Maritime Decarbonization Strategy 2022

A decade of change

Mærsk Mc-Kinney Møller Center
for Zero Carbon Shipping

Executive Summary

Global warming is a climate emergency, and all sectors, including the maritime industry, must take immediate collective action to reduce emissions in line with the Paris 1.5°C trajectory. For the maritime industry, this means reducing emissions by 45% in 2030 compared with 2010-levels, thereby limiting the fossil fuel consumption of the global fleet to about 6 EJ in 2030 and reaching net zero by 2050. In this Maritime Decarbonization Strategy 2022, we report on the status of the transition in the maritime industry and outline key actions that lie ahead in this decade.

Recent momentum across the maritime industry demonstrates that the sector already has the most important component of any decarbonization strategy – a willingness to act. But current actions are not enough, and the industry must turn to take even more drastic means to bend the rising emissions curve.

This will require overcoming technical, commercial, and regulatory barriers as well as new levels of collaboration. It is a huge, complex challenge, but it is not impossible if the maritime ecosystem come together and act.

The future will be shaped by those who engage and shape create the visions, concepts, standards, and solutions in four key areas:

1. Elevating onboard energy efficiency

Onboard energy efficiency offer cost-effective opportunities for decarbonizing and the emissions reduction potential across the industry is significant. Improving efficiency by just 8% - or 1% per year until 2030 - could save ~1 EJ of energy, equivalent to 24 million tonnes of fuel oil and 0.1 $GtCO_2eq$ of greenhouse gas (GHG) emissions.

An array of energy efficiency measures and technologies and solutions are ready for use today but lacking commercial incentives and imperfect regulation mean their uptake is limited. Leveraging their full emissions reduction potential will require:

- Shipowners and operators taking immediate action to increase energy efficiency through rapid uptake of best practice. This should include installing energy efficiency technologies when dry-docking and requesting state-of-the-art designs when ordering new vessels.
- Businesses across the maritime value chain developing collaborative business models driven by transparency and sharing costs and benefits of increased energy efficiency in ship operations.
- The industry supporting the International Maritime Organization (IMO) in increasing their regulatory ambitions around energy efficiency.

2. Enabling alternative fuel pathways

Today our industry uses ~300 million tonnes of fossil fuel oil to produce ~12.6 EJ of energy, emitting more than 1 gigatonne of GHG emissions. We must replace fossil fuel oil with low-GHG alternatives to reach our decarbonization goals. The main alternatives include bio-methane, e-methane, bio-methanol, e-methanol, blue ammonia, e-ammonia, bio-oils, and e-diesel. We expect the industry will use multiple fuels in the future, however, all alternatives face technical, safety, commercial, and regulatory challenges.

Current plans for upcoming alternative fuel production capacity suggest that supplies will be unable to meet demand in the coming decades. Long lead times mean we must start now to secure sufficient alternative fuel capacity in 2030 and beyond. The maritime industry can prepare to scale up alternative fuels by:

- Achieving technological readiness for all alternative fuel pathways and developing standards and regulations that ensure they are used safely, and with environmental and social responsibility.
- Addressing the imbalance between planned alternative fuel production supply and demand with solid investment commitments in large-scale fuel production infrastructure and building the competencies needed to scale up all alternative fuel pathways.
- Developing regulations and measures that ensure alternative fuel pathways become commercially attractive.

3. Promoting abatement action through regulation, policy, and commitments

Emissions reduction and uptake of new technology need to be incentivized through industry commitments and regulatory reform. Companies across the industry must set ambitious decarbonization targets and report their progress to create the traction and transparency needed to drive the transition forward. In this, it is critical to maintain a people-centered approach to ensure a safe and just transition. As the main regulatory body, the IMO must focus on creating policies, targets, standards and regulations that drive the uptake of decarbonization technologies, eliminate uncertainty, and close the cost gap between fossil and alternative fuels. Specific actions needed this decade include:

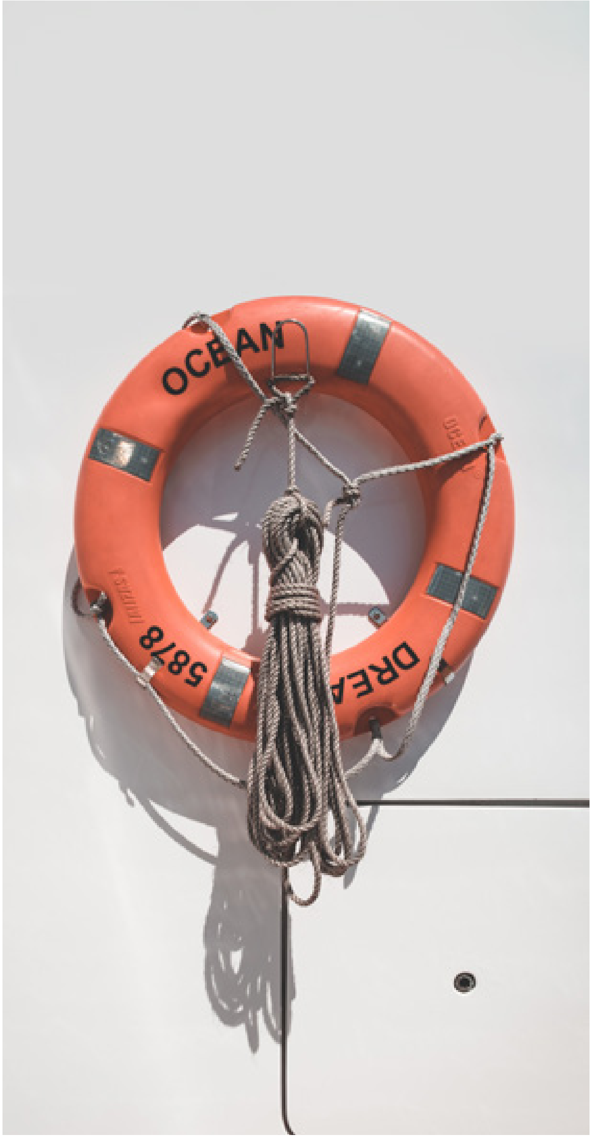
- Ambitious absolute emission targets from the IMO to reduce all GHG emissions from a well-to-wake perspective and reach net zero by 2050, aligned with the Paris 1.5°C trajectory.
- Supplementary emissions intensity and efficiency targets, intermediate targets for 2030 and 2040, global GHG pricing, and transparent emission reporting.
- Fast-tracked development of international rules and standards by the IMO to support alternative fuels and decarbonization technologies.
- Regional, national, and local policy roadmaps encouraging dedicated investments in green energy and fuel infrastructure for the maritime industry transition and engineering capacity to build these facilities.

4. Promoting bold first movers and fast followers to unlock the trasition

First movers will be key transition accelerators. Their early actions and pilot projects will inform and inspire decision makers as they unlock technological innovations, identify gaps, develop solutions, and contribute to cost reductions.

The speed of the transition will depend on how quickly first movers from across the supply chain can come together and demonstrate decarbonization solutions, business models, and best practices for fast followers. However, being a first mover can be costly and uncertain. To support them in initiating the transition, we must share the costs, benefits, and risks for first movers. This means:

- Close collaboration across the value chain, between alternative fuel producers, ports, vessel owners/operators and cargo owners to demonstrate and prove technologies, business concepts, and standards/regulations, and share the learnings, challenges, opportunities, and best practices.
- Mobilizing regulatory, policy and financial bodies to help de-risk first mover investments and decarbonization activities.
- Wide support for first mover initiatives that drive collective decarbonization and share costs, benefits, and risks, such as green corridors and Book & Claim systems.



Decarbonization won't happen overnight. We must prepare ourselves for decades of working together towards this common goal. We must change our mindsets from individualistic cost leadership to collaborative environmental leadership. And we must start now. The future of our industry depends on it.

Table of Contents

Executive Summary 2
About the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping 6
What is the Maritime Decarbonization Strategy 2022? 8
Collaborative climate leadership 9

01 The 2022 Maritime Decarbonization Outlook 11

02 Elevating Onboard Energy Efficiency 16

A toolbox of energy efficiency solutions is ready for implementation today 18
Energy efficiency regulations are well-intended but not perfect 21
Carbon Intensity Indicator (CII) 24
Overcoming barriers with new collaborative business models based on transparency 25
Increasing energy efficiency is an immediate obligation for the entire industry 26

03 Enabling Alternative Fuel Pathways 27

How mature are alternative fuel pathways? 30
From grey to blue ammonia 38
Demand for dual-fueled vessels is increasing 39
There is a disconnect between alternative fuel demand and planned supply 41
Engineering capacity may limit scale up 43
Reducing the cost of alternative fuels will rely on the economy of scale 44
We need urgent action to enable alternative fuel pathways 45

04 Promoting Abatement Action with Regulation, Policy, and Commitments 48

Commitments from shipowners are not enough 49
Global targets must align with the Paris 1.5°C trajectory 51
Regulations must consider all GHG emissions from a well-to-wake perspective 52
Life cycle assessment 53
The IMO must use multiple supplementary indicators to ensure a stable transition 55
Global GHG pricing can drive the transition 56
Rules and standards must support new fuels and technologies 57
ESG reporting can amplify decarbonization efforts 59
Investors and lenders 59
Cargo owners and customers 59
We must ensure a safe and just transition for all 61
We need ambitious regulatory action to drive the transition 61

05 Supporting Bold First Movers and Fast Followers to Unlock the Transition 62

There are advantages to being a first mover 65
First movers face risks and challenges 66
How cost-sharing initiatives can make alternative fuels competitive 68
Green corridors bring together first movers to share risk 70
Book & Claim provides credibility and consolidates demand 72
We must support first movers and fast followers 74

Conclusion 75

Summary of key actions 76
Abbreviations 78

About the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping

The Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMMCZCS) is an independent, not-for-profit research and development center. We were established in 2020 with initial funding from the A.P. Moller Foundation. Our purpose is to guide and accelerate decarbonization of the global maritime industry.

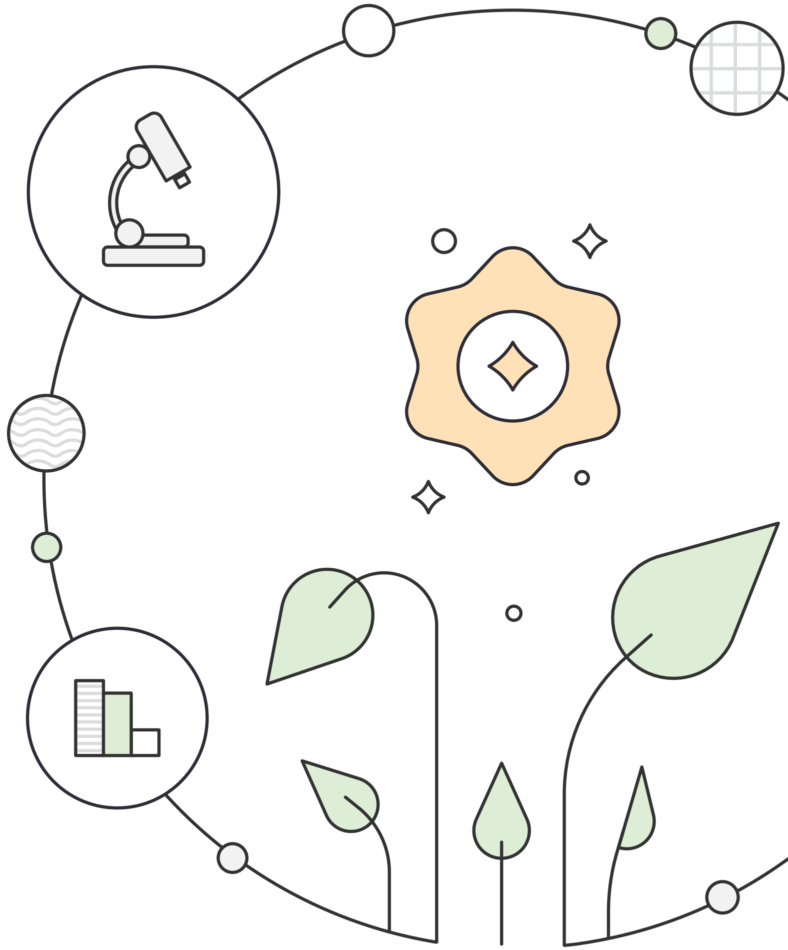
This complex challenge requires unprecedented collaboration across sectors, industries, and geographies, so we work with partners, governments, authorities, public sector bodies, scientists, and organizations from across the maritime industry and around the globe.

We aim to inform, de-risk decision-making, and spark real climate action across the maritime industry. Our staff and partner secondees collect and assess data from our partners, academia, and commercial databases to support NavigaTE, our bottom-up techno-economic modeling tool. Our analyses are technology agnostic, and we have no vested interest in any specific decarbonization solution. We explore and analyze free of commercial considerations and independent of partner strategies.

As a result, we deliver independent analyses of how the transition is progressing and clear, data-driven recommendations for accelerating maritime decarbonization.

For the transition to happen, industry action and regulatory reform must go hand in hand. Therefore, we also use the knowledge we develop to inspire and push for a coordinated and collaborative effort from both public and private stakeholders among industry leaders, scientists, regulatory bodies, and opinion leaders.

We do much more than just model the transition and call for action – we help find solutions that can impact decarbonization. At the MMMCZCS, our experts and partner secondees work closely in integrated research project teams. Together, we are maturing solutions to the most pressing problems across the maritime value chain, from fuels to onboard solutions, regulations, and financing.



Our strategic and knowledge partners:[1]

Strategic Partners

Knowledge Partners

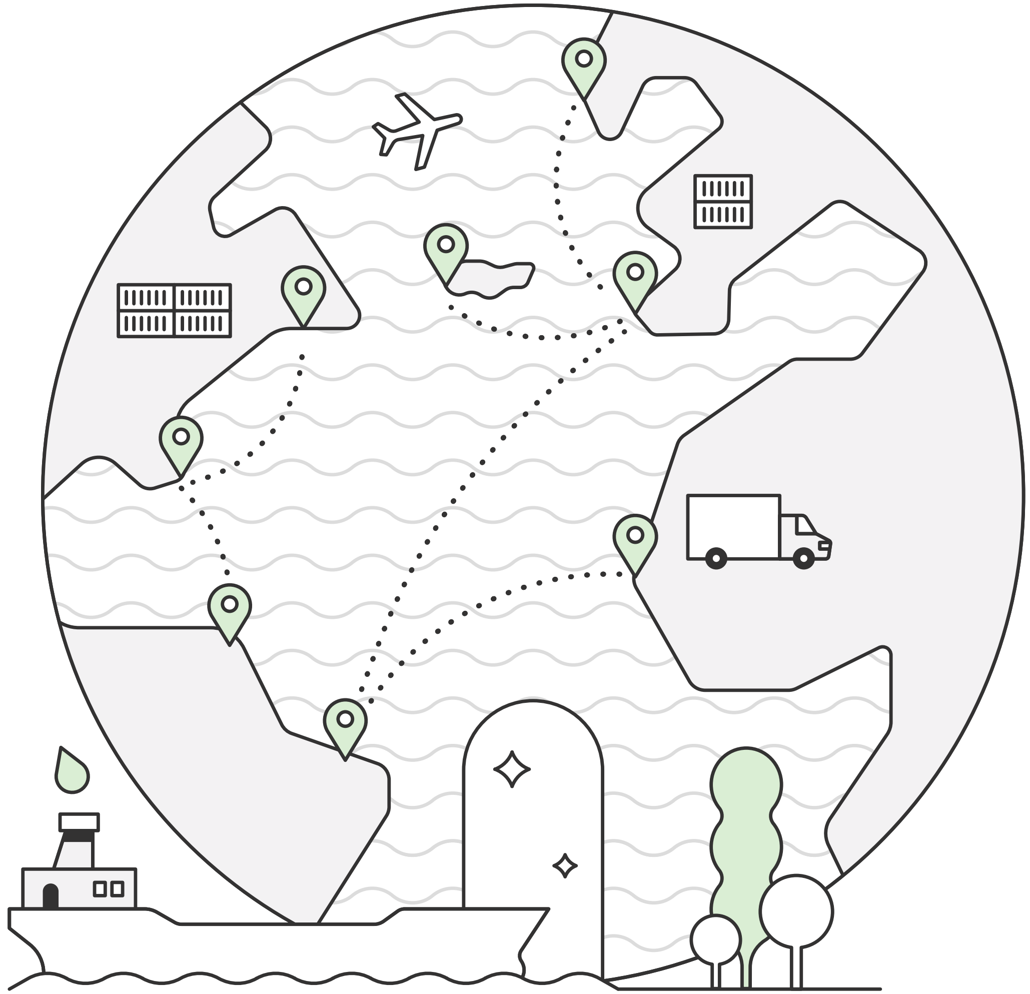
1 This Maritime Decarbonization Strategy 2022 does not reflect the positions of individual partners.

What is the Maritime Decarbonization Strategy 2022?

This report reviews the progress of the transition in the shipping sector so far and outlines the actions we must take to move closer to the Paris 1.5°C trajectory. This is the 2022 update of last year's 'Industry Transition Strategy 2021', with a new name highlighting our specific focus on the maritime industry and decarbonization. The conclusions and recommendations presented in this report are based on our analyses, NavigaTE modeling, interviews with industry stakeholders, outcomes from our workshops, and the results of our research projects.

Throughout this report we use the following colored boxes to highlight key actions, facts, examples, and deep dives:

- Key actions
- Deep dive
- Key facts
- 1 EJ example



Collaborative climate leadership

By Bo Cerup-Simonsen, CEO, Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping

The climate crisis is painfully real. It is no longer a theory of a gloomy, distant future – we are seeing the consequences here and now across the globe. Scientific research led by Intergovernmental Panel on Climate Change (IPCC) is telling us that the extreme weather events we are experiencing are not just blips on a curve. And reputable organizations such as International Energy Agency (IEA) and United Nations Environment Programme (UNEP) are confirming that with the current policies and projections, we are headed towards a climate disaster.

Fortunately, we are seeing rapidly growing commitment and real climate action from governments, companies, and individuals across the globe. The US Inflation Reduction Act (IRA) is a good example of public sector action that will accelerate decarbonization at scale through rapid activation of enormous resources to support innovation and creation of future solutions. The energy crisis in Europe is also accelerating large-scale changes through a combination of energy, climate, and industrial policies that will help expedite innovation, energy security, energy cost-down, and green solutions.

In the maritime world, the EU is taking bold and concrete steps to regulate shipping with its Emissions Trading System (ETS) and fuel standards, and the IMO is reviewing its initial GHG strategy in July 2023. At the same time, we see the maritime private sector – energy companies, shipping companies, cargo owners – starting to mobilize and demonstrate climate leadership. We are witnessing how transformative it is, even for large companies, when top leadership articulates a clear ambition and turns it into climate action and a company culture that brings enormous pride, energy, and creativity.

However, despite these many good developments – some even on an exponential growth path – challenges remain. When we compare the scale of efforts and planned actions across the sector against the necessary timeline of the transformation, it becomes evident that we are still not doing enough to stay on the recommended track. Our sector needs more countries and companies to publicly articulate a decarbonization ambition, make plans, act accordingly and report on their progress.

"The future will be shaped by those who engage and shape the visions, concepts, standards, and solutions – and there is no time to waste. Future generations depend on our collaborative climate leadership."

Bo Cerup-Simonsen
Chief Executive Officer

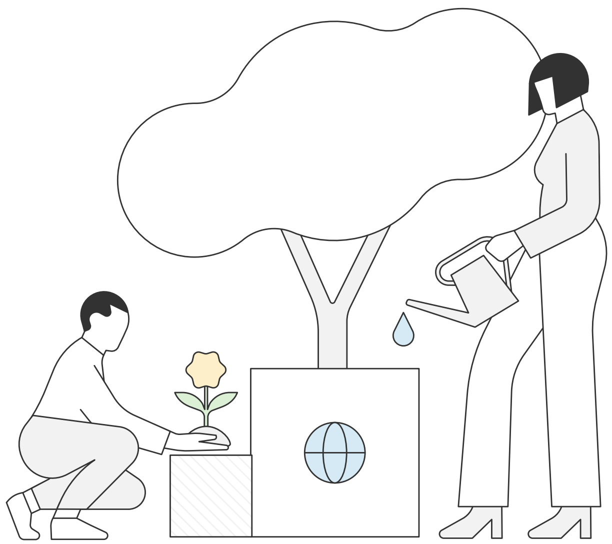
In this urge for more action, it is important to acknowledge that the status quo is very well established and offers strong competition to the needed transition. With both time and resources limited, we need new tactics to win, and the 'secret weapon' is collaboration and strong leadership combined. No single company or country – regardless of size – can solve the challenge of replacing today's fossil fueled shipping solutions on their own. Instead, communities of leaders must come together to catalyze systemic changes and deliver the mature, collaborative climate leadership needed to scale the technical, commercial, and regulatory developments.

