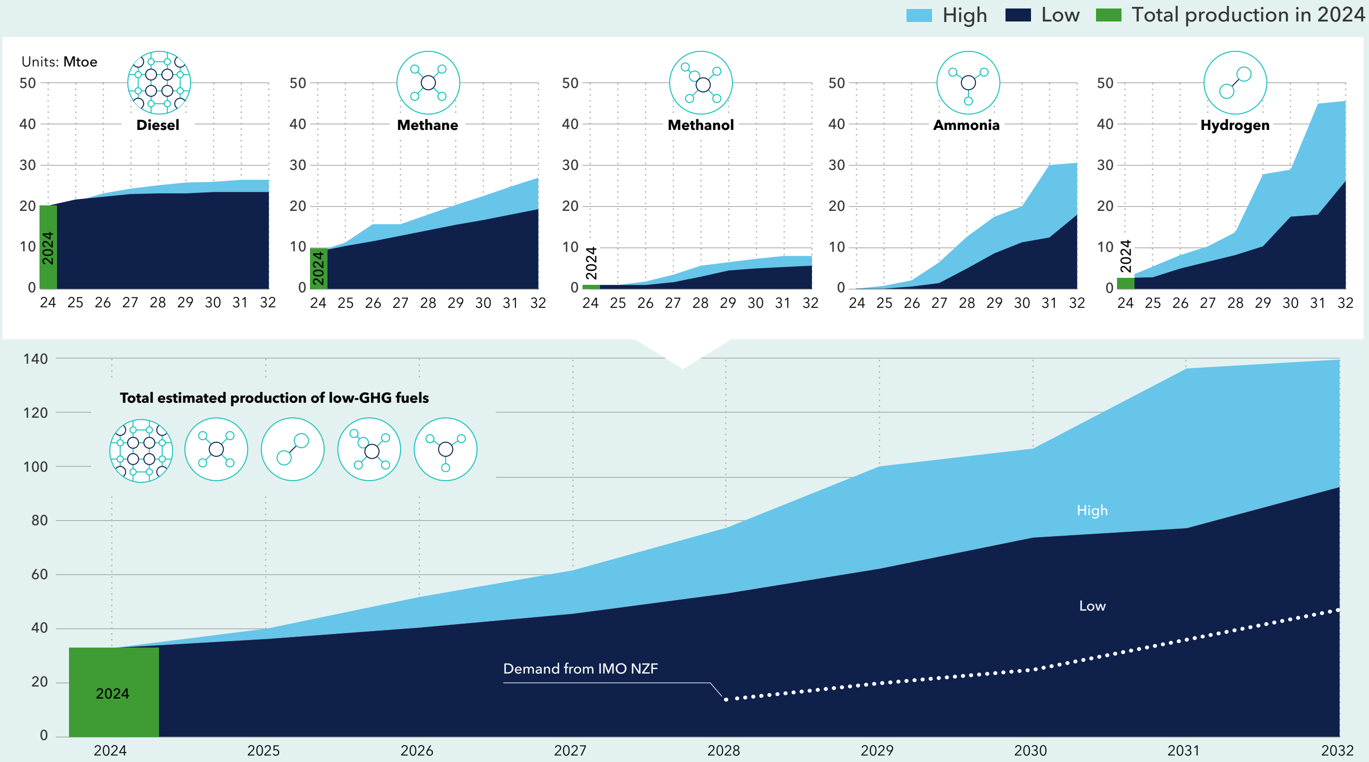
Overall, there is significant difference in progress made by each low-GHG fuel across ship technologies, fuel supply, and infrastructure – the three pillars necessary for the uptake of these fuels. For example, there are 1,539 vessels in operation that can run on bio-LNG or e-LNG, compared to three vessels capable of operating on blue ammonia or e-ammonia. Global annual production of biodiesel amounts to about 20 million tonnes oil equivalent (Mtoe), while production of bio-methanol/ e-methanol is only about 1 Mtoe. Similarly, on the infrastructure side, there are 106 bunkering facilities catering to bio-LNG and e-LNG, while for ammonia there is only one.

With the number of vessels capable of running on alternative fuels set to more than double by 2028, we are seeing a rapid increase in the capability to burn such fuels, led by a growing shift towards dual-fuel LNG.

There are, however, large differences between the ship segments. While three-quarters of the order book for large container vessels have dual-fuel capability, this is true for only one in five large tankers and only one in

FIGURE 1-3

Estimated global production of low-GHG fuels across all sectors



twenty large bulkers. For container vessels above 2,000 TEU, half the order book is LNG-capable, one quarter methanol-capable and only one quarter being built solely for conventional fuel.

This represents promising progress, but fuel availability and cost remain significant hurdles.

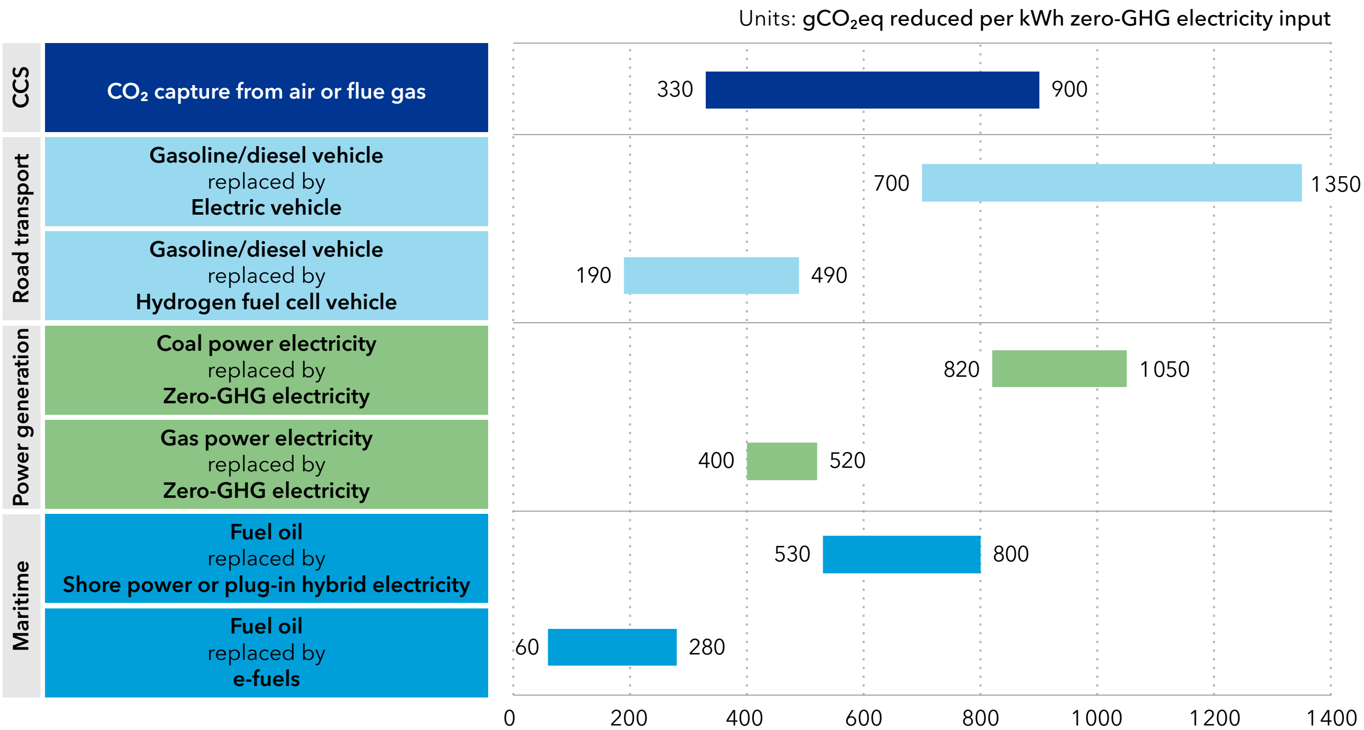
The maritime industry currently consumes an estimated 1 Mtoe per year of low-GHG fuels. To meet the IMO's 2030 Base target, DNV simulates that this needs to increase to as much as 25 Mtoe.

By 2030, the global fleet will have the capacity to consume over 50 Mtoe per year of low-GHG fuels (other than biodiesel) on ships with alternative fuel technology. Yet the development of low-GHG fuel production, particularly hydrogen and its derivatives, has encountered substantial headwinds, with no increase in estimated production by 2030 (when we exclude bio-methane) from our 2023 and 2024 estimates. Currently, only around 4% of the hydrogen-derived low-GHG fuel project pipeline has successfully reached final investment decision, with an even smaller fraction of approximately 1% reaching operational status.