At the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, we are honored and delighted to be part of such a community. Established as an independent not-for-profit organization two years ago, we provide progressive climate leaders in the maritime industry with a meeting place and a collaboration platform for strategizing and co-visions, objectives, concepts, standards, and solutions. Our partners, mission ambassadors and project partners include some of the most forward-leaning companies and public players in the shipping eco-system and they demonstrate exactly the behavior and courage that climate action demands. Despite being competitors in the existing markets of energy, technology, and shipping, they come together as partners to the Center to take shipping safely into the zero-carbon future.

The Maritime Decarbonization Strategy 2022 has been created in this spirit of collaboration between the Center and its partners. It outlines the status of the transition today and points at the actions needed in within this decade. Combined, it might look like a lot – and it is, - but it is not impossible. Much is already happening, and the shipping industry has shown repeatedly that it can manage huge changes when they are broken down into manageable components and concrete action. The future will be shaped by those who engage and create the visions, concepts, standards, and solutions – and there is no time to waste. Future generations depend on our collaborative climate leadership.

Let's show the world it is possible!

Bo Cerup-Simonsen
Chief Executive Officer




01
The 2022 Maritime Decarbonization Outlook
Mærsk Mc-Kinney Møller Center
for Zero Carbon Shipping

The 2022 maritime decarbonization outlook

In 2015 at the COP21 in Paris, 196 parties negotiated the Paris Agreement, a legally binding international treaty to avoid dangerous climate change by limiting global warming to well below 2°C and pursuing efforts to limit it to 1.5°C. To aid implementation of the agreement, the IPCC - a UN body for assessing climate change science - was invited to prepare a report on how global warming could be limited to 1.5°C.

In 2018, the IPCC released its special report,[2] which modeled pathways for global emission reduction and provided carbon budgets for limiting global warming to 1.5°C. Although the IPCC report describes multiple modeling pathways, they all have the following general requirements for global decarbonization:

- First, global GHG emissions must peak between 2020 and 2025 at the latest.
- Second, emissions must be reduced by 45% by 2030 compared with 2010 levels and reach net zero by 2050.
- Third, the transition must continue beyond 2050 and reach net negative CO_2eq levels to compensate for historic emissions.

Limiting global warming to 1.5º C
means reducing emissions by

45%

in 2030 and reaching net zero in 2050

Based on their modeling, the IPCC called for a swift decline in global emissions and deep emissions reductions in all sectors.[3] Figure 1 shows a trajectory for the maritime industry that meets the IPCC requirements of a 45% reduction in emissions in 2030 compared with 2010 and net zero in 2050, labeled 'Paris 1.5°C trajectory.' To take our share of the responsibility for limiting global warming, the maritime industry should aim to align with this pathway as soon as possible.

In recent years, maritime stakeholders have been calling on the industry to align with the Paris 1.5°C trajectory. The resulting focus on decarbonization has inspired action across the industry. We have also seen evidence of a mindset shift, with companies beginning to consider green shipping as a business opportunity rather than a pure license-to-operate exercise. For example, stakeholders across the maritime value chain are implementing digitalization, automation, and smart technologies to increase competitiveness, enhance efficiency, and cut costs in addition to reducing emissions (see Chapter 2 of this report for more detail). Other highlights from the last year include step-by-step developments in onboard technologies allowing vessels to run on alternative fuels (see Chapter 3); countries and regulatory bodies working on new targets, and GHG pricing initiatives (see Chapter 4); first movers presenting ambitious transition strategies; and the number of green corridor projects increasing to 21[4] (see Chapter 5).

With current decarbonization efforts,
emissions from the maritime industry will increase by nearly

10%

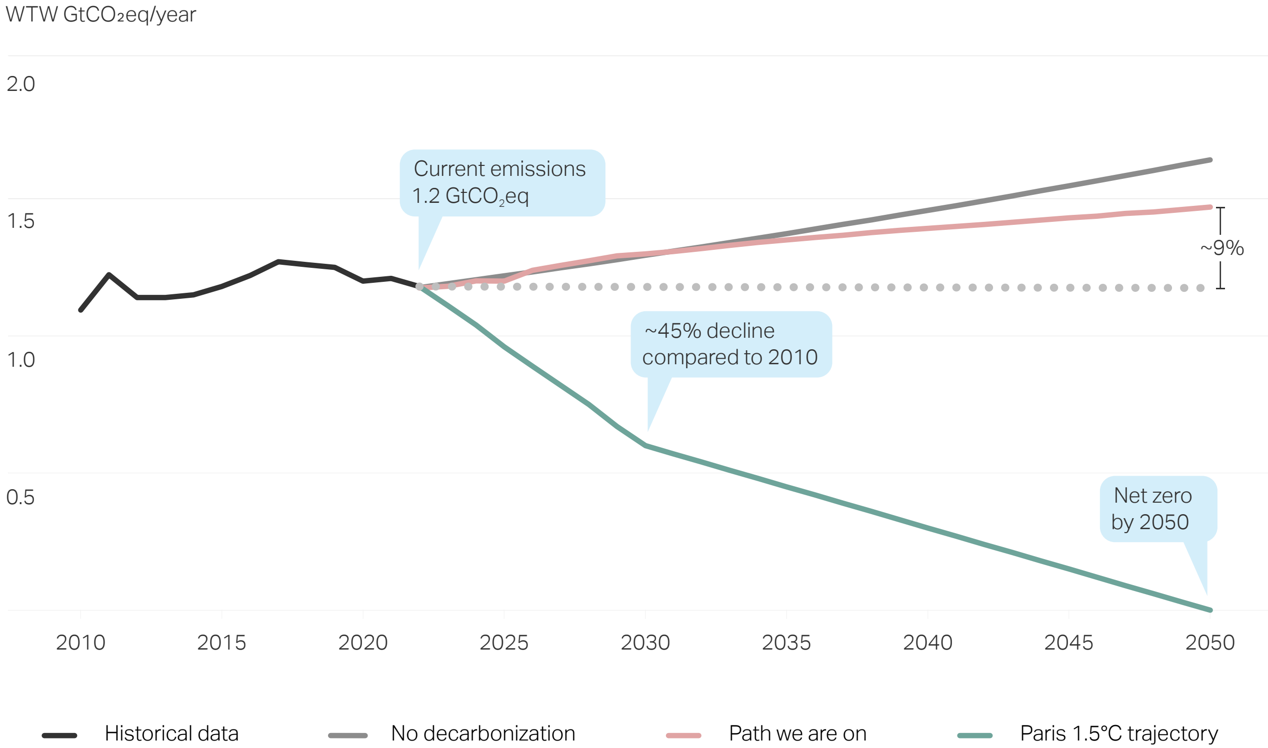
in 2050 compared with today

2 Global Warming of 1.5 °C, IPCC, 2018
3 Although IPCC calls out for action by all countries and all sectors, it should be highlighted that shipping and aviation are not directly included in the Paris Agreement. This has in turn called for debate and uncertainty of what decarbonization trajectory are to be followed. In this debate, some argue for an S-curve that accepts slow progress in this decade if followed by disruptive actions (origin from e.g., technologies that do not yet exist, reducing world trade, etc.) and dramatic emissions cuts in a very short time frame. We see big risks with such strategies if they lead to acceptance of our current situation and/or inaction to take swift action to reduce emissions already today. The maritime industry must therefore aim for equal responsibility by addressing and contributing to decarbonization in line with Paris ambitions.
4 Annual progress report on green shipping corridors, Getting to Zero Coalition & GMF, 2022.

Despite the increasing attention around decarbonization, ongoing and planned actions are still not enough to translate into sufficient emission reductions. We modeled the effects of continuing business as usual with current decarbonization efforts and planned regulations. This pathway is illustrated in Figure 1, labeled as the 'path we are on'.

The path we are on suggests that if the maritime industry sustains the same levels of ambition over the coming decades, emissions will continue to increase. Decarbonization efforts and strategies will reduce the emissions associated with individual vessels, routes, or companies. However, as global maritime trade is forecasted to grow at an average rate of 1.2% per year,[5] we can expect emissions to grow by nearly 10% in 2050 compared with today.

Figure 1: Emissions between 2010 and 2050 based on historical data, 'the path we are on,' no decarbonization, and a 1.5°C trajectory based on shipping following the global trajectory presented by the IPCC.[6]



WTW = well-to-wake.
Historical data is based on the Third IMO GHG Study[7] and Fourth IMO GHG Study.[8] 'The path we are on' is based on MMMCZCS data and analysis as described in the ITS 2021.[9]

5 MMMCZCS forecast based on global trade outlooks from the International Monetary Fund, the World Bank Group, and the Organisation for Economic Co-operation and Development (OECD)
6 IPCC SR15 Summary for Policymakers, IPCC 2018.
7 Third IMO GHG Study, IMO, 2014
8 Fourth Greenhouse Gas Study 2020, IMO, 2020
9 Industry Transition Strategy, MMMCZCS, 2021

Today, we are very far away from aligning with the Paris 1.5 °C trajectory. International and domestic shipping uses approximately 12.6 EJ of energy each year, corresponding to around 300 million tonnes of fossil fuels resulting in ~1.2 $GtCO_2eq$ emissions from a well-to-wake (WTW) perspective. To reduce our emissions by 45% in 2030 compared with 2010, we must limit our fossil fuel consumption to ~6 EJ of the total energy demand from the global fleet. We can use a combination of two levers to meet this goal: reducing the total energy demand of our global fleet with energy efficiency measures and/or replacing fossil fuels with low-emission alternative fuels.

We must limit the fossil fuel consumption of the global fleet to approximately

6 EJ

in 2030

The following sections of this report focus on how we can use these levers to break the emissions curve and how we can scale up our efforts to target aligning with the Paris 1.5°C trajectory by 2030. The next two chapters deep dive into the levers. Chapter 2 covers progress, barriers, and solutions for elevating onboard energy efficiency, and Chapter 3 discusses how we can enable alternative fuel pathways. The last two chapters examine how we can accelerate progress using regulation, policy, and commitments (Chapter 4) and by supporting first movers and fast followers (Chapter 5).

To give perspective on the scale of the actions required, throughout the report, we show how we can reduce or replace 1 EJ of energy demand (see green boxes below for context on what 1 EJ represents). We also summarize the key actions for aligning with the Paris 1.5°C trajectory at the end of each chapter in pink boxes.

How much is one exajoule (EJ) of energy?

Global fleet
1 EJ (10^{18} joules) is about

8%

of the energy consumed by the global fleet each year

Fuel oil
1 EJ is equivalent to approx.

24

million tonnes of fuel oil

Electricity
1 EJ corresponds to nearly

280,000 GWh

of electricity. That's the annual electricity consumption of Mexico[10]

Petroleum
1 EJ is approx. equivalent to

173

million barrels of petroleum. That's roughly 25% Germany's annual petroleum consumption[11]

Solar and wind
1 EJ of energy per year corresponds to around

80 GW

of installed solar and wind capacity assuming a 40% capacity factor

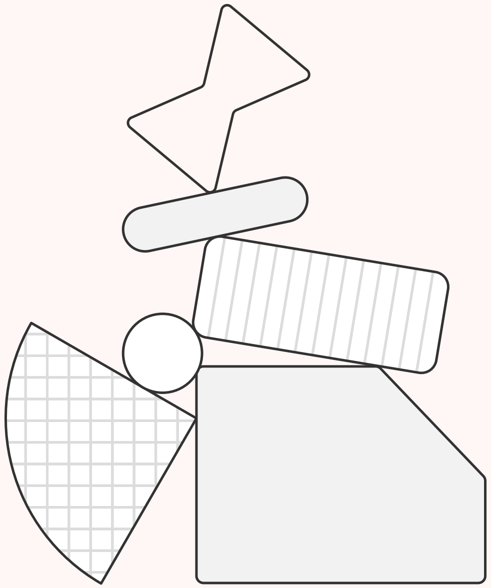
10 US Energy Information Administration
11 BP Statistical Review of World Energy

Breaking the emissions curve this decade will require collective action across the maritime industry: We must develop and deploy new technologies and fuel pathways and implement firm regulations demanding their use. For a hard-to-abate sector such as shipping, this transition will take time. It is, therefore, important that we begin dedicating resources to these efforts today. We cannot wait for others to do the work for us. This decade will be crucial.

Key actions

The maritime industry must take **immediate collective decarbonization action** on an **unprecedented scale** to bring us closer to the Paris 1.5°C trajectory, including:

- Reducing emissions by **45%** in **2030** compared with 2010.
- Limiting the fossil fuel consumption of the global fleet to **6 EJ** in 2030.
- Reaching **net zero** by **2050**.



02
Elevating Onboard Energy Efficiency

Mærsk Mc-Kinney Møller Center
for Zero Carbon Shipping

Elevating onboard energy efficiency

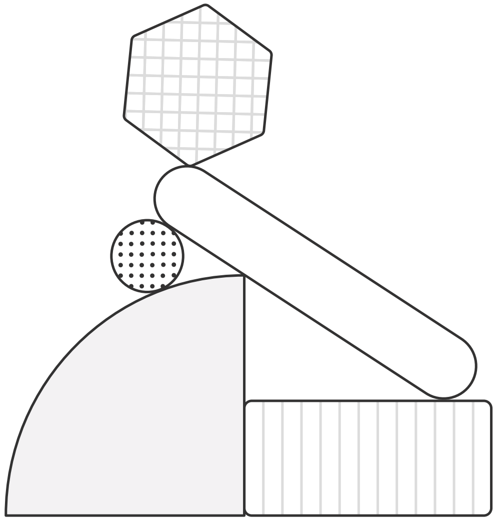
The cleanest energy is the energy that we don't use. One way to reduce the maritime industry's consumption of fossil fuels, and therefore emissions, is to reduce the amount of energy we use by employing energy efficiency measures.

The current global fleet energy consumption of 12.6 EJ results in 1.2 $GtCO_2eq$ of GHG emissions (WTW) every year. If we improved energy efficiency by 1 EJ and used 8% less fuel, we would save 24 million tonnes of fuel[12] and 0.1 $GtCO_2eq$ of GHG emissions (WTW) each year.

Employing energy efficiency measures provides fuel savings and immediate emissions reductions on individual vessels, but it also benefits the entire maritime industry and other sectors worldwide. Forecasts suggest that demand for renewable electricity and sustainable biomass will grow rapidly over the coming decades as all industries decarbonize. However, sustainable biomass is scarce, and renewable energy capacity takes time to build. As a result, green electricity and alternative fuels may be limited while we build enough infrastructure to meet demand. Increasing the energy efficiency of the global fleet will lower the demand for alternative fuels and increase availability across the maritime and other industries, speeding up global decarbonization.

Saving 1 EJ of energy across the fleet could reduce demand for alternative fuels by, for example, 50 million tonnes of e-ammonia, therefore reducing the demand for renewable electricity by approximately 140 GW of installed capacity (the energy required to create 1 EJ of ammonia is more than the energy in 1 EJ of electricity stated in the previous chapter due to energy losses at each stage of the production process).

An array of energy efficiency measures and technologies are ready for shipowners and operators to implement today. However, despite the obvious advantages of reducing energy demands, efficiency measures remain inconsistently applied in many shipping segments. This chapter provides a deep dive into the barriers and opportunities for encouraging industry-wide uptake of energy efficiency measures. We also discuss the strengths and weaknesses of existing regulations intended to increase uptake. Finally, we outline how adopting new technologies, building new business models, and improving regulations can drive the highest ambitions for energy efficiency across the global fleet.



12 Based on vessels using internal combustion engines with a typical efficiency of ~50%

A toolbox of energy efficiency solutions is ready for implementation today

Enhancing vessel and fleet efficiency are not new concepts in the maritime industry. Over the past 15 years, the most advanced ship designers, owners, and operators have developed and implemented impactful solutions for increasing energy efficiency. As a result, there are now many technical solutions and operational measures that provide significant energy savings, as outlined in Table 1. Some solutions are fully commercialized, while others are still in development, but there is no shortage of available solutions for increasing energy efficiency in the maritime industry.

Companies looking to increase their energy efficiency often start by implementing operational measures such as hull and propeller cleanings, voyage planning, and weather routing. Operational measures such as these require little investment and offer large fuel savings (up to 15% compared with standard operational practices), making them win-win solutions that simultaneously reduce fuel costs and emissions.

Table 1: Energy efficiency levers, their potential impact and current uptake.

Area	Category	Examples	Potential energy efficiency gains per ship	Current fleet uptake*			
				Bulk	Tanker	Container	Passenger
Operational measures	Voyage optimization	Voyage planning, and weather routing, trim and draft optimization, energy management, hull, and propeller fouling management	1-10%	Growing adaption	Growing adaption	Best practice	Best practice
	Fleet strategies	Fleet portfolio optimization, vessel deployment and utilization, scheduling, and speed optimization	1-15%	Limited adaption	Limited adaption	Growing adaption	Best practice
Technological solutions	Hull & propeller efficiency	Hull form optimization, propeller design, anti-fouling systems, propulsion-improving devices, and air lubrication	1-8%	Limited adaption	Limited adaption	Growing adaption	Best practice
	Engines and systems	Engine technology, electrification and hybridization, waste heat recovery system, and shaft generator	1-5%	Limited adaption	Limited adaption	Growing adaption	Best practice
	Alternative power systems	Wind assisted propulsion	1-8%	P	P	Not applied	P

Not applied P Pilot installations Limited adaption Growing adaption Best practice

The Illustrated energy efficiency gains were calculated by combining all the measures in a category, averaged across vessel segments and routes in worldwide operations. Individual measures on specific routes may provide smaller or greater energy savings. Efficiency gains cannot be added across categories as they may overlap or work against each other. Uptake data is based on an analysis of publicly available information, knowledge from our partners, and industry experts at the MMMCZCS.

*Based on an analysis of publicly available information, knowledge from our partners and industry experts at the Center.

The orderbooks from the last few years demonstrate increased interest in technical energy efficiency solutions, including hybridized onboard power production with batteries (mostly on smaller vessels in short sea shipping) and air lubrication. A wide range of wind assist solutions are also being piloted on commercial vessels with deck space and designs that make retrofitting these systems practical.

The implementation costs, GHG abatement impacts, and expected payback periods of technical energy efficiency solutions differ widely across segments and between individual vessels. Our estimates of abatement costs based on average efficiency gains suggest that most technical solutions provide savings of more than 100 USD/tCO_2eq. However, these abatement costs are uncertain as they depend on factors such as the remaining vessel lifetime, operational patterns, and market conditions.

Operational measures
offer energy efficiency
gains of up to

15%

Uptake of operational and technical energy efficiency measures varies across vessel categories and segments, as shown in Table 1. There are some areas of growing application, particularly in the passenger, cruise, and container segments. In the fragmented bulk and tanker segments, although leading operators are applying energy efficiency measures, overall adoption remains low. As a result, the industry still has substantial potential to save onboard power, reduce energy consumption, and limit emissions.

As outlined in Chapter 1, to align with the Paris 1.5 °C trajectory we must reduce the global fleet's consumption of fossil fuels to 6 EJ by 2030. Energy efficiency measures will play a vital role in meeting this goal by reducing the total energy demand of the global fleet. The green box to the right illustrates how energy demand could be reduced by 1 EJ. Reducing energy demand by 1 EJ will rely on increasing willingness to invest in energy efficiency solutions at newbuilding and retrofits. Furthermore, shipyards and technology providers must prepare for an accelerated installation program that will require yard capacity, up-skilling competencies, technology availability, and longer dry docks than usual.

What will it take to save 1EJ of energy with efficiency measures by 2030?