The maritime industry faces an urgent challenge in competence development, and additional training capacity is needed.

FIGURE 1-4

GHG reduction from use of 1 kWh of electric energy – not considering emissions from production of electricity



Nonetheless, although the steady growth of the project pipeline has stalled, an estimated total production capacity of between 70 and 100 Mtoe for low-GHG fuels (for all sectors and including biodiesel) is expected in 2030.

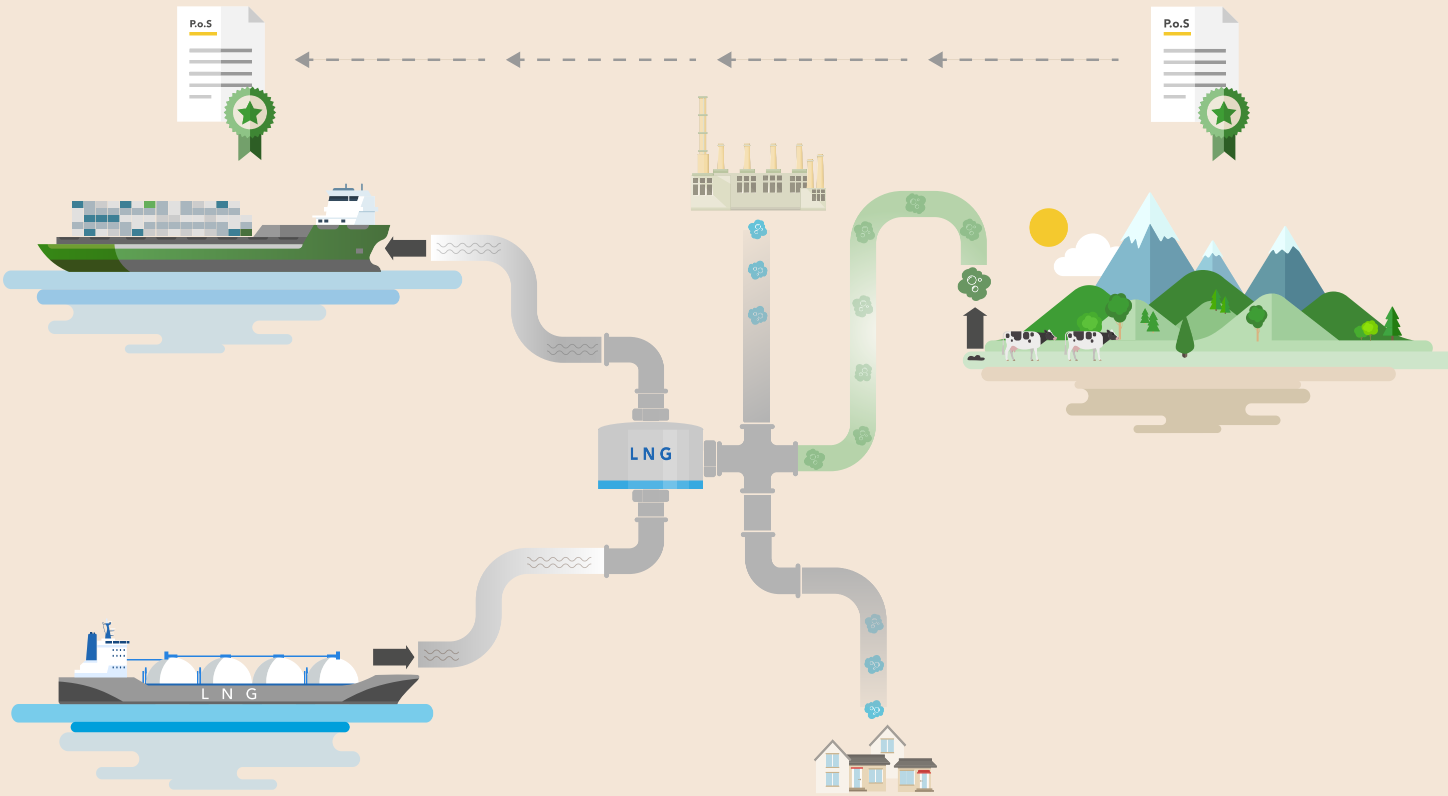
As different industries move towards decarbonization, there will be competition for low-GHG energy and fuel. To illustrate this, we have calculated how the net GHG reduction achieved through electricity usage varies significantly depending on the sector, the end-use of electricity, and the displaced energy use.