1/3 of all vessels must have optimized hull forms and propulsion-improving devices fitted on their hull, rudder, and propeller*

... that would mean a 3x increase in adoption of propulsion -improving devices in the bulk, tanker, and container fleets compared with today

AND 1/4 of all vessels must include new, CapEx intense technologies such as air lubrication and wind assisted propulsion

... that would mean a 400x increase in adoption of new technologies like air lubrication and wind assistance in the bulk, tanker, and container segments compared with today

AND all vessels must utilize all operational efficiency measures

All vessels' includes the bulk, tanker, container, gas carrier, passenger and RORO car carrier fleets. Applies to both newbuilds and retrofit programs.
*Adoption will be driven by compliance with EEDI Phase 2 and 3.

As energy efficiency technologies are available and provide obvious benefits, we might expect to see widespread uptake. However, currently, that is not the case and uptake is limited to leading operators. So why aren't energy efficiency measures widely adopted? In 2022, we hosted a working group with companies from across the value chain to identify the most common barriers preventing widespread uptake. The group highlighted industry-wide hesitancies, combined with various interconnected commercial and technical barriers (see Table 2):[13]

1. Industry hesitancy around new technologies and long-term investments

The maritime industry is generally risk-averse and often demands full-scale demonstrations before new technologies are widely adopted, slowing uptake. Furthermore, building energy-efficient ships requires customized, innovative designs and non-standard technologies. However, shipyards typically only fit their own technologies as standard, and can be reluctant to include third party equipment that may affect performance guarantees or conflict with their design principles.

Including non-standard technology increases costs and, as a result, payback periods can be lengthy. Asset management (buying and selling ships, and profiting from the cyclic nature of markets) plays a central role in the maritime industry. An owner may be unwilling to pay for customized designs if they only plan to hold the vessel for a short period. Furthermore, fuel costs and charter rates are volatile, making payback periods uncertain. As a result, the industry does not use the same criteria for assessing onboard energy efficiency investments as traditional capital investments within shipping. Typically, energy efficiency investments are only implemented if payback periods are less than five years.

2. Commercial barriers

The maritime industry is fragmented, particularly in the bulk and tanker segments. While owners pay the initial investment for energy efficiency technologies, charterers usually pay fuel bills. As a result, owners have little incentive to install energy efficiency measures as they cannot recoup their installation costs. The lack of a binding contractual framework for guaranteeing energy efficiency performance further exacerbates these misaligned incentives, as charterers are unwilling to pay premiums for energy efficiency claims.

Liner operators and cruise ships tend to have all the stakeholders influencing vessel design and operation decisions within the same company. Hence, aligning objectives and budgets related to ship design, customization, and the need for energy-efficient operations is easier. This translates to greater uptake of energy efficiency measures in these segments (see Table 1).

Table 2: Summary of commercial and technical barriers preventing energy efficiency uptake.

	Barriers	How common are the barriers today?
Technical	Efficiency impact linked to vessel operations and other measures	
Technical	Lack of performance standards and benchmarking measures	
Technical	Very limited data sharing practices	
Commercial	Misaligned incentives	
Commercial	Lack of commercially-linked performance guarantees	
Commercial	Uncertainty with return on investments	
Commercial	Reluctancy to adopt custom design	
Commercial	Unwillingness to pay	

Degree of prominence: High Low

13 More detailed results from the working group will be published in a separate report soon.

3. Technical barriers

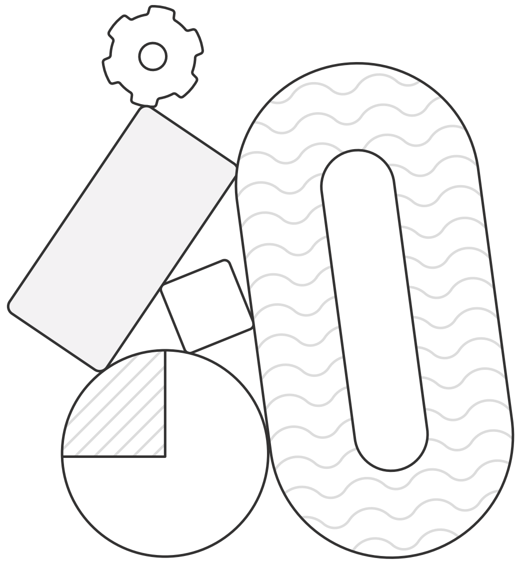
The impacts of energy efficiency measures are difficult to quantify because they are intricately linked to vessel design, deployment, and the unique combination of measures employed onboard. If we could measure their impacts on fuel consumption and emissions directly, shipowners may be more willing to invest, and operators may be willing to share the costs. However, presently many stakeholders are reluctant to share their data due to a cost-leadership mindset. Furthermore, technical barriers, including lacking performance standards and benchmarking measures, are currently preventing a transparent, quantitative approach to sharing energy efficiency savings.

Energy efficiency regulations are well-intended but not perfect

Ambitious and clearly defined regulations could accelerate energy efficiency adoption and significantly reduce emissions. The IMO has been developing a regulatory toolbox for increasing technical and operational energy efficiency for many years. There are now four key measures:[14,15]

- The Energy Efficiency Design Index (EEDI) is a technical measure that defines minimum energy efficiency levels for newly constructed ship designs according to their type and size. It intends to increase the uptake of more efficient technologies and engines on new ships.
- The Energy Efficiency Existing Ship Index (EEXI) provides similar minimum energy efficiency levels for existing ship designs.
- The Carbon Intensity Indicator (CII) is an operational measure and rating system that intends to measure how efficiently a ship transports its cargo using carbon intensity (CO_2 emissions per transport work).
- The Ship Energy Efficiency Management Plan (SEEMP) Part III is a part of the CII that provides a mechanism for ship management and operators to document and manage operations and fleet efficiency over time.

Adopting these regulatory frameworks was a major milestone for the industry, and they reflect the IMO's good intentions around increasing energy efficiency. However, the current regulations reflect a lack of broad consensus on a political level at the IMO, and there are opportunities for further improvement (see Table 3).



14 Index of MEPC Resolutions and Guidelines related to MARPOL Annex VI, IMO
15 Further shipping GHG emission reduction measures adopted, IMO, 2021

Table 3: Strengths and improvement opportunities of current and upcoming energy efficiency regulations.

	Energy Efficiency Design Index (EEDI)	Energy Efficiency Existing Ship Index (EEXI)	Carbon Intensity Indicator (CII)	Ship Energy Efficiency Management Plan (SEEMP)
Strengths	- Common language energy efficiency and standards - Clear and mandatory enforcement mechanisms - Phased approach allows gradual preparation and uptake of technologies - Led to an uptake of energy efficiency measures for newbuilds	- Levelled power reduction across segments and fleet age - Prevent sudden surge in emissions in a short-time frame - Clear and mandatory enforcement mechanisms - Ensures alignment with EEDI (i.e. for existing vessels to be at par with new builds)	- Creates a common language for the industry on carbon intensity - Provides a standardized framework for operational energy efficiency awareness - Can be adopted for business purposes (e.g., CII rating linked green financing rates)	- Ensures a common reference and guidelines for the crew to plan and execute energy efficiency improvements onboard - Creates a push for more onboard digital monitoring tools and energy efficiency awareness
Further improvement opportunities	- Address overlaps with upcoming fuel-centric regulations also regulating CO_2 emissions - Remove opportunity for easier compliance by changing to a fuel with a lower carbon factor by considering energy consumed rather than CO_2 emissions	- Consider how optimization could drive increased uptake of energy efficient technologies - Remove opportunities for compliance using fast and easy solutions (e.g. power limitations) without any major energy efficiency upgrades	- Develop clear enforcement mechanisms - Develop incentive for vessels with over-compliance - Regulates all stakeholders in the value chain who influence the rating	- Provide guidance on what makes an effective and robust plan - Provide objectivity in guiding SEEMP audits (e.g., audit triggers, auditor's role)

The IMO first implemented EEDI almost ten years ago. The regulation provides mandatory energy efficiency levels for newbuilds and includes clear enforcement mechanisms. When EEDI first came into force, it translated into increased power optimization in new vessels by reducing installed power and increasing propeller diameter. EEDI uses a phased approach that allows gradual preparation and uptake of energy efficiency technologies. As a result, it is now driving increased uptake of innovative technologies, and newbuild vessels are more energy efficient than ten years ago. However, despite being a design measure, EEDI uses CO_2 emissions per tonne nautical miles. This implies that shipowners can achieve EEDI compliance by simply switching to a fuel with lower tank-to-wake CO_2 emissions than fuel oil, such as liquified natural gas (LNG), while deploying limited or no energy efficiency measures. The IMO could strengthen EEDI in the future by addressing this weakness. For example, this could involve using energy consumed in EEDI ratings rather than emissions, which would remove the impact of fuel choice on a vessel's rating.

EEXI uses the same formulation as EEDI but applies to existing vessels. It comes into force in January 2023, and ships must reach EEXI compliance by the first periodical survey in 2023 at the latest. Ideally, EEXI should drive increased uptake of energy efficiency measures in existing ships. However, the index design allows owners to achieve compliance using power limitations rather than implementing energy efficiency technologies. Many vessels are already operating well below maximum service speeds and design powers.

As a result, EEXI may not increase the uptake of energy efficiency technologies or significantly reduce emissions compared with present fleet operating profiles. Motivating and enforcing full energy efficiency technology retrofits would strengthen EEXI and allow it to drive the intended emissions reductions.

CII and SEEMP Part III come into effect from January 2023, with the first ratings and reports issued in 2024. CII represents a significant milestone as the first carbon intensity regulation from the IMO. It provides a standardized framework for defining performance ratings and a common language for carbon intensity performance. As a result, CII could be used in contracts and agreements, preventing vessels with a poor rating from being chartered or financed. However, owners are uncertain about how they can take a holistic and cost-effective approach to CII (see deep dive box for more detail), and the regulation could be strengthened with better targeting and clearer enforcement mechanisms.

The existing and upcoming regulations address various aspects of improving energy efficiency. However, they may not initiate the behavior the IMO may have hoped for. To enhance their impact, the IMO must raise regulatory ambitions, optimize regulation designs, and provide stronger, well-defined enforcement mechanisms (see Table 3). Well-designed regulations that share the burden across all stakeholders affecting emissions (including owners, charters, and operators) could unlock the collaborative mindset and shift towards environmental leadership needed to overcome the barriers discussed earlier in this chapter.

Deep dive:

Carbon Intensity Indicator (CII)

What is CII?

CII provides ratings for a vessel based on its actual energy efficiency in grams of CO_2 emitted per cargo-carrying capacity and nautical mile. It uses A-E ratings, with A representing the best energy efficiency performance. The rating thresholds will become increasingly more stringent over time. If a vessel gets three consecutive D ratings or one E rating, the owner must provide a plan of corrective actions demonstrating how they will reach compliance in the following calendar year.

How do stakeholders influence CII ratings?

CII is part of the IMO's International Convention for the Prevention of Pollution from Ships (MARPOL) regulations, which apply to vessel owners. The vessel owner sets the baseline for technical efficiency. However, decisions by other stakeholders, including operators and third parties, also directly impact a vessel's CII rating.

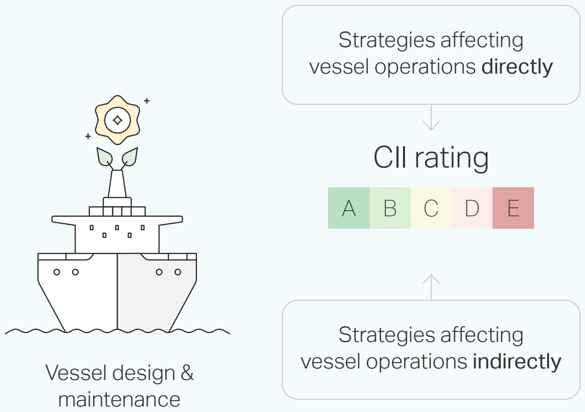
Operators make decisions about speed instructions, trade deployment, and utilization, impacting efficiency. Decisions by ports and terminals can cause idle periods, unnecessarily long port stays, and speed increases to catch up after delays, impacting CII ratings. Furthermore, cargo owners can affect CII when carrying a specific cargo limits the ability to reduce power, requires calls to challenging ports, or influences vessel utilization. Therefore, owners must engage in dialogue and cooperation with all parties that can indirectly influence CII ratings. However, when only the shipowner is penalized, interest in cooperation may be one-sided.

What challenges does CII face?

CII is a holistic regulation that, with clearer guidance, could drive transparency and cross-value chain action. However, very few companies have the in-house capabilities to influence all the stakeholders whose day-to-day operational decisions will impact CII. Owners can only act on some aspects of CII, such as enforcing speed limitations through charter party agreements, vessel maintenance, retrofitting energy efficiency technologies, etc. It is difficult for them to predict or influence the actions of others.

Some shipowners have called for exclusions and corrections to CII to allow for actions that are out of the owner's control. Implementing such exclusions may undermine the potential impact of CII regulations. Ensuring a compliant and effective CII rating requires a balance of technical solutions, operational considerations, and commercial drive across multiple stakeholders. This will be challenging when the regulatory burden is solely on shipowners. There is, therefore, a risk that compliance will be managed through contracts, restrictions on vessel operations, and penalties rather than concerted action across the value chain to reduce emissions and achieve optimal vessel performance.

The IMO must update CII to share responsibility across all those influencing vessel emissions. Furthermore, they must provide clear enforcement mechanisms, such as specific consequences for vessels that fail to comply after implementing a plan of corrective actions.



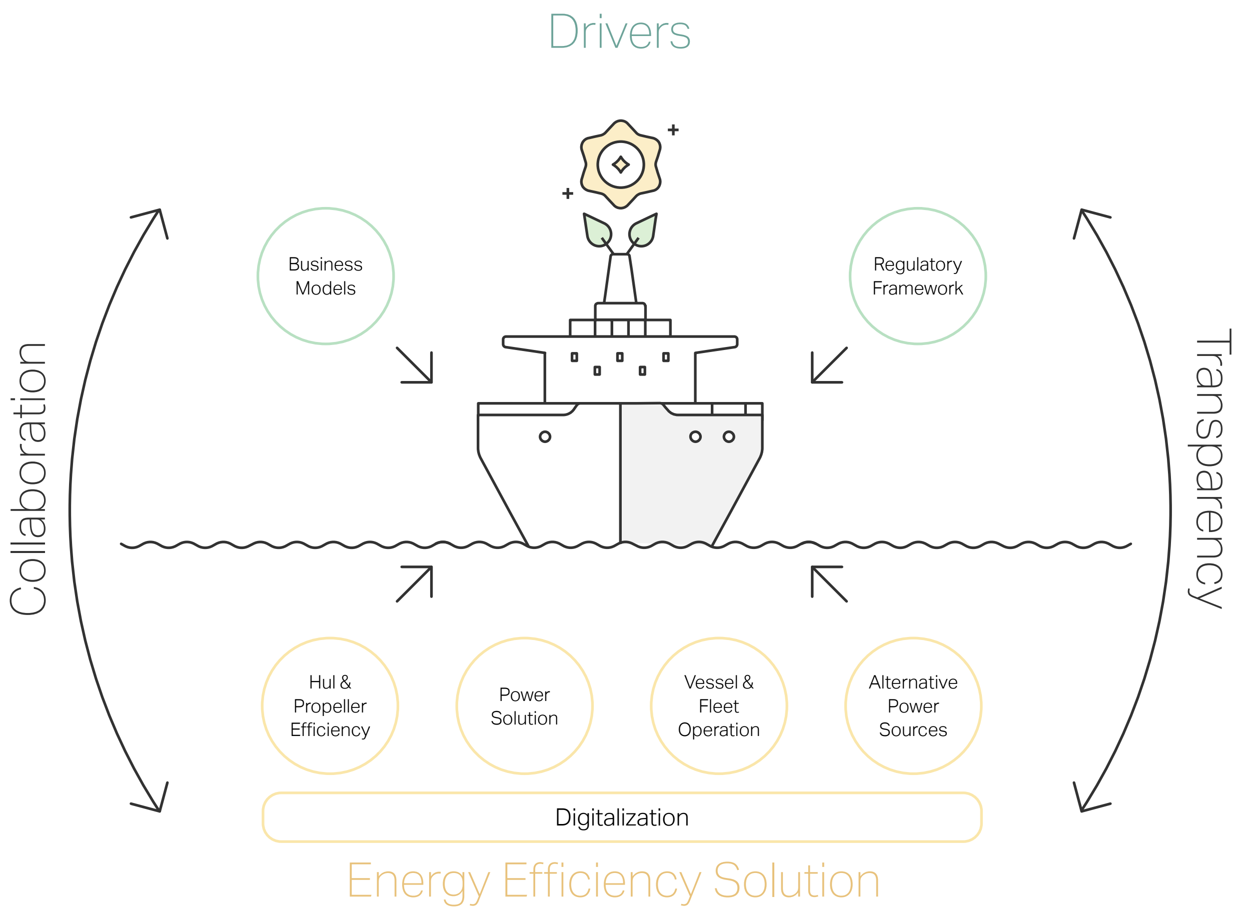
Overcoming barriers with new collaborative business models based on transparency

Currently, energy efficiency uptake is driven by cost reductions and increasing commercial competitiveness. As a result, to maintain their competitive advantage, companies are unwilling to exchange technical and operational best practices around energy efficiency. Optimizing energy efficiency across the global fleet will require a mindset shift from individualistic cost leadership to collaborative environmental leadership and accountability, resulting in shared visions and new business models.

Our dedicated energy efficiency working group is continuing to explore how new collaborative business models might look. Examples could include equipment leasing with performance guarantees or pooling vessels into larger fleets to maximize utilization.

Multi-stakeholder collaboration and transparency will be paramount to driving new, environmentally-led business models. Such collaborations are likely to rely on obtaining and sharing quantitative data that make the impacts of energy efficiency solutions and operational decisions visible to all stakeholders. This would allow performance monitoring and benchmarking, paving the way for sharing savings.

Data sharing (for example, emissions reporting in an environmental, social, and corporate governance (ESG) context, as explained in Chapter 4) would also enable data-driven dialogue with third-party stakeholders (such as ports and terminals) about the impacts of their decisions on onboard emissions. Digitalization will be vital in enabling data-driven collaboration and dialogue. A robust digital infrastructure onboard and on-land would promote transparency, provide data security, enable continuous improvement of processes and underlying technologies, and allow regulators to develop data-driven compliance requirements.



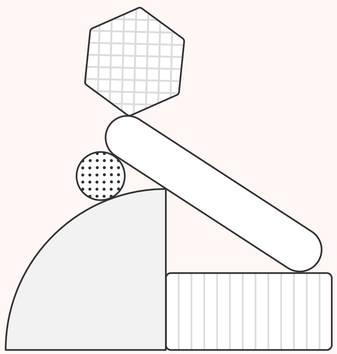
The cruise ship industry provides a good example of how effective collaboration can maximize energy efficiency uptake. Cruise ships are among the most complex vessels, requiring highly customized and integrated solutions. Building cruise ships requires close cooperation between owners, shipyards, technology, and original equipment manufacturers. The complex network of stakeholders involved in cruise ship design and construction can make it difficult to maintain a common drive toward maximal energy efficiency. To solve this dilemma, one owner has developed a simple energy efficiency benchmarking index and an associated reward/penalty mechanism for the shipyard according to the ship's performance. The reward mechanism creates a shared incentive for the cruise company and shipyard to measure the vessel's performance and ensure maximal efficiency post-delivery. Furthermore, it necessitates transparent data sharing and close engagement between shore teams, onboard crew, shipyard, and technology vendors. Sharing knowledge, best practices, and continuous feedback improves the vessel's energy efficiency and ensures that later sister vessels can achieve even higher standards. It also provides feedback to the shipyard and technology vendors who can use this knowledge to improve future ship designs and energy efficiency solutions.

Increasing energy efficiency is an immediate obligation for the entire industry

Shipowners and operators can apply a host of solutions to increase energy efficiency today. Utilizing these measures will immediately reduce emissions and help break the maritime emissions curve while alternative fuel pathways continue to develop. Energy efficiency measures often provide savings in the long term, so they are a no-regret move that the industry should treat as an immediate necessity. Various commercial and technical barriers are currently limiting uptake. However, we can overcome these barriers with clear regulatory action and new collaborative business models based on transparent data sharing.

Key actions by 2030

- Shipowners and operators must take **immediate action** to **increase energy efficiency.** This should include installing energy efficiency technologies when dry-docking and asking for state-of-the-art designs when ordering new vessels.
- Businesses across the maritime value chain must develop **collaborative business models** driven by **transparency** to reduce emissions from ship operations.
- The industry must support the IMO in increasing their regulatory ambitions around energy efficiency.
- The IMO must provide **clear enforcement mechanisms, tighten compliance levels**, and find regulatory solutions for **sharing responsibility** among all those who influence vessel emissions.



03
Enabling Alternative Fuel Pathways

Mærsk Mc-Kinney Møller Center
for Zero Carbon Shipping

Enabling alternative fuel pathways

Transitioning from fossil fuels to alternative fuels will be vital in decarbonizing the shipping industry.

Today, the maritime industry is considering four main alternative fuel pathways: methane, methanol, ammonia, and bio-oils/e-diesel. Some maritime players are also considering hydrogen. However, there are several barriers to using hydrogen in deep-sea shipping, including its low volumetric energy density, resulting impact on deck and cargo space, high pressure and low temperature storage requirements, and flammability concerns. Therefore, we do not consider hydrogen a likely fuel choice for long-haul marine traffic, and we do not cover it in this report. Likewise, direct electrification is being considered by some maritime players. However, factors including the low energy densities of battery packs, large onboard space requirements, and high costs render electrification unviable for long-haul marine traffic. Alternative marine fuels can be delivered from various alternative feedstocks and production processes, as shown in Figure 2. Electro-fuels (also known as e-fuels) are produced with renewable electricity, blue fuels are produced from fossil feedstocks with carbon capture and storage, and biofuels are made from sustainable biomass and biowaste. Our analyses suggest that switching from low sulfur fuel oil (LSFO) to alternative fuels could reduce well-to-wake emissions by 80 to 100%.

This chapter discusses the status of the four major alternative fuel pathways, their challenges, and how current forecasts for fuel supplies and demand from the shipping industry compare. Finally, we identify how we can use alternative fuels to break the emissions curve this decade and how scaling up production can bring us closer to the Paris 1.5°C trajectory.

Alternative fuels

Alternative fuels can reduce GHG emissions by over

80%

compared with LSFO

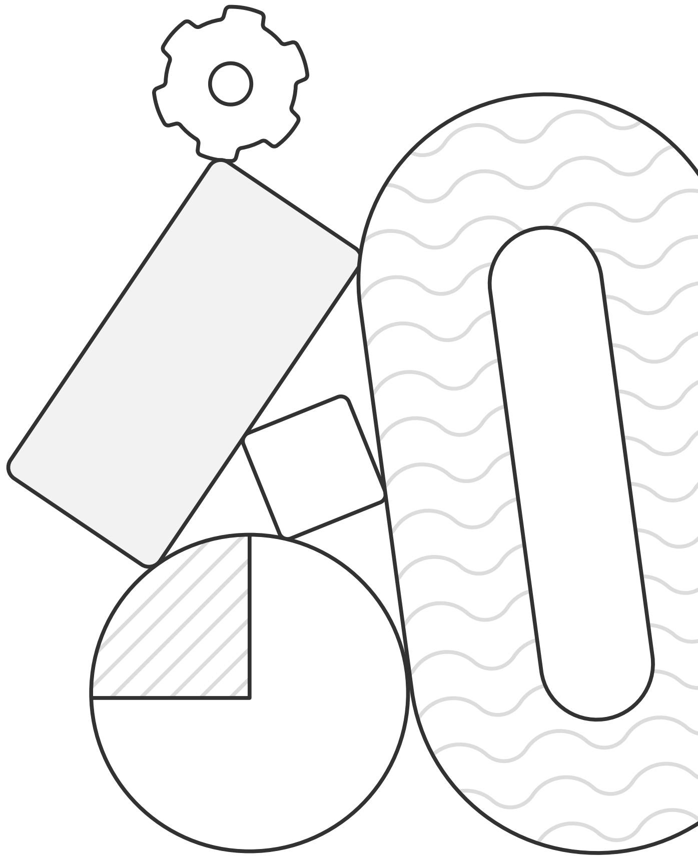
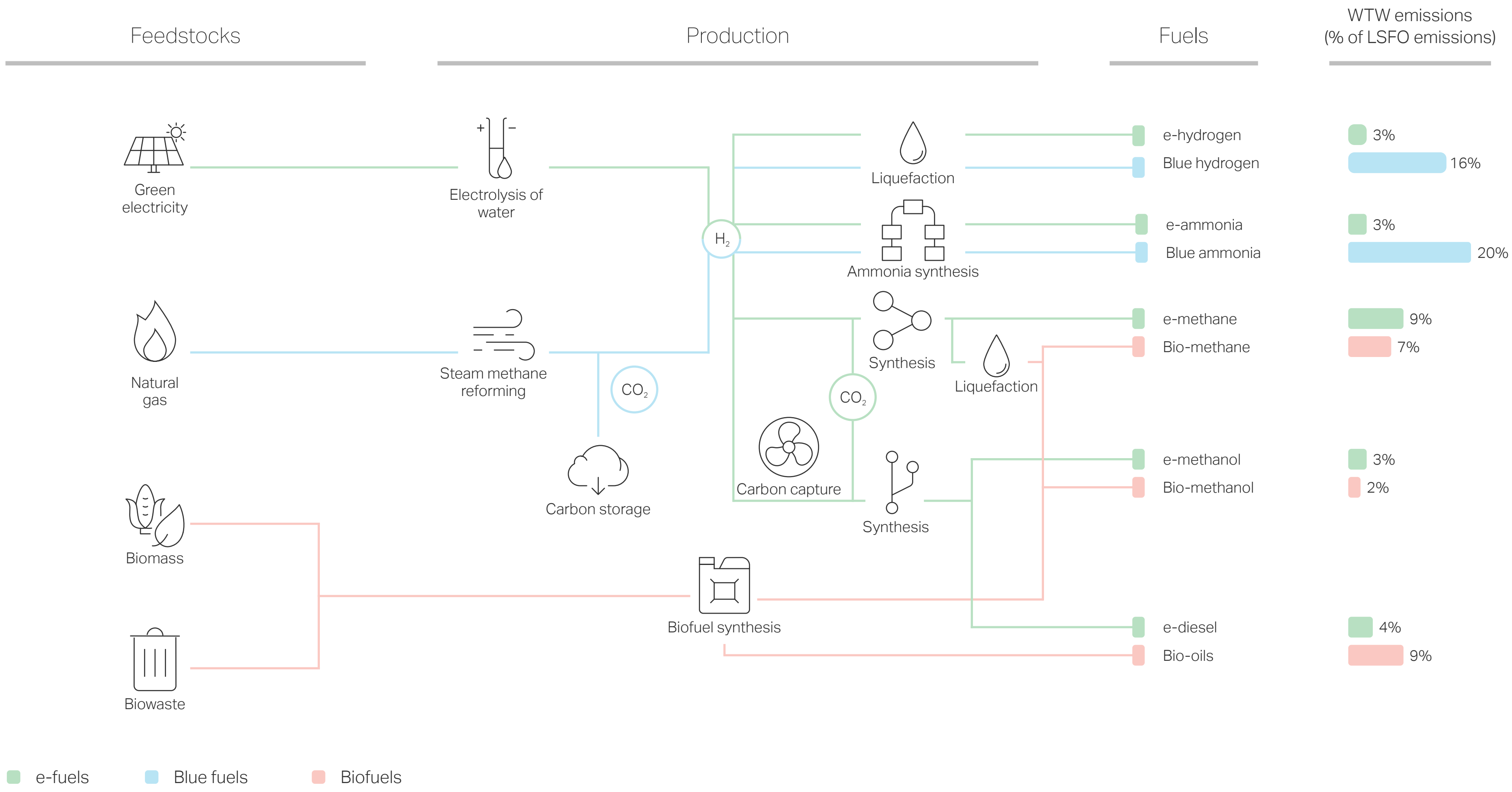


Figure 2: Alternative fuel production pathways in shipping.



Note: Only key processes are included; Methane slip in upstream production processes of blue ammonia and bio-methane are factored into emissions estimations based on the technology maturity levels forecasted for 2030. Emissions are well-to-wake emissions as a percentage of LSFO emissions of 93gCO_2eq /MJ in 2030. Data source: NavigaTE, MMMCZCS.

How mature are alternative fuel pathways?

Due to feedstock availability and technology limitations, no single alternative fuel can fulfill demand from the entire maritime industry in the short term. As a result, we expect the fuel landscape to utilize a mix of alternative fuels over the coming decades. To realize industry-wide decarbonization, we must enable **all alternative fuel pathways**. This means for each fuel, we must:

- Ensure onboard and environmental safety
- Develop regulatory frameworks to enable and steer deployment
- Achieve the required technological readiness for fuel production and vessel operation
- Scale up infrastructure and operations along the supply chain, including production, logistics, storage, and bunkering
- Close the cost gap with fossil fuels to make them commercially attractive

All the alternative fuel pathways are at different stages of maturity. The Fuel Pathway Maturity Map in Figure 3 presents an overview of the readiness at each step in the maritime industry value chain for the four major alternative fuel pathways. You can find an interactive version of the maturity map on our website. As Figure 3 shows, some areas are mature and well-developed, but none of the pathways are free from barriers across all value chain steps.

Figure 3: Fuel Pathway Maturity Map.[16]

	Feedstock availability	Fuel production	Fuel storage, logistics & bunkering	Onboard energy storage & fuel conversion	Onboard safety & 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
e-diesel	Solutions identified	Solutions identified	Mature	Mature	Mature	Mature	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

16 Fuel Pathway Maturity Map, MMMCZCS

Methane is the most mature alternative fuel pathway. Bio-methane is commercially available today, though production is dispersed. It is unclear how much bio-methane will be available to the maritime industry and whether feedstock availability will limit overall supply (see next section for more detail). e-methane production will rely on developing biogenic CO_2 capture projects and increasing green hydrogen availability. Bunkering infrastructure and onboard technology for methane are also mature, thanks to the growth of LNG-fueled vessels.

Methanol is a more mature option than ammonia. However, green methanol availability is currently extremely limited, at around 110,000 t/year. Like methane, carbon feedstock availability may limit future production (see next section for more detail). Although methanol bunkering has been demonstrated, it is not yet established at large-scale. However, we foresee no major barriers to developing bunkering capabilities. Methanol is a liquid fuel at ambient temperatures, making it relatively easy to store and handle onboard. Onboard methanol technology is mature, with 10+ years of experience. As a result, the orderbook for methanol is growing quickly, and we expect retrofitting to be possible from 2024.

There is growing interest in ammonia as a fuel. However, as Figure 3 shows, the ammonia fuel pathways are the least mature. No green or blue ammonia is being produced today, although a few plants are under construction. Ammonia is a commodity chemical and is already stored close to cities and ports, bunkering ammonia may increase the risk of exposure, and we need to develop safety regimes to mitigate these risks. Furthermore, onboard safety and technology are still developing (see later in this chapter for more detail), with engine technology expected in 2025.

e-diesel may also have a role in the transition as either pilot fuel or as a preferred alternative for owners operating legacy single-fuel vessels. The technology is mature and scalable and, as a result, looks promising in Figure 3. However, we expect e-diesel will be expensive and face significant competition from other segments. Therefore, we do not foresee that e-diesel will play a significant role in decarbonizing shipping. Bio-oils produced by hydrothermal liquefaction or fast pyrolysis are also suitable substitutes for conventional fuel oil. However, their scale-up potential depends on hydrothermal liquefaction and fast pyrolysis commercialization. Furthermore, sustainable biomass[17] availability and cross-sector competition may limit bio-oil supply (see next section for more detail). We do not expect bio-oils to play a key role in the shipping industry.

In the following sections, we outline the major challenges faced by methane, methanol, and ammonia, as the main candidates for alternative fuels in the shipping industry.

17 Defined as biomass that has been cultivated and/or sourced from a system of agricultural practices aimed at fulfilling the relevant ecological, economic, and social functions of the land used to cultivate the biomass.

Bio-methane and bio-methanol may face extensive cross-sector competition

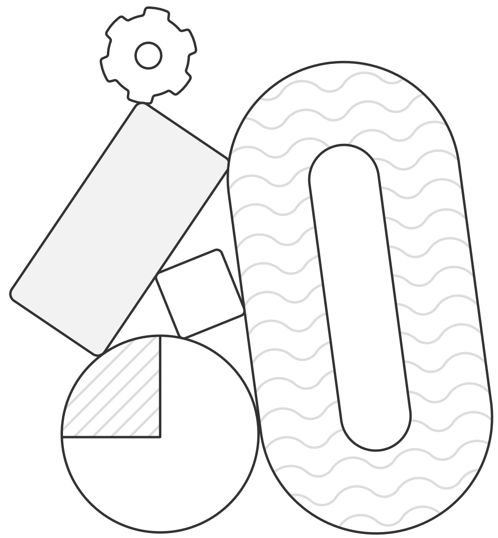
Biofuels, including bio-methanol and bio-methane, are promising alternative fuels that can offer significant emissions reductions compared with LSFO on a well-to-wake basis. However, biofuel producers must use sustainable biomass to avoid creating new ESG problems while reducing emissions. How much sustainable biomass will be available to the shipping industry in the coming decades for producing bio-methane and bio-methanol remains unclear.

Determining the sustainability of biomass for industrial uses is a complex yet central issue for ensuring biofuels deliver the intended environmental performance. Natural ecosystems remove CO_2 from the atmosphere, so damaging these ecosystems by harvesting biomass for fuels is counter-productive from a climate perspective. As a result, we must carefully balance biomass harvesting with natural regeneration rates. Protecting biodiversity, using sustainable processing methods, carefully considering land-use changes and social impacts, and taking care not to divert biomass from food supply chains must also be managed to ensure biomass sustainability. Lifecycle analysis approaches can clarify the sustainability of biomass feedstocks. However, common frameworks are still under development (see Chapter 4 for more details). This means interpretations of sustainable biomass remain highly subjective, and potential supplies are difficult to estimate.

Ongoing work on frameworks and certification programs for sustainable biomass shows that sustainability requirements from regulatory bodies are getting stricter over time as understanding of biological cycles, biodiversity, and ecosystems continues to mature. These increasing demands mean that our forecasts of the potential global availability of sustainable biomass are becoming progressively less optimistic. Early estimations were bold, with some as high as 300 EJ/year, but current assessments have consolidated around 50-100 EJ/year.[18,19]

While supply forecasts for biomass have continued to decrease, demand projections remain high. According to estimations based on a roundtable with key stakeholders from the materials energy sectors, the global demand for biomass will be between 190 and 430 EJ/year by 2050. The greatest demands are expected to come from the plastic industry (100-200 EJ/year), construction (30-40 EJ/year), and industrial manufacturing (20-40 EJ/year). The expected demand from shipping varies from 0-10 EJ/year, with shipping expecting up to 80% of its total energy will come from sustainable biomass at the highest range of the estimate.

Comparing supply and demand projections (Figure 4) suggests that significant cross-sector competition for sustainable biomass may limit the scaling potential for biofuels in the shipping industry.



18 Biomass in the EU Green Deal, Institute for European Environmental Policy, 2021.
19 Biomass availability and sector competition, Henrik Wenzel, University of Southern Denmark, 2022.

Figure 4: Expected sustainable biomass supply vs. expected demand from global energy and materials sectors in 2050.[17,18]

Bio-methane could be an attractive option for first movers because it is commercially available today and could significantly reduce emissions. Furthermore, bio-methanol is also promising due to its emissions profile and technological readiness for use onboard. Maritime regulators and the industry should therefore work to improve the certification of biofuels for marine use.

Companies who wish to use bio-methane or bio-methanol should carefully weigh their pros and cons. Although bio-methane is available, production is decentralized, uncertificated, and not coupled with liquefaction. As a result, obtaining bio-methane for use as a marine fuel may be challenging. Furthermore, cross-sector competition may increase prices as demand outstrips supply. However, individual companies or conglomerates could protect themselves from price increases by securing long-term contracts with fuel suppliers, building close upstream integration, acquiring feedstock-producing assets, using less upgraded fuels, or acquiring fuels produced in less accessible zones.

We must address fugitive methane emissions and methane slip

Although tackling CO_2 emissions is key to limiting climate impact, the IPCC has also highlighted the effects of other greenhouse gases like methane.[20] Methane has a global warming potential more than 28 times higher than CO_2 over 100 years.[21] Estimates suggest that methane emissions have caused approximately 0.5°C of warming since pre-industrial times.[22] Furthermore, The Global Methane Pledge, signed at COP26, commits signatory countries to reduce their methane emissions by at least 30% by 2030 compared with 2020.[23] As a result, for methane-based fuels to form a part of the future fuel landscape in shipping, we must identify sources of methane emissions, determine acceptable levels, and address fugitive emissions in the supply chain and slip onboard vessels.

Methane has caused approximately

0.5°C

of **global warming** since pre-industrial times

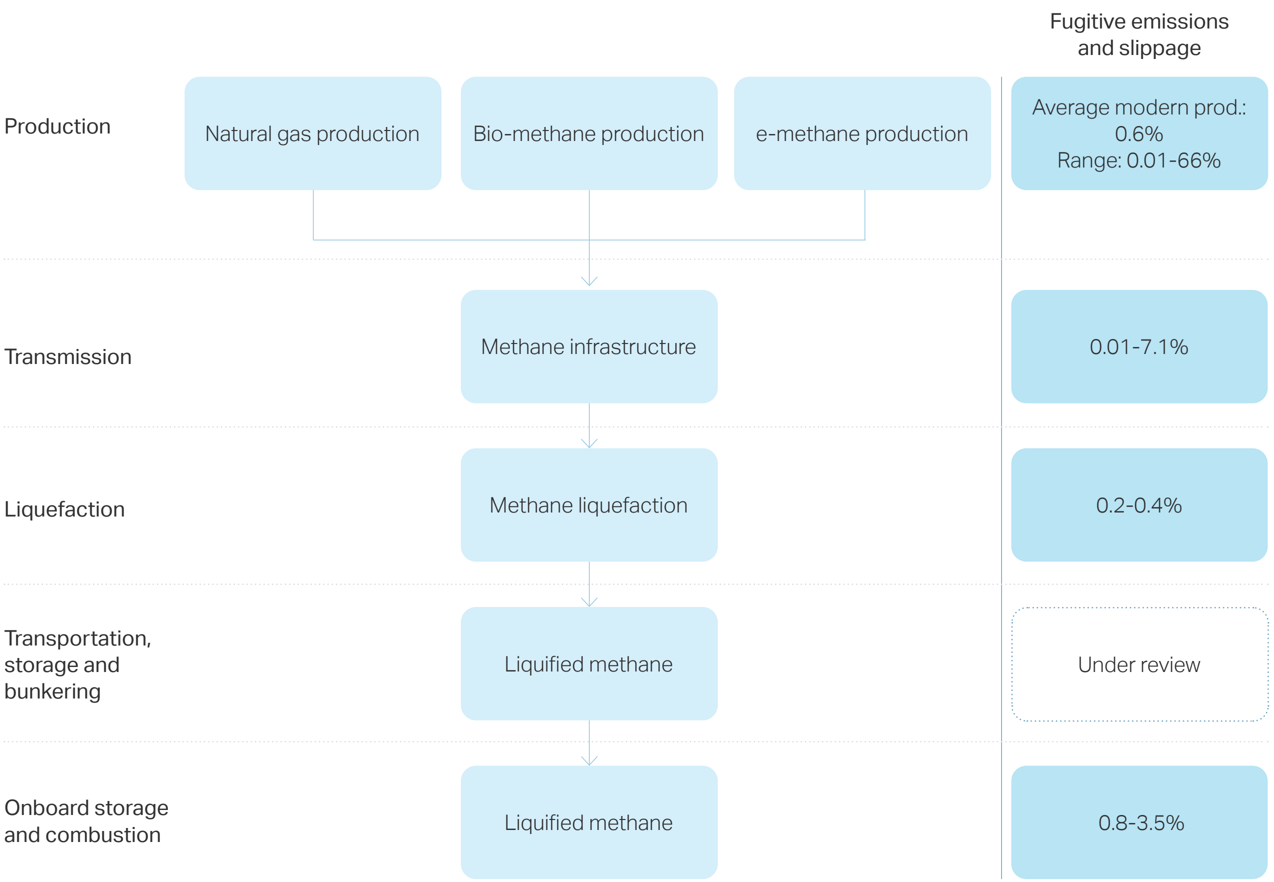
Methane emissions occur throughout the supply chains of all methane-based fuels, as shown in Figure 5. In addition to onboard emissions and methane slip, there are potential sources of significant on-land fugitive emissions from methane supply chains. These emissions highlight the need to consider all GHG emissions of marine fuel production and use from a well-to-wake perspective, rather than concentrating on only CO_2 and tank-to-wake emissions (see Chapter 4 for more detail).