The adoption of low-GHG fuels requires substantial onshore investments and developments, both in production of low-GHG fuels and in bunkering and distribution infrastructure. The cost of establishing bunkering and distribution infrastructure for low-GHG fuels varies between fuel types and, in addition, the total costs will depend on the rules adopted for using different GHG-intensity versions of the same fuel, directly impacting the reusability of infrastructure.

These challenges can be mitigated through the adoption of flexible Chain of Custody models, which can

FIGURE 1-5

Mass balancing principle in the EU, where a ship can buy bio-methane injected into and transported on the natural gas grid: a Proof of Sustainability will accompany the bunker delivery note, ensuring the fuel counts as bio-LNG under the EU ETS and FuelEU Maritime regulations



trace and verify the sustainability of low-GHG fuels in the fuel supply chain. For example, in the case of LNG and bio-LNG, if a mass balance Chain of Custody model is applied to interconnected infrastructure, the fossil LNG terminals and natural gas pipelines can be used instead of building separate infrastructure for bio-LNG/ bio-methane. This also has the added benefit of reducing energy consumption, emissions, and costs associated with further infrastructure expenditure, thereby further incentivizing the production of low-GHG fuels.

Allowing full flexibility, for example through the book-and-claim Chain of Custody model, would lead to even greater energy savings, amounting to approximately 0.55 Mtoe per year if all the bio-methane produced in the EU were to be used as fuel for ships, assuming 10% energy loss from liquefaction and 3% from regasification. Purchasing bio-LNG in this way would result in the bunkered volume having a Proof of Sustainability document, enabling reduced GHG intensity towards FuelEU Maritime and EU ETS.

Increased use of these models could also strengthen markets for bio-LNG, incentivizing further production for a fuel which provides an increasingly clear path to decarbonization as the number of LNG-fuelled ships in the global fleet continues to grow.

As alternative-capable newbuilds enter operation over the next three to four years, we estimate that around 33,000 additional seafarers will require additional training to operate these vessels. This indicates that the maritime industry faces an urgent challenge in competence development, and that additional training capacity is needed.

Growth in the uptake of alternative-fuelled vessels is also being mirrored by an increase in other technologies which can drive GHG emissions reductions. In simulations of the development of the world fleet, DNV sees retrofit numbers of energy-efficiency packages peaking at around 1,700 a year, similar to the scrubber retrofit peak.

Maritime wind energy can potentially contribute to reduced fuel consumption and this could be a breakthrough year for several wind-assisted propulsion systems (WAPS) with several pilot systems being tested and moving into commercial operation. With upcoming third-party verifications of these technologies providing confidence in their performance, and the IMO NZF driving shipowners to explore all routes to decarbonization, WAPS adoption is set to accelerate.

Uptake of onboard carbon capture (OCC) is also increasing but its contribution to maritime decarbonization requires the development of regulatory frameworks, the installation of equipment on ships, and supporting infrastructure on land. The IMO has launched a workplan to create a regulatory framework for OCC, targeted for completion by 2028. While the EU ETS provides incentives for OCC deployment, FuelEU Maritime currently does not, but this will be considered during its scheduled review in 2027.

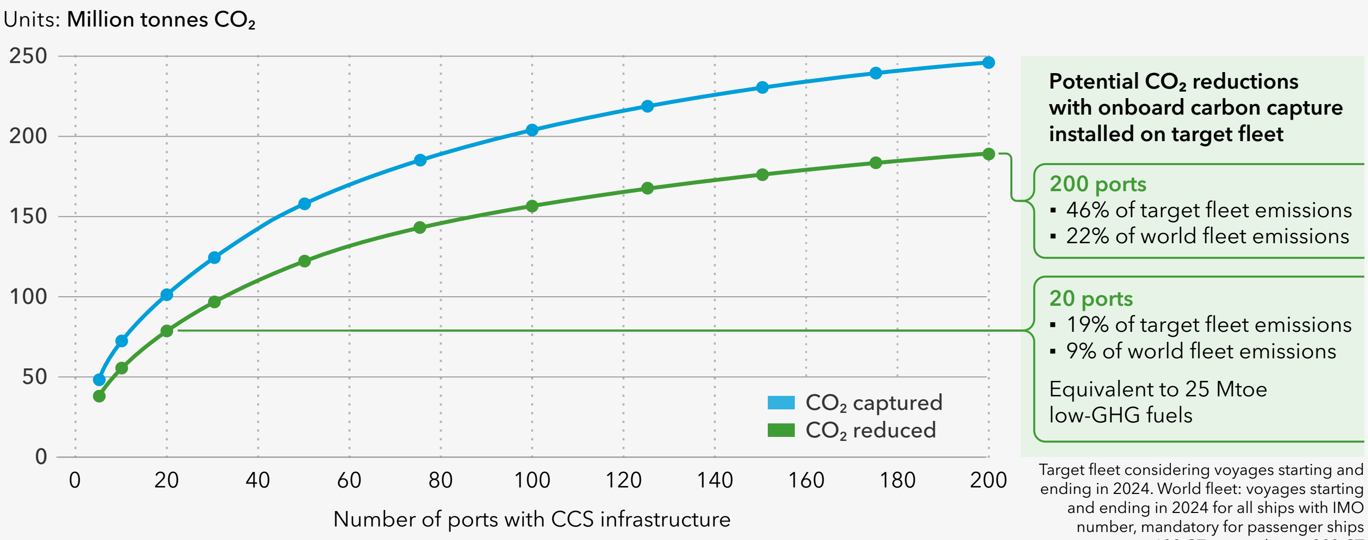
The CO_2 storage capacity on a ship will limit how much can be captured on a given voyage, and to assess realistic tank sizes for storing CO_2 captured on board, we assume similar volumes as for existing LNG tank installations. By combining these tank sizes with estimated emissions from voyages to specific ports, we have found that by equipping 20 of the largest ports with CO_2 offloading infrastructure, over 75 million tonnes of CO_2 emissions could potentially be removed from large bulkers, tankers, and containerships with onboard CCS equipment, amounting to 9% of world fleet CO_2 emissions and equivalent to using 25 Mtoe of low-GHG fuel.

Shipping has started moving towards a cleaner future, with biofuels, LNG, and wind as good short-term measures. With the IMO NZF on the horizon, shipowners and other stakeholders need to investigate all options to find cost-effective solutions for the next two and a half decades.

This is a pivotal moment for maritime decarbonization. Success will depend on synchronized progress across ships, fuel supply, and port infrastructure, supported by investment, regulatory clarity, and industry-wide collaboration.

FIGURE 1-6

The potential CO_2 capture from large bulkers, tankers, and containerships in million tonnes (blue line) and the corresponding net CO_2 reduction (green line), as a function of number of ports with CO_2 deposit infrastructure



Target fleet considering voyages starting and ending in 2024. World fleet: voyages starting and ending in 2024 for all ships with IMO number, mandatory for passenger ships ≥ 100 GT, cargo ships ≥ 300 GT

CONTENTS OF FULL REPORT

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INTRODUCTION

This publication is part of DNV's 2025 suite of Energy Transition Outlook (ETO) reports. This latest Maritime Forecast to 2050 provides an independent outlook on shipping's energy future and examines how the technology and energy transition will affect the industry.

With the Net-Zero Framework (NZF) approved by the International Maritime Organization (IMO) in April 2025, the course is being set for the global maritime fuel transition. The NZF aims to meet the emission reduction targets set out in the 2023 IMO GHG Strategy. Pending adoption in October 2025, a GHG fuel intensity (GFI) metric, in combination with a two-tier GHG pricing mechanism, will require operators to reduce their ships' GHG emissions intensity by 21% by 2030, with financial penalties for those who fail to do so. Beyond 2030, the requirements become rapidly stricter.

In response to the NZF, shipowners should carefully identify, evaluate, and use technologies, fuels, and solutions that help minimize energy consumption and lower GHG fuel intensity for ships. Many ships contracted in the coming years may still be in operation in 2050, and need to consider the upcoming stringent requirements to retain their commercial attractiveness, asset value, and profitability in the following decades. In addition, as we move beyond 2030, ships in operation may need to consider retrofit options to allow the use of low-GHG emission fuels.

In this year's report, we aim to improve our understanding of what the IMO Net-Zero Framework is, and its implications. We also want to provide fresh insight into the status of the maritime fuel transition today – onboard and onshore – so as to better understand the work that remains to be done to meet the requirements.