Some fugitive emissions from fuel production are scheduled, for example as part of maintenance programs, and some are accidental, for example, in the case of ruptures. They may be constant, as in a leak, or sporadic – for example, from a pressure relief valve. Methane production plants can effectively reduce fugitive emissions by adopting good practices, including frequent measurements, selecting gas-tight equipment and materials, and developing contingency plans to prevent leaks during maintenance. Newer biogas plants that have adopted these measures have significantly reduced their fugitive methane emissions to as low as 0.01%.[24]

Monitoring fugitive emissions can be challenging. While plants can measure ground-level emissions on small sites with handheld devices, they need drones, helicopters, or airplanes to monitor emissions at heights, and satellites to survey emissions from large sites. The cost of such measurements makes continuous monitoring prohibitive, and as a result, site managers typically measure emissions in campaigns. Although quantifying fugitive methane emissions on-land is challenging, technologies and standards used in the oil and gas industry (for LNG) could be transferred to methane-based alternative fuel production to grade fuels and production facilities. Still, we need effective regulation to drive the uptake of these standards and ensure best practices are transferred from the best-performing plants to the rest of the industry.

20 Control methane to slow global warming — fast, Nature, 2021
21 Global Warming Potential Values, Greenhouse Gas Protocol.
22 Climate Change 2021: The Physical Science Basis, IPCC, 2021
23 Global Methane Pledge, European Commission, United States of America, 2021.
24 Greenhouse gas and methane intensities along Equinor's Norwegian gas value chain, Equinor, 2021.

Figure 5: Methane emissions across the LNG, biomethane, and e-methane supply chains.



Sources: MMMCZCS data, IPCC, literature data, interviews with supply chain actors, partner data, Reducing methane emissions onboard vessel, MMMCZCS, 2022, Greenhouse gas and methane intensities along Equinor's Norwegian gas value chain, Equinor, 2021, Alana K Ayasse et al. 2022 Environ. Res. Lett. 17 084039, Yu Gan et al 2020 Nat. Comms. 11:824.

The IMO's fourth GHG study[25] showed that although the use of LNG as a marine fuel only increased by 28% between 2012 and 2018, methane emissions rose by 150%, demonstrating that methane emissions are poorly controlled and rapidly growing. The total onboard methane emissions of a vessel depend highly on its operations, system dimensioning, machinery configurations, and connected technologies. However, the main source of methane emissions onboard is methane slip from main and auxiliary internal combustion engines. Methane slip typically occurs due to partial methane combustion or methane gas flowing directly through the exhaust valve during gas admission.[26]

Our recent study[27] showed that cost-efficient onboard vessel methane emission reduction is possible (see Table 4).[28] For the vessels studied, emission reduction technologies can reduce onboard methane emissions by 40-80% for a newbuild and 20-50% for an existing vessel. While it is technically feasible to further reduce methane emissions beyond these levels, it may be more cost-efficient to look at other options, such as changing fuel. Although effective methane emission reduction technologies provide opportunities for shipowners who want to reduce their environmental impact, their uptake is currently limited, likely because existing regulations don't encourage their use.

25 Fourth IMO GHG Study 2020, IMO, 2020.
26 See Reducing methane emissions onboard vessels, for more details about the causes of methane slip and fugitive emissions onboard.
27 Reducing methane emissions onboard vessels, MMMCZCS, 2022.
28 'Cost-efficient' was defined as an abatement cost less than about 200 USD/tCO_2eq (which is assumed to be the approximate abatement cost for using biomethane).

Table 4: Methane emission reduction technologies and their representative abatement costs.

Emission reduction category	Emission reduction technology/solution	Representative abatement cost (USD/tCO_2eq)
Engine technology	Exhaust gas recirculation	25-50
	High pressure injection	Engine technology development and implementation is driven by engine designers and integrated directly into the latest engines.
	Engine tuning & control software	
	Component design optimization	
After-treatment technology	Methane oxidation catalyst	75-175
	Plasma reduction technology	200-275
System solutions	Shaft generator	-50-25
	Shore power	150-250

Methane emission reduction technologies and their representative abatement costs based on a techno-economic analysis of an LR2 tanker and LNG carrier with different engine types.
Source: MMMCZCS data, see 'Reducing methane emissions onboard vessels' report for more details.[26] LNG fuel price is estimated to be 610 USD/t.

Strong incentives and regulatory requirements to reduce methane emissions would encourage fuel producers and shipowners to adopt methane emission reduction solutions both on-land and onboard. Fortunately, methane emissions are already an area of focus for regulators. There are ongoing discussions at the IMO about including methane in life cycle assessment methodologies using a CO_2-equivalent approach like FuelEU Maritime.[29] Methane could also be regulated more directly using a vessel's technical file, similar to NO_x emissions. Such regulations could directly target methane slip onboard and offer significant emissions reductions.

Given the environmental and regulatory risks, shipowners choosing methane as a fuel should follow best practices, install fuel and engine systems with minimum slip, and onboard methane emission reduction technologies as soon as possible. This will improve the emissions profile of their vessels and allow them to avoid potentially costly modifications later in the vessel's lifetime when future methane regulations come into force.

29 FuelEU Maritime, European Economic and Social Committee, 2021.

Technology and safety are key to realizing ammonia fuel pathways

Although ammonia is already widely manufactured and used across sectors, it is the least mature alternative marine fuel, as reflected in the Fuel Pathway Maturity Map in Figure 3. Ammonia is a promising marine fuel because it does not require carbon for production and does not generate CO_2 under combustion. It is produced from nitrogen and hydrogen, with the hydrogen coming from electrolysis in the case of e-ammonia or fossil fuels in the case of grey and blue ammonia (see deep dive box).

The first hurdle for ammonia is that the technologies required to use it onboard, including internal combustion engines and boilers, are not ready yet. Engine manufacturers expect ammonia engines to be ready for commercial application in 2025.[30] As the engines are not yet ready, the emissions profile of ammonia is uncertain. However, we expect ammonia internal combustion engines will produce N_2O, a GHG with a global warming potential nearly 300 times greater than CO_2 over 100 years.[31] As a result, emission reduction technologies may also need to be developed or optimized in parallel with ammonia engines.

To prepare to scale up the implementation of ammonia as a marine fuel this decade, we must accelerate technological developments. However, we must do so without compromising safety and reliability by employing strong risk-based change management approaches. Acceleration will involve conducting steps that are typically conducted sequentially in parallel. This includes maturing multiple engine types in tandem rather than gaining experience on first vessels, creating retrofitting kits for multiple engine sizes and types in parallel, and placing orders without mature and proven fuel pathways. We must build new ammonia-fueled vessels as quickly as possible and prepare to convert ships to ammonia fuel by expanding shipyard and/or engineering capacity.

Ammonia, which is highly toxic, also introduces risks for safety and the environment. Although ports and operators already handle ammonia as a commodity chemical for global trading purposes, using it as a fuel exposes crew and port personnel to increased safety risks. As a result, we must develop good practices and safety infrastructure before deploying ammonia as a marine fuel.

There are currently no prescriptive rules for using ammonia as a fuel, so shipowners must use a risk-based alternative design process to gain approval from flag states. To ensure maximum scaling, prescriptive rules, including IMO guidelines, updates to the International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels (IGF Code) and International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) should be in place as soon as possible (see Chapter 4). To be ready for scaling by the end of this decade, we must prepare regulations, standards, and safety guidelines while technology is still under development.

30 According to MAN Energy Solutions.
31 Global Warming Potential Values, Greenhouse Gas Protocol.

Deep dive:

From grey to blue ammonia

Most ammonia manufactured today is grey ammonia, produced from nitrogen from air and hydrogen derived from natural gas steam reforming or coal gasification. As a result, its production generates significant GHG emissions (Figure 7).

Blue ammonia (Figure 6) offers significant emissions reductions compared with LSFO. The price and availability of renewable electricity may mean vessels have to run on blue ammonia early in the transition while renewable electricity supplies scale up, availability increases, and prices drop.

To generate blue ammonia, producers must capture and store all CO_2 produced during ammonia synthesis, and limit methane leaks. However, capturing CO_2 from steam methane reforming (SMR) is prohibitively expensive because 1/3 of the natural gas is burned outside the process feed (see 'SMR heating' in Figure 7).

Auto thermal reforming could allow plants to decrease emissions and produce blue ammonia. It confines more than 90% of the carbon within the stream instead of burning some externally, making it easier to capture. It is a proven technology, and there have already been several announcements about large blue ammonia plants that plan to use it.

Blue ammonia plants must store the CO_2 they capture using sequestration. Safe, effective practices for CO_2 storage are well established, but are not current common practice. Policymakers must regulate and certify safe, permanent CO_2 storage and incentivize its uptake with measures such as carbon crediting. CO_2 storage is already high on the agenda of national decarbonization strategies, with the US among the most advanced. There, Environmental Protection Agency (EPA) certifications and increasing carbon credits has led to multiple announcements related to blue ammonia plants planned for this decade.

Many producers are already making these improvements, and blue ammonia production is expected to increase over the coming decades (see Figure 8 for more details).

Figure 6: Blue ammonia production process

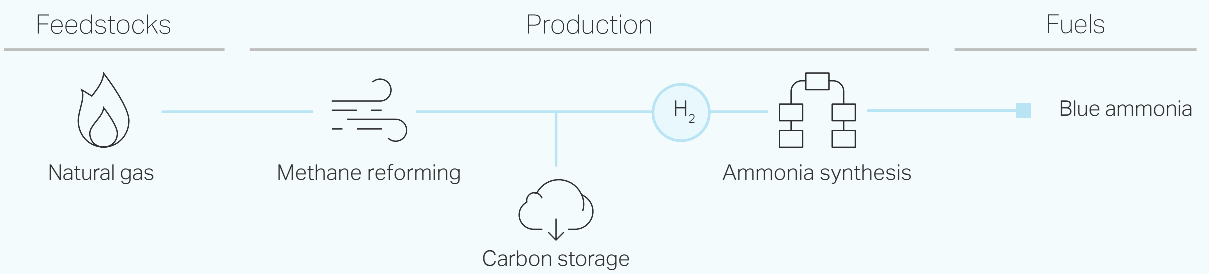
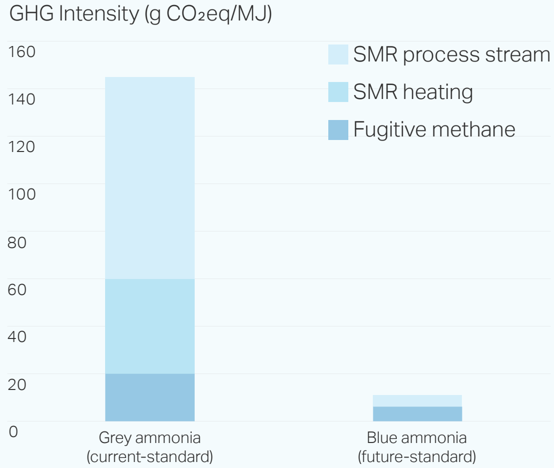


Figure 7: GHG emissions from grey ammonia and blue ammonia. Source: NavigaTE, MMMCZCS.



Demand for dual-fueled vessels is increasing

Vessels sailing on alternative fuels will be a key part of reducing our reliance on fossil fuels. The green box below provides an illustrative example of how many vessels must sail on alternative fuels to reduce our fossil fuel consumption by 1 EJ. Despite the ongoing uncertainty about future fuels, shipowners have continued to signal their willingness to invest in alternative fuel technologies by ordering dual-fuel vessels or preparing newbuilds for conversion later in their lifetime. In 2022 (Jan-Sep), almost 60% of all newbuild orders by tonnage were for dual-fuel vessels.

Hundreds of methane dual-fuel vessels are now operating commercially, representing around 3% of the global propulsion power.[33] This is driven by an increase in LNG use, so it is unlikely to reduce emissions significantly. Still, these vessels could switch to bio-methane or e-methane when they become widely available, or convert to ammonia fuel more easily. For more details about converting methane vessels to ammonia, see our recent publication, 'Preparing Container Vessels for Conversion to Green Fuels.'[34]

LNG dominates the contracted capacity for dual-fuel vessels, but methanol dual-fuel orders and interest in retrofitting existing ships for methanol is growing rapidly. Methanol dual-fuel vessels represent around 1% of propulsion installed globally.[35] Methanol vessels benefit from proven safety, operational frameworks, and marine engine reliability. Ammonia dual-fuel orders remain pending until the technology is ready (see the previous section).[36]

Dual-fuel vessels provide flexibility that allows vessels to operate on conventional fossil fuels like LSFO or LNG until alternative fuels become available, are less expensive, or are needed for regulatory compliance. This flexibility can help reduce regulatory compliance risk and costs associated with investing in unproven fuels. However, owning a dual-fuel vessel doesn't automatically translate to running on green fuel or reducing emissions. For vessel owners and operators to sail on alternative fuels, they must be both available at scale and cost-competitive, which is not the case today.

What will it take to replace 1 EJ of fossil fuels using alternative fuels onboard?

To replace 1 EJ of fossil fuel, the number of vessels sailing on alternative fuels must increase from around 700 today to approximately

3,000

by 2030, including:

Over 300 bulk carriers

Around 1,300 container vessels

Nearly 200 tankers

33 NavigaTE, MMMCZCS.
34 Preparing Container Vessels for Conversion to Green Fuels, MMMCZCS, 2022.
35 NavigaTE, MMMCZCS.
36 Green Technology Uptake, Clarksons, Oct 2022

Scaling up alternative fuel capacities is a huge challenge. The green box to the right shows the drastic action required to produce just 1 EJ of each alternative fuel. However, aligning with the Paris 1.5°C trajectory means we must decrease the shipping industry's reliance on fossil fuels from 12.6 EJ down to about 6 EJ by 2030, which will require more than just 1 EJ of alternative fuel.

In 2022

60%

of newbuild orders were for
dual-fueled vessels

What will it take to produce 1EJ of each alternative fuel by 2030?

Alternative fuel type	Capacity in millions of tonnes per year required for 1 EJ of each fuel	Production required to produce 1EJ of fuel	Assumed plant size	How can we put this into perspective?
e-hydrogen	8	50 (GW) electrolysis	-	**20%** of all the world's announced electrolyzer projects with targeted completion by 2030 would need to be dedicated specifically to shipping
Blue hydrogen	8	53 SMRs	~200,000 Nm^3/hr SMR capacity	Would require 90 million tonnes of CO_2 storage, **2x** the global annual capacity for CO_2 storage today
Bio-methane	20	1,120 plants	~25 million Nm^3/yr	Equivalent to **2/3** of all current production of biogas produced in the world today (including all sectors)
e-methane	20	320 plants	~8.75 million Nm^3/yr	**2** times more methane than used by shipping today as LNG
Bio-methanol	50	480 plants	~105,000 t/yr	Equivalent to **50%** of all current production of grey methanol produced in the world today (including all sectors)
e-methanol	50	426 plants	~120,000 t/yr	Requires 70 million tonnes of biogenic CO_2 feedstock, more than **5x** the CO_2 produced by the Drax biomass power plant.[37]
Bio-oils	25	400 plants	~65,000 t/yr	Needs more than **10x** the global biomass feedstock available today
e-diesel	25	500 plants	~50,000 t/yr	This is **~75%** the amount of synthetic petroleum produced globally today from coal or natural gas feedstocks
Blue ammonia	50	48 plants	~1.1 million t/yr	Equivalent to **20%** of all current production of grey ammonia produced in the world today (including all sectors)
e-ammonia	50	63 plants	~840,000 t/yr	More than **5x** the potential annual e-ammonia production of the Asian Renewable Energy Hub[38]

Source: MMMCZCS data and analysis.

37 Innovating for a positive future, Drax, 2022
38 Renewable energy hub in Australia, bp.

There is a disconnect between alternative fuel demand and planned supply

The increase in dual-fueled vessels is increasing demand for alternative fuels from the maritime industry. Figure 8 shows the expected demand for the other major alternative fuels, methanol, and ammonia, from the maritime industry between 2022 and 2040, according to an analysis by MAN Energy Solutions.

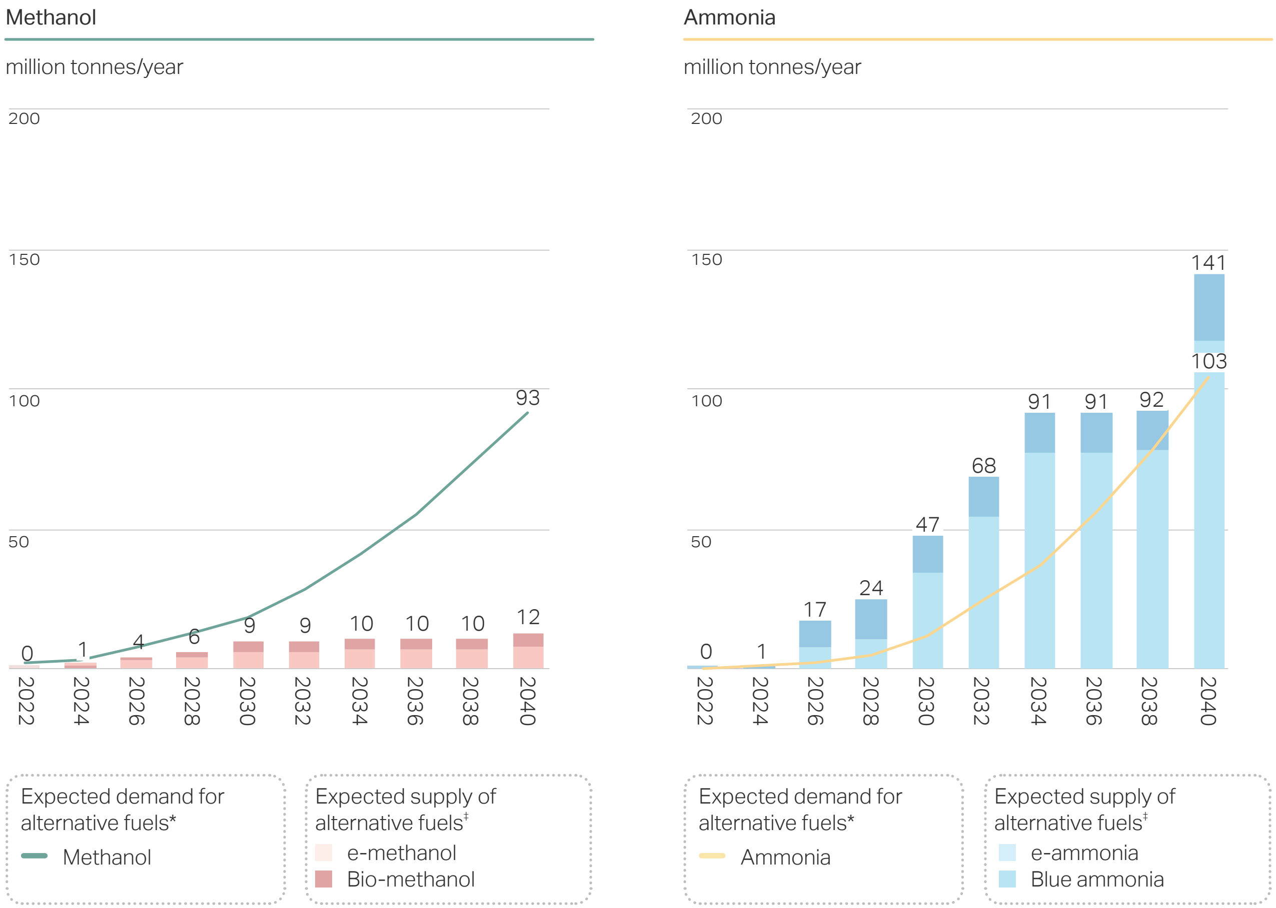
Announcements about projects developing alternative fuel capacity have been plentiful. Figure 8 also shows the expected cumulative supply of alternative fuels between 2022 and 2040 based on the announced production capacity. However, it's important to note that all the announced projects are in early development and have not yet completed feasibility assessments. It's unlikely that all the announcements will translate into fuel production. Historically, 2-4 plants (ammonia and methanol combined) have reached a final investment decision each year. Expected project timelines may be speculative and ambitious, with potential delays from local and national regulatory procedures and constraints around engineering, procurement, and construction contracting. As a result, the number of plants that reach production may be lower than forecasted.

Figure 8 suggests that alternative fuel supplies will be sufficient in 2030. However, sector competition may result in a significant under-supply. Furthermore, there is a disconnect between the available fuel mix and the demand for different fuels, with methanol supplies particularly limited. In the following decade, projected supplies will be unable to meet the total demand, with a yearly shortfall of up to 20 million tonnes of alternative fuels. Furthermore, although the outlook indicates there will be a surplus of ammonia, methanol demand may outstrip supply by up to 80 million tonnes.

It is clear that shipping is currently investing more in alternative fuel technology than fuel producers will be able to supply. This disconnect is partly because on-land investments in production infrastructure are much larger and riskier than investments in onboard technologies for alternative fuels. As a result, vessels with dual-fuel capabilities will continue to operate on conventional fuels for the foreseeable future.

Significant measures must be taken today to scale up fuel production and resist supply falling further behind demand. This includes incentivizing first movers in alternative fuel production, developing policies to ensure increased demand for alternative fuels, using an innovative blending of public and private capital to swiftly close gaps related to technology or fuel costs, and engaging in partnerships to better commercialize operations (see more details in Chapters 4 and 5).

Figure 8: Expected alternative methanol and ammonia demand from the shipping industry based on orders of ships and industry's own indication of future investments vs. their expected global supply based on announced project development plans between 2022 and 2040.



*Source: MAN Energy Solutions, Shipping en route to Paris Agreement Overshoot, 2022
‡Source: Cumulative global production capacity based on announcements aggregated by MMMCZCS. Announced production is not targeted to shipping industry.

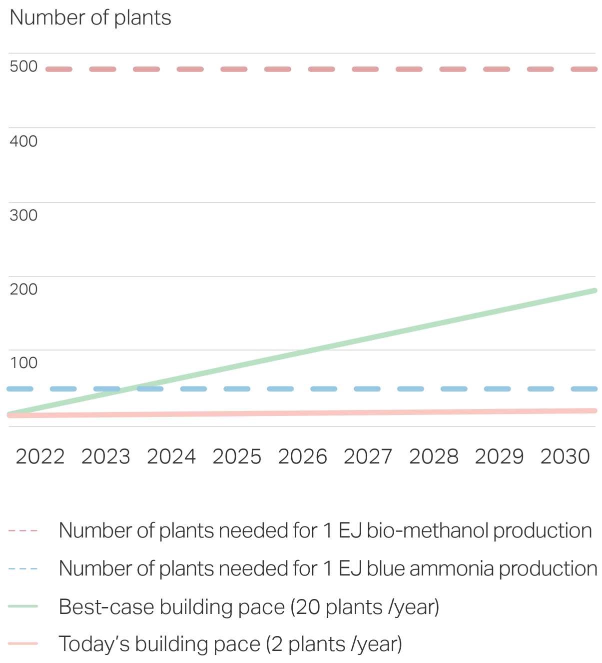
Engineering capacity may limit scale up

Engineering, procurement, and construction (EPC) companies are responsible for delivering large-scale petrochemical engineering and construction projects worldwide. They deliver projects in the oil and gas industry, the power sector, and "smaller" industrial projects such as ammonia and methanol plants. However, most of the world's relevant EPC capacity is currently tied to the oil and gas industry.

Estimates and forecasts made by major EPC suppliers indicate that the global capacity to build methanol and ammonia plants in the next few years is limited to approximately 1-2 plants per year for each fuel type.[39] If EPC resources can be shifted from other segments, this could increase to 10-20 plants annually, with current restraints including experience, know-how, and restrictions set by licensors and EPC alliances. However, replacing 1 EJ of shipping's energy demand with alternative fuel production would require approximately 50 million tonnes of annual production capacity. This translates to about 50 large-size blue ammonia plants or 480 bio-methanol factories. As the industry today demands 12.6 EJ of energy each year, the real need is likely to be much greater than the 1EJ example illustrated, indicating a significant shortfall in EPC capacity (see the box "what will it take to replace 1 EJ of fossil fuel with alternative fuels" and Figure 9).

Meeting the demand for alternative fuels will rely on significant investments in re-training, upskilling, and attracting new talent to the engineering design, production, and construction sectors this decade. If capacity in the oil and gas industry could be down-prioritized and current project pipelines re-purposed towards building alternative fuel facilities, EPC supplies could execute hundreds of ammonia and methanol projects each year. However, this would require a significant change of strategy by oil and gas, possibly driven by a strong regulatory push supported by detailed roadmaps.

Figure 9: Forecasted cumulative number of ammonia and methanol plants.



39 Based on EPC expert (on ammonia and methanol) interviews in Q2-Q3 2022.

Reducing the cost of alternative fuels will rely on the economy of scale

Currently, alternative fuels are much more expensive than fossil fuels. We must close the cost gap to enable a transition to alternative fuels. Conventional wisdom suggests that the biggest fuel production plants will be the cheapest because of the economies of scale. Alternative fuel production can realize these cost reductions by increasing plant size, number, and efficiency, which may help reduce the cost gap with fossil fuels.

The largest cost reductions from scale up will be for e-fuels as they use renewable energy and water as their feedstocks, which are not likely to be globally limited in the same way as biomass. Furthermore, their production relies on chemical processes with standardized modular elements that are easier to scale. Although the economy of scale may also drive cost improvements for bio-methane and bio-methanol, this will require a radically different approach as they are typically small, decentralized plants.

Figure 10 illustrates how increasing production volumes, mass, standardized production, and efficiency improvements could reduce future e-methanol production costs. Increasing facility size will have the largest cost-reduction effect, with gains achieved by using larger equipment for methanol synthesis, upgrading, and carbon capture units, thereby lowering the capital investments per production volume. This will also reduce fixed operating expenses, such as labor, consumables, leases, and insurance.

Mass manufacturing, standardization, and replication will also bring down costs. This will be particularly evident for e-fuels, when electrolyzer technologies can be scaled up using standardized, parallel units, and improved electrolyzers reduce electricity demand. Although the economy of scale will help to reduce the cost gap between fossil and alternative fuels, we will still require GHG pricing to make alternative fuels cost-competitive (see Chapter 4 for more details).

Figure 10: CapEx cost development for e-methanol production (index, 2025-2040).

Calculation made for e-methanol production considering a 100 tonnes per day production plant in 2025 and a 1,000 tonnes per day production plant in 2040 and adapting the projected capital cost reductions of electrolyzers and their efficiency improvements, while capital cost of mature technologies, including methanol synthesis, upgrading, and carbon capture is only adjusted for the effect of plant size. For both cases, a similar loan-based payment with constant payment and constant interest rate was considered assuming 30 years lifetime and 7% weighted average cost of capital.

We need urgent action to enable alternative fuel pathways

Technological developments around alternative fuels are progressing, but they are currently only available at small scale and high cost. For industry-wide decarbonization to become a reality, we must overcome the barriers highlighted in this chapter that are preventing alternative fuel scale up and widespread application. Executing the critical actions for methane, methanol, and ammonia in Figure 11 will allow the industry to move swiftly from ambition to implementation and scale-up, so alternative fuels can play a wider role in decarbonization. Across the industry, work towards these critical actions is already underway. Still, we must increase our efforts to be ready for scaling at the end of this decade.

Methane is the most mature alternative marine fuel today from production, supply chain, and onboard use perspectives. Transitioning from LNG to bio-methane or e-methane would allow existing vessels, onboard operations, and infrastructure to be used while reducing emissions. Regulations and frameworks considering well-to-wake emissions could drive this switch. However, fuel producers, shipowners, and operators must address methane emissions onboard and from upstream fuel production using available technologies and standards. Furthermore, regulatory bodies must develop regulations demanding methane emission control.

Methanol is also used in commercial shipping operations today. However, current global methanol production is mostly based on fossil fuels, resulting in grey methanol which should not be used as an alternative fuel in the maritime industry as it has a worse emissions profile than traditional LSFO. Switching to bio-or e-methanol would provide significant emissions reductions. On-going work to prepare bunkering procedures, safety guidelines, fuel specifications, and standards and a global framework to quantify well-to-wake emissions will enable more widespread application of methanol as a fuel and should be completed by 2025.

Ammonia is not used as a marine fuel yet and is the least mature alternative fuel pathway. Technologies for using ammonia onboard are in development, and infrastructure needs are currently being evaluated. For the ammonia pathway to be ready to scale by the end of this decade, many actions will have to happen simultaneously. The industry must mature and prove ammonia as a marine fuel while establishing global safety standards, well-to-wake emissions tracking frameworks, fuel specifications, and standards by 2025. This will help to shorten the time between the first ammonia-fueled vessel put on water and industrial-scale adoption in the global fleet.

When these critical milestones have been achieved, the industry can and should prepare for the scale-up challenge. Enabling and scaling alternative fuels in the shipping industry is a significant challenge, but it is achievable – if we start now.

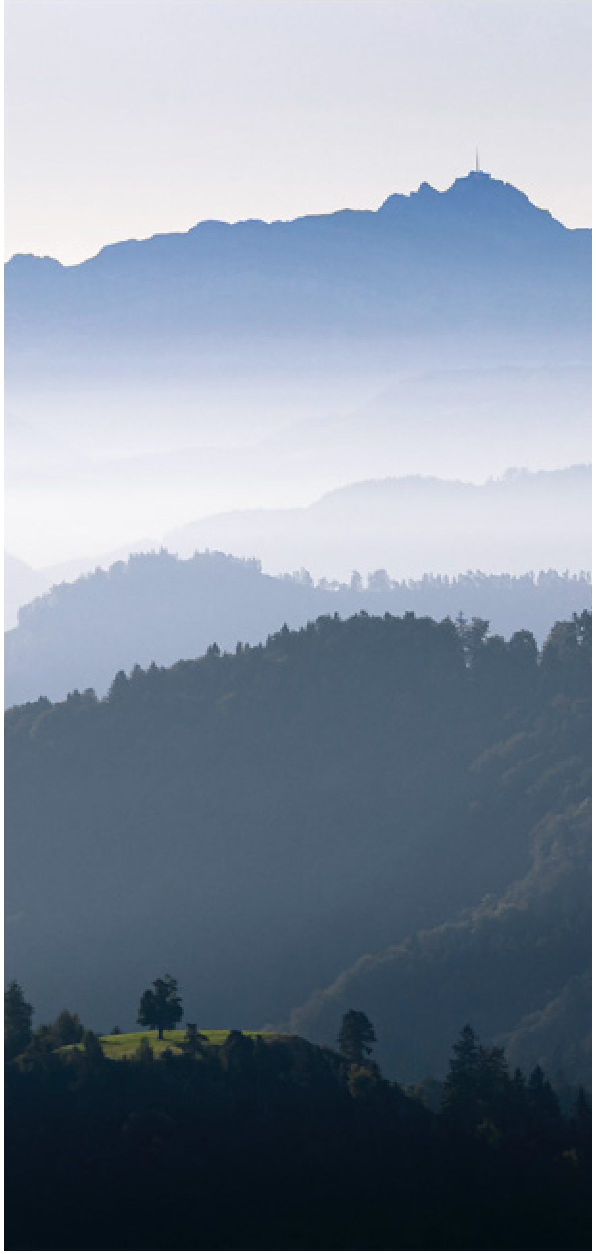


Figure 11: Critical actions needed this decade to enable all alternative fuel pathways.

		2023	2024	2025	2026	2027	2028	2029	2030
Methanol	Fuel production, bunkering and logistics	- Fuel specification and certification established for bio-methanol - Bunkering procedures & safety guidelines available	- WTW emissions quantified and agreed for bio-methanol		Scale				
	Onboard fuel consumption and emissions management	- Methanol engines (2, 4 stroke) w. diff. power ratings commercially available		- IGF Code for methanol ready					
Methane	Fuel production, bunkering and logistics	- Grading and certification of production fugitive emissions in place	- Fugitive emission targets agreed - WTW emissions quantified and agreed for bio-methane	- Enforcement of agreed emission targets					
	Onboard fuel consumption and emissions management	- Validation of the approach to measure realistic operational methane emissions - Methane slip reduction solutions validated by classification societies	Enforcement of agreed emission targets						
Ammonia	Fuel production, bunkering and logistics	- Permanent sequestration of individual CO_2 storage fields verified and approved	- Bunkering operational & safety guidelines established and demonstrated - Build-out of bunkering infrastructure on major ports	- Global standards of verification and approval for CO_2 storage fields signed off by IMO		Demonstrate			
	Onboard fuel consumption and emissions management	- Safety guidelines for ammonia fuel ships ready - Bunkering vessel design ready	- Ammonia engines commercially available	- First ammonia vessel on water	- IGF code for ammonia ready				

Key actions by 2030

Over the next five years, the industry must focus on enabling all alternative fuel pathways by:

- Achieving technological readiness for alternative fuel production and vessel operations.
- Developing regulatory standards to unlock use of alternative fuels.
- Ensuring uncompromised safety onboard and on-land for bunkering and operation on alternative fuels.

To be ready to scale up alternative fuels this decade, the industry must:

- Address the mismatch between planned alternative fuel production supply and demand.
- Build infrastructure and establish competencies that can support scaling of all alternative pathways.
- Make alternative fuel pathways commercially attractive by closing the cost gap with fossil fuels.

04
Promoting Abatement Action with Regulation, Policy, and Commitments

Mærsk Mc-Kinney Møller Center
for Zero Carbon Shipping

Promoting abatement action with regulation, policy, and commitments

Ambitious voluntary actions, commitments, targets, and regulations can stimulate decarbonization and bring us closer to the Paris 1.5°C trajectory.

After the IPCC released its special report in 2018, the IMO adopted its first strategy for reducing emissions from shipping.[40] The strategy committed to "reduce the total annual GHG emissions by at least 50% by 2050 compared with 2008, while, at the same time, pursuing efforts towards phasing them out entirely."

Since 2018, the IPCC has released more reports calling for policymakers to make proactive decisions and the private sector to implement net zero commitments.[41] Although IMO targets have, so far, remained unchanged, several member states are working towards strengthening the targets in 2023 at MEPC 80.

This chapter outlines why the IMO and the whole shipping industry must set more ambitious targets. It also discusses important considerations for setting targets and developing supportive global regulations.

Commitments from shipowners are not enough

As the IMO's strategy falls short of IPCC demands, the maritime industry has relied on more ambitious pledges and commitments from individual companies to drive decarbonization. During spring 2022, we investigated the role of these pledges in reducing emissions. We analyzed decarbonization pledges made by the top 30 shipowners in the container, bulk, tanker, and roll-on/roll-off (RORO)/car segments in financial reports, sustainability reports, ESG information available on home pages or public statements.[42]

At the time of the analysis, 12 companies had a public net zero target by 2050 or earlier. Now, that number has increased to 16, indicating a growing ambition to accelerate decarbonization efforts. Shipowners are taking action to reduce emissions and they are embracing the opportunity to drive innovation, increase competitiveness, and stimulate resilient growth. However, if all the announced net zero pledges materialize, this will only translate to a 13% reduction in global emissions in 2050 (Figure 12).

40 Cutting GHG emissions from shipping - 10 years of mandatory rules, IMO, 2021
41 Climate Change 2022: Impacts, Adaption and Vulnerability, IPCC, 2022.
42 Ready, Set, Decarbonize! MMMCZCS, 2022.

Figure 12: Decarbonization targets from the top 30 shipowners in the tanker, bulk, container, and RORO/car segments and their potential impact on global maritime emissions.

	Share of global maritime CO_2eq emissions, (WTW, 2020)	Top-30's owned share of global fleet, % (DWT)	Pledges made by top-30 companies in each segment, % (DWT): Net zero 2050 pledge	IMO pledge	No IMO or net zero pledge	2050 reduction potential from net zero pledges, % of global emissions
Tanker	22%	41%	17%	31%	52%	~2%
Bulk	19%	32%	22%	32%	46%	~1%
Container	23%	87%	44%	37%	19%	~9%
RORO/Car	5%	78%	24%	46%	30%	~1%

Net zero 2050 pledge IMO pledge No IMO or net zero pledge

If all the largest owners made net zero pledges and worked to make them a reality, the emission abatement impact could be significant, amounting to up to a 40% reduction by 2050. However, the number of commitments is currently too small as, worryingly, not all the top companies have set targets. Furthermore, the number of targets is growing too slowly. And even if all the leading shipowners made commitments, this still would not decarbonize the entire industry or align with the Paris 1.5°C trajectory.

Although inspiring and impactful, the leading shipowners' combined actions are not enough to transform the industry. We need more ambitious emission abatement targets from the IMO and clear regulations that secure action across the shipping sector. Furthermore, to achieve the changes that need to happen in energy efficiency uptake, alternative fuel production and usage, regulations must be in place quickly and drive progress over the next 5 to 10 years as we transition to a green economy.

Global targets must align with the Paris 1.5°C trajectory

As discussed in Chapter 1, the maritime industry is currently a long way from aligning with the Paris 1.5°C trajectory. Accelerating the transition to come closer to the trajectory will require a combination of significant technology development and supporting their uptake with regulation. As demonstrated by the currently limited uptake of energy efficiency measures outlined in Chapter 2, technology availability alone does not ensure implementation. We must set demanding targets to drive change.

The IMO must target a

45%

reduction in emissions **by 2030** compared with 2010 and

net zero

by 2050

In 2023, the IMO will revise its emission reduction targets, providing a window of opportunity to increase ambitions and signal unambiguous long-term intent. To align with the Paris 1.5°C trajectory, the IMO must target eliminating all GHG emissions from the shipping industry, reaching net zero by 2050. Major economies, including the US, the EU, and China, have already committed to net zero emissions from shipping by mid-century.[43,44,45] These targets could inspire similar goals for the IMO and provide the basis for developing roadmaps to achieve the targets set.

Revised emissions targets for 2050 must be accompanied by

interim targets

for **2030** and **2040**

A revised target for 2050 must be accompanied by interim targets, for example, for 2030 and 2040. To align with the Paris 1.5°C trajectory, the IMO should target a 45% reduction in emissions by 2030. Furthermore, to avoid misinterpretation, interim targets should use a 2010 baseline (used by IPCC) rather than the 2008 baseline currently used by the IMO.

However, simply adjusting the target will not drive the changes needed in the industry. The IMO must swiftly mirror revised targets in existing and forthcoming regulations. Alignment to a steeper decarbonization curve will require catalytic policy action around technology innovation, implementation, and operational practices as soon as this decade. Furthermore, the IMO must leverage improved transparency, emission monitoring, and reporting to support regulatory enforcement. Ideally, this should include publicly accessible data pinpointing when and where emissions happen, their sources, and how large they are.

Revising our long-term and short-term targets to mirror the Paris 1.5°C trajectory and supporting them with clear and effective regulations would show determination and unite the global shipping industry with shared ambitions. What's more, it would reduce policy risks and create the certainty needed for large-scale investments.

43 The Long-Term Strategy Of The United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050, United States Department of State and the United States Executive Office of the President, 2021.
44 Reducing emissions from the shipping sector, European Commission.
45 According to a speech by Chinese President, Xi Jinping, China is aiming to reach carbon neutrality by 2060.