The report first provides an in-depth explanation of the new IMO NZF (Chapter 3), as well as an updated outlook on other GHG regulations and drivers for the maritime fuel transition. These regulations not only affect technology choices and operation of ships (Chapter 4) but also impact the development of shoreside infrastructure and the availability of low-GHG fuels and CO_2 storage (Chapter 5). Further insights into the key mechanisms of the IMO NZF are provided in Chapter 6, with an analysis of the economic impact on a case study vessel. Finally, in Chapter 7, we assess the potential of onboard carbon capture (OCC) to contribute to decarbonizing shipping.

Clarifying low-GHG vs. alternative fuels

Regulations are now maturing, and both the EU and the IMO have made rules that focus on the overall GHG emissions of fuels in a well-to-wake (WtW) perspective; the GHG fuel intensity (GFI) in the IMO; and WtW GHG intensity used in the EU. In this report we will use the term low-GHG fuels when referring to fuels with a significant improvement in WtW GHG emissions from conventional fossil fuel oils, while alternative fuels are fuels that require a different energy converter technology, such as LNG, LPG, methanol, ammonia and hydrogen, regardless of WtW GHG intensity.

CHAPTER HIGHLIGHTS

3 – Outlook on regulations and drivers

As regulation drives shipping's decarbonization, we examine the potentially game-changing new IMO Net-Zero Framework (NZF) and other key developments, including:

- A detailed description of the NZF mechanisms on GHG fuel intensity and its two-tier emissions pricing scheme.
- Critical NZF guidelines to be developed in the coming years.
- The IMO's plans for a future regulatory framework on onboard carbon capture and storage.
- How the NZF's requirements differ from the EU ETS and FuelEU Maritime.
- The latest updates on completed and pending reviews of the Carbon Intensity Indicator for ships.

4 – Outlook on ship technologies and fuels

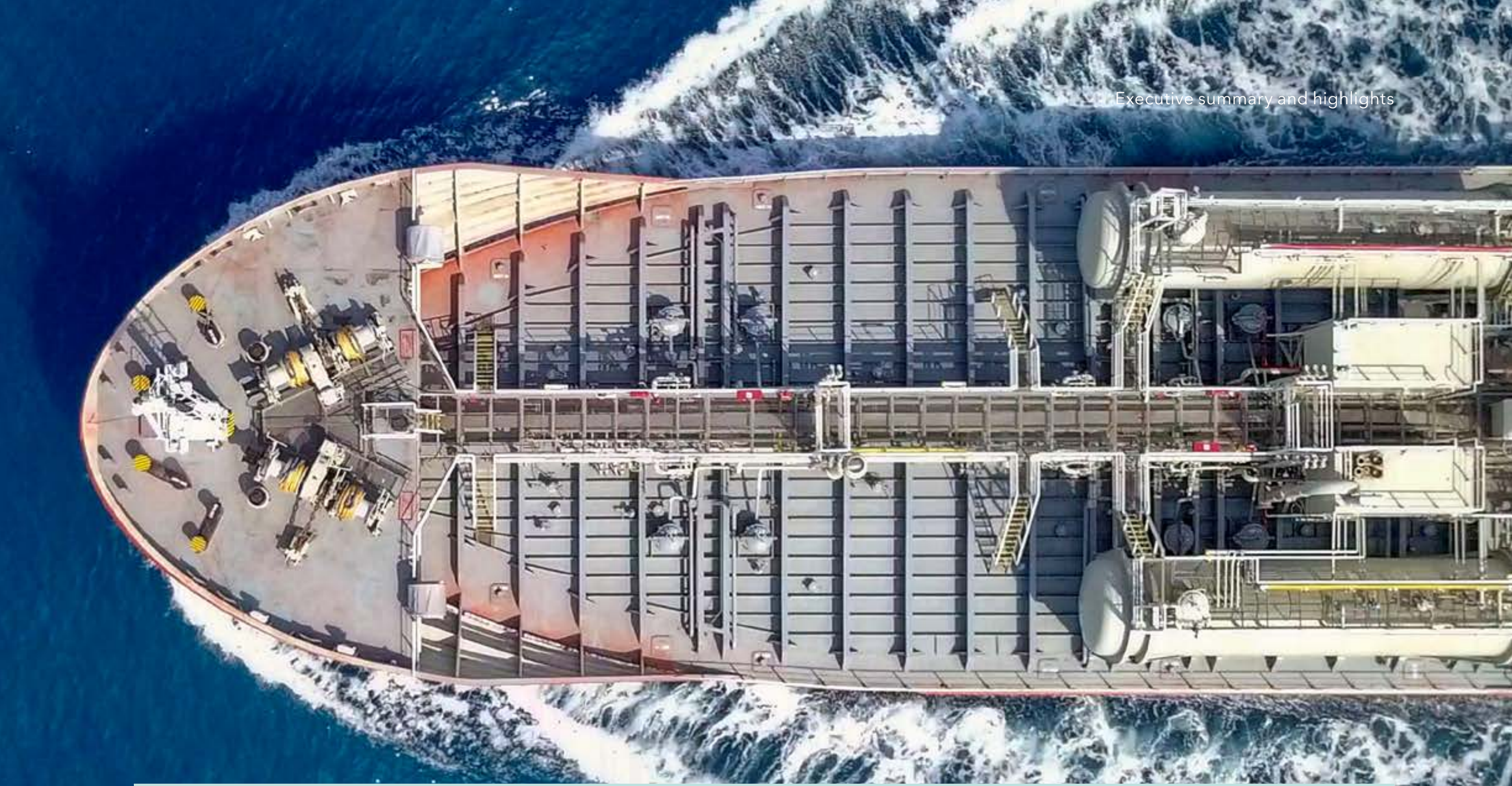
We assess alternative fuel uptake by shipping's major emitters and other decarbonization technology trends, finding:

- LNG fuel use is scaling, methanol ships are sailing, and ammonia, hydrogen, and onboard CO_2 capture are in early trials.
- Nearly as many alternative-fuel ships are on order as in service.
- Dual-fuel ships account for 75% of large containership orders, 20% of tankers, and 5% of bulkers.
- Half of containerships above 2,000 TEU are LNG-capable and a quarter methanol-capable.
- Wind propulsion is gaining ground and biofuels are expanding in ports.
- More alternative-fuel ships create urgent need for better crew training and competence.

5 – Outlook on fuel production, supply chains and infrastructure

For shipping, we analyse the status and future for low-GHG fuel production and permanent CO_2 storage, finding:

- Meeting IMO and EU targets will need major investment in renewable power, low-GHG fuels production, and CO_2 storage.
- Biofuel and LNG bunkering is well established in many locations: methanol, ammonia, and hydrogen need investment in bunkering infrastructure.
- Flexible Chain of Custody models can boost low-GHG fuel availability and reduce the investment needs for storage and bunkering infrastructure.
- Bio-methane via mass balancing in EU ports reduces the energy loss for liquefaction and gasification and will support European bio-methane production.
- Our 2030 CO_2 storage forecast is raised, but maritime players should engage early with storage or utilization project developers.



6 – Case study – IMO net-zero framework compliance strategies and cost impact

Our case study of an 18,000-DWT chemical tanker compares several strategies for complying with the IMO's NZF and finds:

- Fuel and compliance costs rise significantly from 2028 to 2040, varying by strategy.
- Fuel choice is crucial to emissions performance and economic impact, and depends on factors like price, GHG intensity, and availability.
- Costly onboard technologies may be more financially viable in ships eligible for game-changing economic incentives and revenue-earning potential under the NZF.
- Shipowners and stakeholders should make an early start to exploring cost-effective compliance options for the NZF.

7 – Potential for onboard carbon capture for large bulkers, tankers and containerships

We model the potential impact of onboard carbon capture (OCC) for ships responsible for a large share of global fleet CO_2 emissions, and find:

- If they can offload CO_2 on route, allocating space for onboard carbon capture may be no harder than for LNG tanks.
- They could then capture significant amounts, or potentially all, of the CO_2 emissions using tank sizes comparable to existing LNG systems.
- With CO_2 offloading in the 20 busiest ports, widespread use of onboard carbon capture on the world's largest ships could cut global fleet emissions by an amount similar to that needed to meet the IMO's 2030 goal.
- Raising the number of such ports to 200 could almost halve emissions from the ships studied, around a fifth of global shipping emissions.

WHEN TRUST MATTERS

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Published by DNV

Design: printprojekt GbR, Schulterblatt 58, 20357 Hamburg, Germany

Images: DNV: 2; Höegh Autoliners: 7; Shutterstock: 1 (2), 4, 9, 15, 16, 17, 18, 19; Solvang: 12