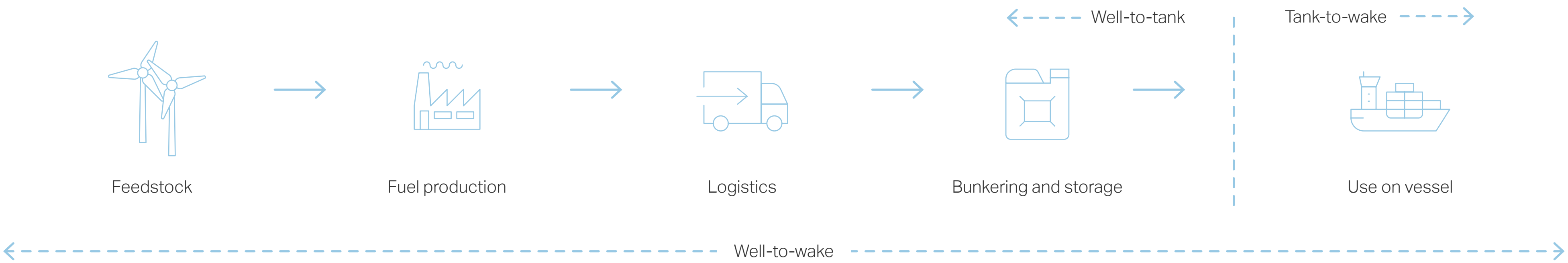
Regulations must consider all GHG emissions from a well-to-wake perspective

Today, emissions tracking and regulation baselines vary across the existing targets, regulations, and guidelines. For example, IMO regulations largely focus on operational CO_2 emissions from shipping (tank-to-wake), while the EU is proposing a mix of tank-to-wake and well-to-wake regulations in their "Fit-for 55" package,[46] including regulating CO_2 emissions from a tank-to-wake perspective in their European Emissions Trading System[47] and all GHG emissions from a well-to-wake perspective in FuelEU Maritime.[48]

To avoid replacing CO_2 emissions with gases with greater global warming potentials, such as methane or N_2O (see Chapter 3 for more detail), we must include all GHG emissions in our tracking, targets, and regulations. Furthermore, we must consider the effects of GHG emissions from a well-to-wake perspective.

Well-to-wake is a simplified methodology that builds on conventional life cycle assessment (LCA) (see deep dive box) and is well suited to policy and regulations. It considers emissions from the entire fuel lifecycle, from energy harnessing (from, for example, wind, solar, or biomass) to producing fuels and using them onboard. Tank-to-wake, on the other hand, only includes emissions from onboard use (see Figure 13).

Figure 13: Well-to-wake, well-to-tank, and tank-to-wake emissions.



46 Fir for 55, European Council, 2022.
47 EU Emissions Trading System (EU ETS), European Commission.
48 FuelEU Maritime, European Economic and Social Committee, 2021.

Deep dive:

Life cycle assessment

What is LCA?

Life cycle assessment (LCA) is a multi-step procedure for calculating the lifetime environmental impact of any product or service. The methodology is standardized and relies on ISO standards stipulating specific steps for goal and scope definition, inventory analysis, impact assessment, and interpretation.[49] LCA is a dynamic and iterative process that relies on continuously updating information and evaluating its applicability.

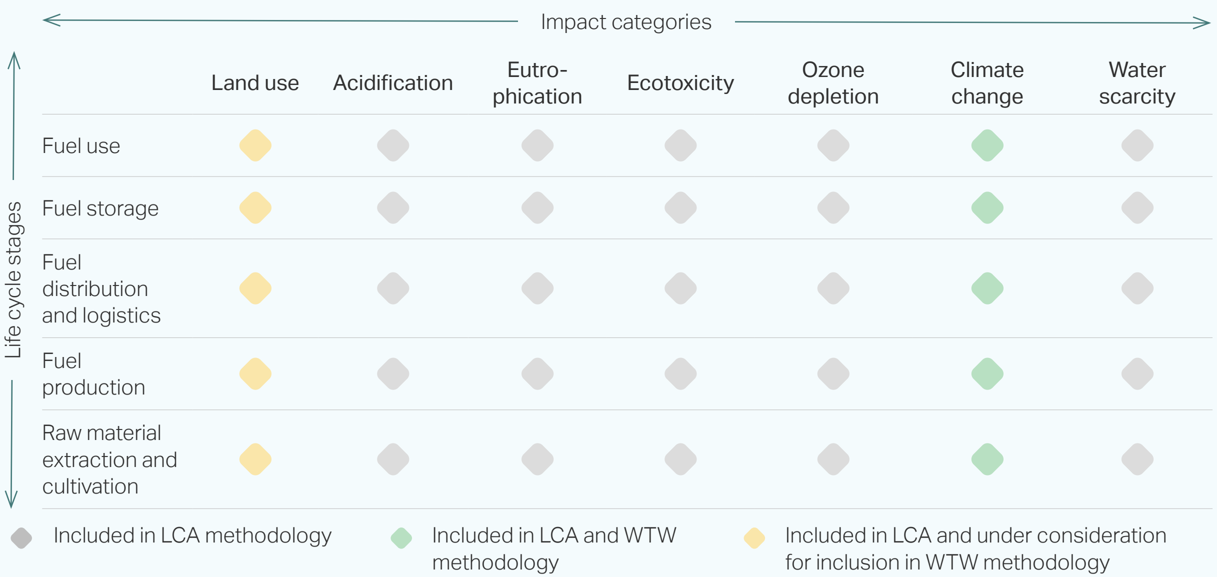
What is the difference between LCA and a well-to-wake approach?

Well-to-wake is a life cycle approach based on LCA principles, but with several key differences (see Figure 14). While well-to-wake includes emissions from entire fuel processes from harnessing energy (well) to fuel use onboard (wake), LCA methodology also incorporates material inputs and energy use. Unlike conventional LCA, well-to-wake is a non-standardized holistic approach focusing on quantifying the climate impact of energy used by the system to produce and use the fuel. As a result, It is a simplified, easy-to-use approach that is well suited for tracking decarbonization.

What roles will LCA and well-to-wake play in decarbonizing shipping?

Both tools have a role to play in decarbonizing shipping. The simplified well-to-wake methodology is easier to use and, therefore, more suited to policymaking. On the other hand, LCA is more suitable for "due care" analyses that go beyond compliance for understanding the potential environmental impacts of fuels and appropriate mitigation actions. For example, fuel producers should conduct LCA of their fuel portfolios to gather evidence to show that their fuels do not create any unintended environmental impacts.

Figure 14: Well-to-wake (WTW) and LCA approaches to understanding fuel emissions. Impact categories listed are non-exhaustive.

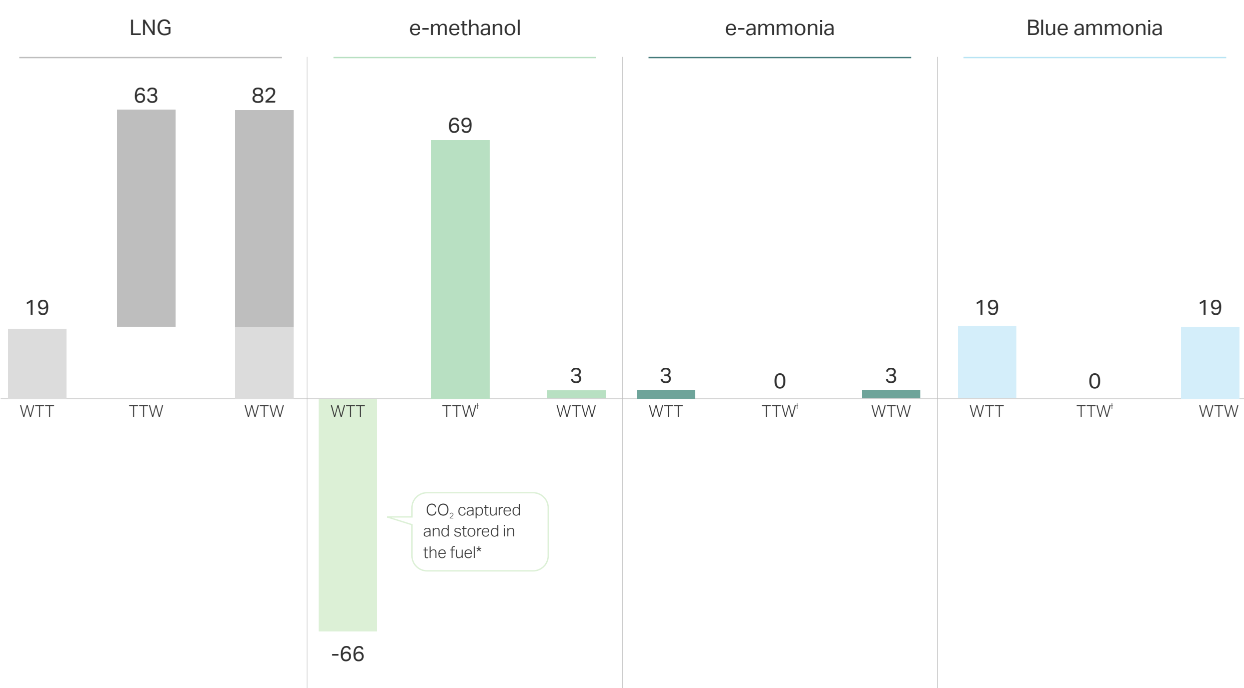


49 For more detail about impact categories see the International Reference Life Cycle Data System (ILCD) Handbook

If regulators, including the IMO, set targets taking a well-to-wake emissions perspective, the industry can ensure that alternative fuels deliver the climate performance needed and avoid shifting the burden of responsibility for emissions upstream to those producing fuels. Well-to-wake targets and regulations would also stimulate sustainable fuel production and consumption patterns, accelerating the transition.

Understanding the well-to-wake GHG emissions of different fuel pathways provides transparency and comparability between different fuels, which may not be obvious from a tank-to-wake or CO_2 only perspective. For example, as shown in Figure 15, from a tank-to-wake perspective, using LNG and e-methanol seem very similar, with emissions of 63 $kgCO_2eq/GJ$ and 69 $kgCO_2eq/GJ$, respectively. However, the upstream emissions from LNG and e-methanol are very different, with LNG producing 19 $kgCO_2eq/GJ$, while e-methanol production removes CO_2 from the atmosphere, resulting in negative emissions of -66 $kgCO_2eq/GJ$. As a result, the well-to-wake emissions from the two fuels are very different: 82$kgCO_2eq/GJ$ for LNG vs. 3 $kgCO_2eq/GJ$ for e-methanol. A regulation that took a tank-to-wake perspective might erroneously encourage more production and uptake of LNG than initially intended and punish carbon-based alternative fuels. There is a similar story for e-ammonia and blue ammonia, which look very similar from a tank-to-wake perspective, but different from a well-to-wake perspective (Figure 15).

Figure 15: Well-to-wake, well-to-tank, and tank-to-wake emissions.



Well-to-wake (WTW), well-to-tank (WTT), and tank-to-wake (TTW) emissions from LNG, e-methanol, e-ammonia, and blue ammonia. WTT, TTW, and WTW values are in $kgCO_2eq/GJ$.
* CO_2 captured using biogenic CO_2 or direct air capture.
ⱡ N_2O emissions assumed to be zero.
Source: NavigaTE, MMMCZCS. More information on WTW emissions of alternative fuels can be found in our 'NavigaTE well-to-wake position paper'.[50]

50 NavigaTE well-to-wake position paper, MMMCZCS, 2022

The IMO must use multiple supplementary indicators to ensure a stable transition

Tracking absolute emissions reflects changes in energy demand, increases in energy efficiency and uptake of alternative fuels, providing an overview of the progress of the transition. However, absolute emissions also reflect the impacts of commercial factors such as trade growth, operating speeds, the profitability of older fleets, and operational challenges (for example, port congestion). For instance, a temporary drop in shipped goods can reduce absolute emissions as seen during the COVID-19 pandemic. As a result, changes in absolute emissions may not accurately reflect the long-term transition. Using supplementary indicators such as emissions intensity and transport work efficiency in combination with absolute emissions targets could provide a better overview and ensure a more robust transition overall.

Emissions intensity targets would account for well-to-wake GHG emissions of the fuel per unit energy consumed, highlighting the impact of alternative fuels in the fleet. It is also unaffected by external factors such as the number of shipped goods and a change in average vessel speed. However, using emissions intensity targets alone does not provide an incentive to reduce the energy demand of the vessel by investing in energy efficiency technologies or reflect overall emissions reductions in the same way as absolute emissions, so it should not be used alone.

> Supplementary decarbonization indicators must support absolute emissions targets to ensure a robust transition

Similarly, transport work efficiency, measured in units of energy consumed per tonne of cargo carried over a nautical mile, captures the effects of energy efficiency measures on the overall energy consumed by a vessel or fleet. However, it doesn't consider the emissions from the fuel used and is, just like the absolute measure, impacted by factors such as trade development, ship size, speed, etc.

The IMO must use targets combining absolute emissions, emissions intensity, and transport work efficiency to ensure a stable, efficient transition. No measure alone can impact all the necessary aspects of the transition.

Today, the IMO complements their absolute emissions targets with targets for reducing carbon intensity, measured in CO_2 emissions per transport work, by at least 40% by 2030 and towards 70% by 2050 in comparison with 2008 levels. CII regulations support these targets (see Chapter 2 for more detail). Including supplementary targets for emissions intensity and transport work efficiency could provide complementing insights on the progress of the transition. The IMO can take inspiration from the FuelEU Maritime[51] and US Clean Shipping Act[52] to develop these new supplementary indicators.

51 FuelEU Maritime, European Economic and Social Committee, 2021.
52 H.R.8336 - Clean Shipping Act of 2022, Congress.Gov, 2022.

Global GHG pricing can drive the transition

Currently, alternative fuels are much more expensive than conventional fossil fuels. The cost gap between fossil and alternative fuels must be closed to support increased global ambition, de-risk decarbonization investments, and enable the transition. GHG pricing, in one form or another, is likely to be essential in closing the gap and enabling industry-wide abatement.

In 2015, the World Bank and OECD determined that "carbon pricing is necessary to bring down greenhouse gas emissions and lower climate risk."[53] Our modeling also shows that the IMO must implement a GHG pricing scheme this decade to maintain an ambition to align with the Paris 1.5°C trajectory. Furthermore, without global GHG pricing to close the cost gap, we risk being unable to reach net zero by 2050.

GHG pricing is a policy tool that aims to reduce CO_2 and other GHG emissions by placing a fee on emissions. It is also commonly called 'carbon pricing,' but it can, and should, include other GHG emissions; therefore, we use the name GHG pricing. GHG pricing can take many forms, including "polluter pays" schemes such as carbon tax, emissions trading systems, and credit mechanisms, or support schemes that encourage decarbonization through, for example, subsidies, enhanced CapEx depreciation rights, tax credits, and product support pricing. You can read more about the different options for GHG pricing and their advantages and disadvantages in our Options Paper on Market-Based Measures.[54]

The IMO should select a method that is well suited to the broader maritime policy environment, will encourage action in companies of all sizes, and, importantly, they can deploy as soon as possible. Furthermore, they must consider six essential areas as they develop a GHG pricing strategy:

- Transparency: Effective GHG pricing must be designed and executed transparently. Global emissions reporting would support this.

- Scope: GHG pricing will only affect the emission sources it applies to, so the broader the application, the fewer emitters can continue to pollute for free.

- Commercial effectiveness: In many cases, the gap between fossil and alternative fuels is still wide. The price of polluting needs to be high enough to encourage all alternative fuel pathways and increase the economic efficiency of reducing emissions.

- Stability: A stable and predictable policy framework will send a clear, consistent, and strong signal that GHG emissions must decrease and guide companies in their business decisions. Predictable, transparent GHG pricing from final investment decisions to production would also facilitate investments in infrastructure that will enable new fuel pathways. The use of price corridors, where regulators commit to keeping the GHG price within a certain range, could help maintain price predictability while allowing for flexibility and increasing price levels over time if needed.

- Alignment to other policies and objectives: GHG pricing is not a stand-alone mechanism. It should work in combination with decarbonization efforts and be effective across different countries, regions, states, and administrations.

- Just & equitable transition: Revenues from GHG pricing should be dedicated to supporting global climate financing and ensuring the entire world is included in the transition. In addition, some revenues should be dedicated to earmark & return schemes that will make alternative fuels and technologies more competitive than fossil fuel alternatives in the maritime industry.

53 The FASTER Principles for Successful Carbon Pricing: An approach based on initial experience, OECD and World Bank Group, 2015.
54 Options Paper on Market-Based Measures, MMMCZCS, 2021.

Rules and standards must support new fuels and technologies

The maritime industry is traditionally governed and guided by prescriptive rules and standards for ship design and operation. These rules increase safety and reliability while protecting the environment. However, new decarbonization technologies and alternative fuels with different chemical properties, such as low flash points, higher toxicity, instability, and non-compatibility, introduce operational uncertainties and risks, necessitating new rules and standards.

In our eagerness to transform, we must not compromise on safety, reliability, and environmental protection by overlooking the risks associated with new fuels and technologies. To maintain the same high safety, reliability, and environmental standards we have achieved in the maritime industry thus far, we must identify risks and develop proper safeguards rapidly. This will ensure a smooth transition with zero harm to people, assets, and the environment.

Initially, the industry will inevitably work through a risk-based approach while learning and demonstrating proper safeguards and practices. However, the sooner we can move towards a prescriptive regime with reliable frameworks for ship design, shipbuilding, ship operations, fuel standards, bunker management plans, human factor, training and competence guidelines, and safety management systems, the faster we can begin scaling and accelerating the transition. Professional risk methodologies and change management principles must be applied to design proper safety cases and frameworks that will enable regulators to rapidly revise rules, codes, guidelines, and standards.

In Table 5, we provide an overview of the maturity of maritime rules and standards for the major alternative fuels and technologies. As the table shows, class societies are well underway with developing new rules and guidelines. Furthermore, industry organizations and first mover ship operators, ship designers, shipyards, and port authorities are working through hazard identifications (HAZIDs), hazard and operability studies (HAZOP), and quantitative risk assessments (QRAs) to enable new solutions. However, many rules and standards are still interim drafts or need further development.

Many of these regulatory gaps are creating uncertainty and hesitation, preventing action. For example, technology developers and manufacturers are eagerly innovating the solutions of the future, but they need guidance about which standards may apply to their products and how they can ensure compliance. Fuel producers and vendors are unsure how future life cycle analysis and well-to-tank carbon accounting might apply to their fuels and which standards they will need to meet to demonstrate engine and onboard reliability, where ISO 8217 will no longer apply. Furthermore, ship operators are awaiting strong guidance on future well-to-wake accounting requirements and bunker note documentation and reporting.

To enable new fuels and technologies, we must ensure that rules and standards that support their use are in place by 2025 at the latest.

Table 5: Gap analysis of maritime rules and standards for alternative fuels and other technologies for decarbonizing vessel power or propulsion.

Maritime rules and standards	Fuels						Power/Propulsion technologies		
	Bio-fuels	Methane	Methanol	LPG	Ammonia	Hydrogen	Batteries	Fuel Cells	Wind
IMO Safety of Life at Sea (SOLAS), safety revision	[58] Interim draft, partial	Low flashpoint fuels are referenced in SOLAS and pointed to the IGF Code. However, the IGF doesn't cover all these fuels explicitly, refer to alternative design approach.					[57] To be further developed	To be further developed	To be further developed
IMO MARPOL, emissions and environmental impact revision	Interim draft, partial	Available	Available	Available	To be further developed	To be further developed	To be further developed	To be further developed	[59] Interim draft, partial
IMO IGF Code[60]	Firm need is debated	Available	Available in 2025	N/A	To be further developed	To be further developed	N/A	N/A	N/A
IMO IGC Code	[55] N/A	Available	Available	Available	Available	To be further developed	N/A	N/A	N/A
IMO Guidelines / Unified Interpretation / Circulars	Interim draft, partial	Interim draft, partial	Interim draft, partial	Interim draft, partial	To be further developed	Interim draft, partial	To be further developed	Interim draft, partial	Interim draft, partial
International Association of Classification Societies (IACS) Unified Requirements/Unified Interpretation	Interim draft, partial	Interim draft, partial	Interim draft, partial	Interim draft, partial	To be further developed	To be further developed	Interim draft, partial	To be further developed	To be further developed
Class Rules/Guidelines	Available	Available	Available	Available	Available	Available	Available	Available	Available
Bunkering Standards – generic (Society of International Gas, Tanker, and Terminal Operators (SIGTTO) , International Bunker Industry Association (IBIA), etc)	[58] Interim draft, partial	Available	To be further developed	To be further developed	To be further developed	To be further developed	N/A	N/A	N/A
ISO standards[56] Bunkering, fuel safety, fuel quality, sea trials	Interim draft, partial	Available	Interim draft, partial	Interim draft, partial	Interim draft, partial	Interim draft, partial	Interim draft, partial	Interim draft, partial	Interim draft, partial
LCA / WTW methodology standard	Interim draft, partial	Interim draft, partial	Interim draft, partial	Interim draft, partial	Interim draft, partial	Interim draft, partial	Interim draft, partial	Interim draft, partial	Interim draft, partial

Available Interim draft, partial To be further developed Firm need is debated Available in 2025 N/A

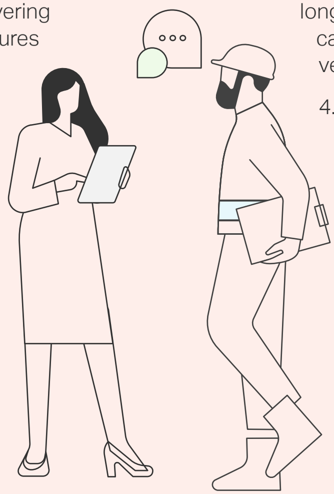
55 Fuels falling under this item may be considered as fully drop-in. May not need specific amendments
56 Many of these are from inland usage for some of these fuels or available for their fossil-based alternative that can be readily applicable for green versions of the same fuel
57 Covered for some considerations such as those involved in emergency power generation
58 Transferable from fossil fuels but not explicitly covered
59 A circular is available for EEDI and EEXI calculations, but it could be further improved
60 The objective is to have interim guidelines transposed eventually in the IGF code for low flashpoint fuels

Figure 16: Examples of how investors, lenders, customers, and cargo owners can use ESG reporting to engage in dialogue with shipowners and operators.

Investors and lenders

... can increase climate awareness and pressure by including six key climate considerations in lending decisions:

1. Publicly support stronger climate targets for international shipping
2. Reward shipowners that show commitment to reach net zero by 2050, and those with ambition to do it earlier
3. Request reporting of current and short-term adoption of interim emissions reduction targets consistent with long term goals – both covering fuel pathways and energy efficiency measures
4. Advocate for stronger abatement policies in IMO
5. Encourage provision of cargo-level emissions data for customers
6. Support the development of alternative fuel infrastructure developments and engage in green corridors



Cargo owners and customers

... can increase climate awareness and pressure if they adopt five key considerations in shipping and logistics decisions

1. Publicly support stronger climate targets for international shipping
2. Reflect own sustainability ambitions and scope 3 emission reduction targets accurately in procurement policies and decisions by including and rewarding climate performance
3. Request publication of information about short- and long-term emissions reductions and place cargos on the cleanest, most fuel-efficient vessels possible
4. Support the development of "green corridors", alternative fuel infrastructure and large-scale demonstration projects that can be accelerated or in other ways benefit from active involvement by customers and cargo owners.
5. Signal a willingness to pay more for zero-carbon shipping services beyond pilot- and demonstration phases

ESG reporting can amplify decarbonization efforts

For businesses, environmental, social, and governance (ESG) reporting is an increasingly critical component of their value propositions to stakeholders including investors, customers, and employees. ESG involves setting clear targets, developing roadmaps for meeting targets, and reporting progress. It, therefore, has the potential to drive climate action and more sustainable behavior, including reducing GHG emissions, by improving the reliability, comparability, and transparency of company ambitions and actions.

With the growing number of voluntary ESG frameworks and methodologies, the ESG reporting landscape has become increasingly complex to navigate. Today, there are at least 3,700 sustainability regulations globally, 67 guidance documents from stock exchanges, seven standards, seven ratings, and 16 frameworks all addressing ESG reporting.[61] As a result, assessing the credibility of ESG reports and making meaningful comparisons across companies is challenging.

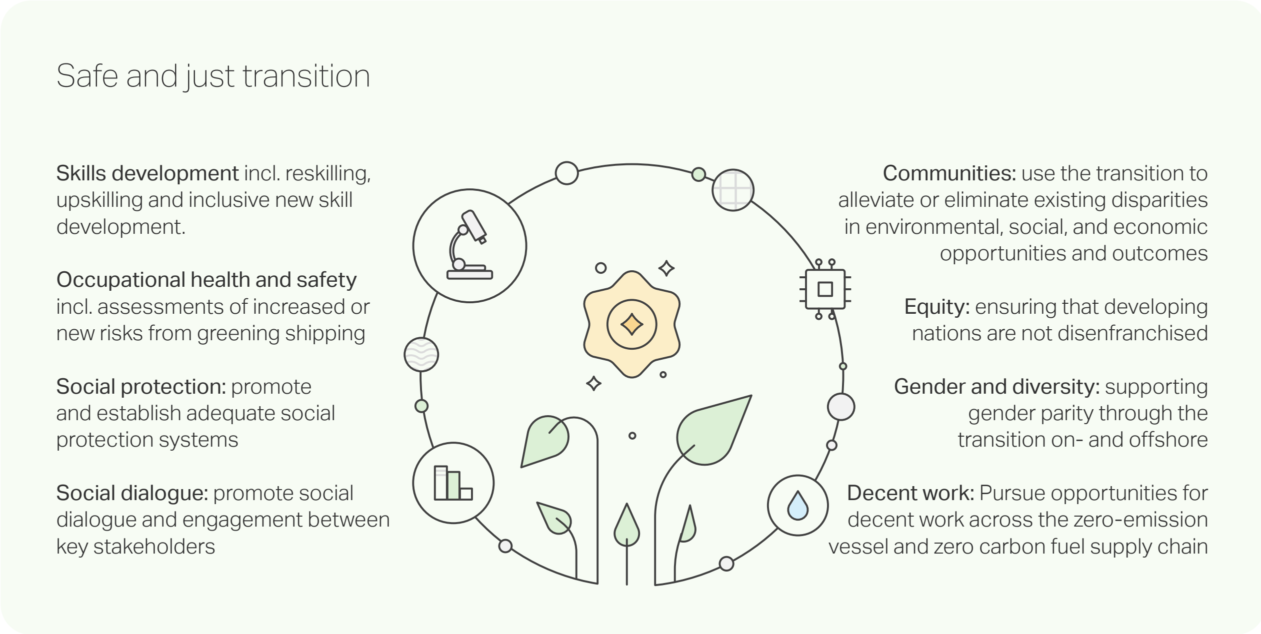
Work is ongoing to reduce this complexity. For example, in 2021, the International Financial Reporting Standards Foundation announced the formation of the International Sustainability Standards Board[62] to develop a global baseline of high-quality sustainability disclosure standards for ESG reporting that meets investors' needs. The standard will not be mandatory but will guide existing frameworks and advance upcoming regulations.

61 ESG Insights, ESG Book, 2022.
62 International Sustainability Standards Board, IFRS.

The Race to Zero campaign, initiated by the United Nations Framework Convention on Climate Change Climate Champions, has identified four key elements that qualify a pledge: Pledge, Plan, Proceed and Publish.[63] Although meant for decarbonization pledges, the four steps can be applied to most commitments related to sustainable behavior as part of ESG reporting. For companies mandated by regional regulation on non-financial disclosures, the content of the four steps would also need to comply with said regulation.

With demand from investors and clients for ESG information expected to increase, regulators worldwide are likely to continue to push firms for greater clarity and comparability in their ESG claims and disclosures, and to address more advanced issues such as greenwashing. Companies can best prepare for a more comprehensive regulatory approach by taking a more holistic view of ESG and making the issue part of the board's fiduciary duty for long-term value creation (and not just value preservation). The circle of benefits created by getting ESG right also provides an opportunity for companies, investors, and customers to engage in early dialogue on how to best incorporate and push for decarbonization activities in day-to-day operations. As ambitions around ESG accountability continue to grow, we expect that it will soon disrupt demand with increased expectations for sustainable transportation supply chains. Investors and customers can use ESG reporting to drive wider decarbonization, as shown in Figure 16.

Figure 17: Sub-elements of a 'just transition' derived from the Just Transition Maritime Task Force. The guiding principles of just transition are established in the International Labour Organization's Guidelines for a just transition towards environmentally sustainable economies and societies for all, adopted in 2015 through international tripartite consensus.[64]



63 Race To Zero Campaign | UNFCCC.
64 Guidelines for a just transition towards environmentally sustainable economies and societies for all, International Labour Organization, 2016 60 About Just Transitions, Just Transition Initiative.

We must ensure a safe and just transition for all

A just transition to zero-emission shipping is not only about technology and fuels but also about incorporating a people-centered approach (see Figure 17). A safe and just transition safeguards the industry's ability to ensure that the skills and competencies of the future workforce match the needs required to successfully switch to alternative fuels within the designated timeline. A recent analysis suggests that to align with the Paris 1.5 °C trajectory, 400,000 seafarers will require essential training or re- and upskilling by 2030, and 800,000 will require training by the mid-2030s.[65]

Social inclusion and distributional impacts are critical dimensions of a just transition that we must consider as we decarbonize. Social inclusion requires recognizing marginalized groups and including them in decision-making processes, enabling broad stakeholder participation and the ability to shape change processes and outcomes. Securing fair distributional impacts includes ensuring the risks and benefits associated with decarbonization are fairly distributed, addressing issues of contribution, historical injustices (restorative justice), the current allocation of transition outcomes, and considering future impacts.[65]

Given the unequal distribution of natural disasters associated with climate change, aligning with the Paris 1.5°C trajectory is a prerequisite for a safe and just transition. However, we must also consider how decarbonizing the shipping industry may impact transport costs and disproportionally affect the economies of developing countries with less room for price increases. High transport costs are already a concern for many developing countries, and increases could further exacerbate the global cost-of-living crisis.[66] As a result, decarbonization strategies, policies, and regulations must carefully consider how they protect vulnerable countries to secure a just transition.

We need ambitious regulatory action to drive the transition

Current decarbonization commitments and targets are insufficient for the maritime industry to align with the Paris 1.5°C trajectory ambitions. However, ambitious voluntary actions, commitments, targets, and regulations can stimulate decarbonization and bring us closer to the Paris 1.5°C trajectory.

Key actions by 2030

- Members of IMO need to reach consensus on ambitious absolute emission targets to reduce global GHG emissions from a well-to-wake perspective and reach net zero by 2050, aligning with the Paris 1.5°C trajectory.

- These targets must be accompanied by supplementary emissions intensity and efficiency targets, intermediate targets for 2030 and 2040, **GHG pricing**, and transparent emission reporting.

- The IMO must **fast-track** the development of international rules and standards supporting alternative fuels and decarbonization technologies.

- Shipowners should set **ambitious targets**, be transparent, and use clear, comparable ESG reporting.

- Regional, national, and local policymakers must develop roadmaps encouraging **dedicated investments** in green energy and fuel infrastructure for the maritime industry transition and engineering capacity to build these facilities.

65 'Mapping a Just Transition for the Global Maritime Workforce,' The Just Transition Task Force (UNGC), 2022.
66 Why should we talk about a 'just and equitable' transition for shipping?, UNCTAD, 2022.

05 Supporting Bold First Movers and Fast Followers to Unlock the Transition

Mærsk Mc-Kinney Møller Center
for Zero Carbon Shipping

Supporting bold first movers and fast followers to unlock the transition

We are already seeing companies, countries, and regional authorities stepping up as willing first movers to decarbonize the maritime industry. The previous chapters of this report have highlighted some of their actions so far, including developing zero-emission strategies (see Chapter 4), increasing the energy efficiency of their vessels (Chapter 2), ordering dual-fuel vessels that can operate on alternative fuels (see Chapter 3 and Table 6), and proposing new regulations (see Chapter 4).

First movers are transformational entrepreneurs, identified by the characteristics in Figure 18. They are unlocking innovative technologies in every part of the value chain and demonstrating their advantages to the rest of the industry. As a result, they will enable a portfolio of emission mitigation measures, decrease risk, reduce uncertainty, and create a foundation for industry-wide transition.

Table 6: Examples of recent first mover dual-fuel vessel orders and related activities.[67]

Dual-fuel vessel type	Container	Tanker	Bulk	Passenger/Cruise	RORO / Other
Methane	- Hapag-Lloyd (12 x 23,000 TEU) - CMA CGM carriers - Multiple LNG-fueled container carriers	- Terntank modern fleet product and chemical carriers (10-15,000 DWT) - Multiple LNG-fueled tankers	- Multiple LNG-fueled bulk carriers – from handy to cape size	- Leading cruise lines are considering a transition from LNG to bio/e-methane	- NYK line, ammonia ready LNG fueled PCTC (car carrier) - Höegh Autoliners ammonia ready LNG fueled PCTC (car carrier)
Methanol	- Maersk (Feeder, 12 x16,000, 6 x 17,000 TEU) - CMA CGM (6 x 15,000 TEU) - COSCO Shipping (12 x 24,000 TEU)	- Stena Bulk, Proman chemical carrier (49,000 DWT) - NYK Line, MOL chemical carriers (50,000 DWT)	- Fleet Management Handymax design development. - Small handy -regional trade (10,000 DWT)	- Royal Caribbean Group are constructing a methanol-ready cruise ship	- Stena Line, DFDS, and Port of Gothenburg e-methanol RoPax partnership - Svitzer tugboat and fuel cells
Ammonia	- Sabre, Sumitomo, MMMCZCS, Maersk, Seaspan basic design, 14,000 TEU	- M/S NoGAPS carrier (22,000 cbm) - NYK, Yara International VLGC carrier - CASTOR Initiative - Grieg and Wärtsilä tanker (bunker vessel)	- Sumitomo (81,000 DWT) - Cargill ultramax, early-stage new design feasibility	- Awaiting progress in commodity segments and safety case validation before passenger ships	- NYK line tugboat

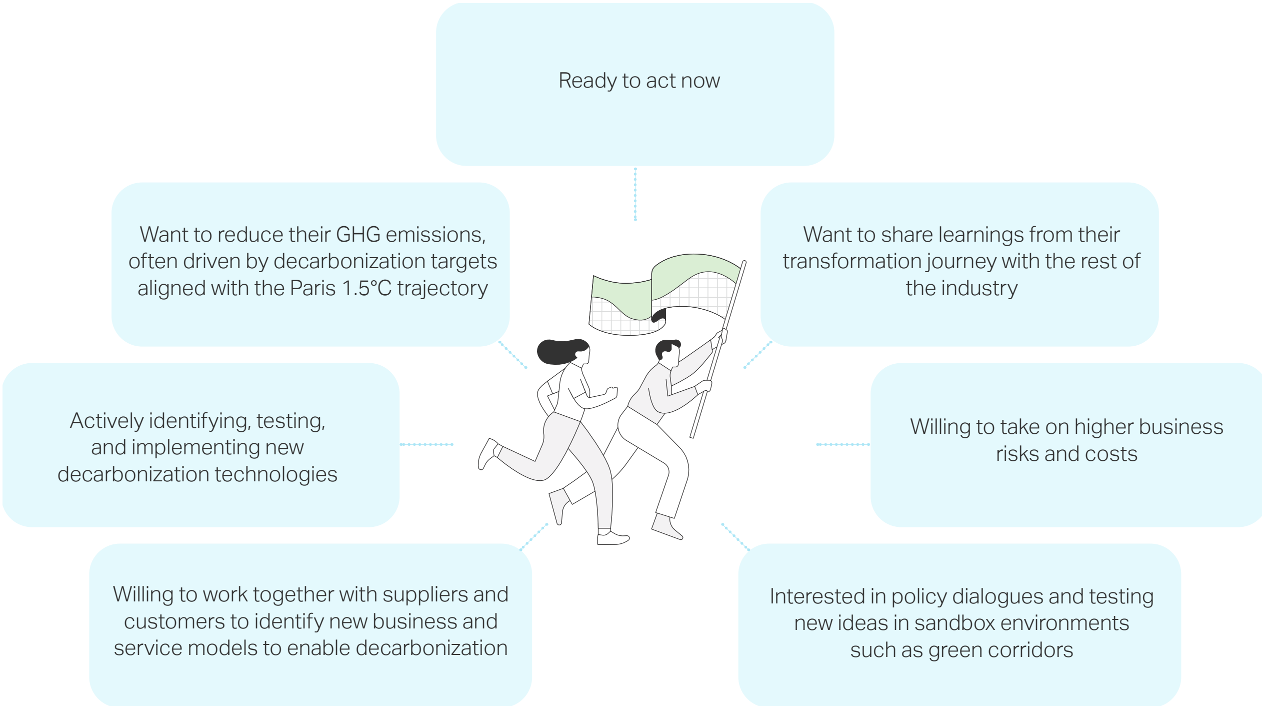
PCTC = pure car, truck carrier, RoPax = passenger RORO.

67 Across all ship segments and future fuel pathways, active development and segways into sustainable green fuel ship design options are being explored and demonstration projects going live. Both for newbuilding and increasing interest in retrofit options. Table 6 is only showing case examples – the project portfolio is counting many more and increasing every week.

However, first movers are currently making pledges and investments in a business environment characterized by uncertainty, low visibility, and low technology, regulatory, and commercial readiness. The maritime industry must support first movers and fast followers to safeguard the transition and accelerate progress. The faster first movers can form and execute on investable pathways, the more interested other industry players will be in following their actions, and the faster the industry can align with the Paris 1.5 °C trajectory.

This chapter highlights the importance of first movers for initiating the transition and creating a ripple effect across the industry. We also identify potential benefits of being a first mover and outline how to minimize the risks. Finally, we highlight two initiatives that are gaining traction with first movers: green corridors and Book & Claim systems.

Figure 18: Characteristics of first movers in the maritime industry.



There are advantages to being a first mover

Although first movers are operating in a highly uncertain environment with many risks and unknowns, they could gain long-term advantages with the right support and risk management. Figure 19 summarizes potential first mover benefits.

Technology head starts, gained by getting involved with new innovations that are yet to be scaled to the wider industry, allow first movers to move ahead on new learning curves. This can give them a position of technology influence and the ability to impact designs. Furthermore, early adoption could allow first movers to secure resources by establishing premium contracts with key suppliers, and avoid long waiting times in shipyards for newbuilding and retrofitting when capacity becomes a constraint.

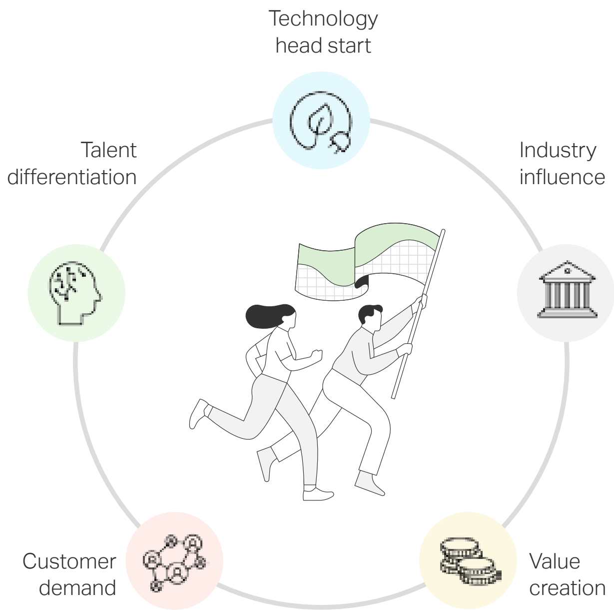
First movers naturally find themselves in positions of industry influence. As a result, their products and services shape new industry standards and set best-in-class environmental benchmarks for new technologies and green shipping services. Furthermore, they can impact new regulations, such as those designed to close cost gaps.

Offering the first products or services allows first movers to build market share in new service models early. Furthermore, they can take the opportunity to lower their barriers to entry by demanding long-term contracts that de-risk investments. They also provide the benchmarks for new service models, against which fast followers and the rest of the industry will later be compared.

There is increasing demand from customers for green transportation services. Being among the first to offer these could bring brand recognition and loyalty, especially if solutions are co-created with customers. This could involve sharing emission data and creating new supply ecosystems aligned with customers' decarbonization plans. First movers may also benefit from increased profit from customers willing to pay more for green services. Furthermore, first movers may gain an advantage and safeguard their customers by demanding long-term contracts, with high costs for customers switching to slower followers later.

Finally, first movers get a head start in attracting and developing niche talent required to drive the transition. Significant workforce transformation and education will be needed onboard ships, head offices, and fuel production (see Chapter 3 for more about EPC capacity limitations). First movers get more time to identify and address inequities and skills shortages and build talent pipelines.

Figure 19: Potential benefits for first movers.



First movers face risks and challenges

Being a first mover often offers strategic advantages, but it also comes with risks. This is particularly true for first movers transitioning to zero-emission shipping, led by environmental imperative rather than financial considerations. The path to decarbonization in the shipping industry remains highly uncertain.

As Table 7 summarizes, this uncertainty translates to interconnected and interdependent regulatory, commercial, and technology risks for all stakeholders in the value chain.

Although alternative fuel technologies are under development in all areas, none are ready at scale, creating uncertainty and technology risks for all stakeholders. Production costs for alternative fuels are likely to be high, with uncertain technology development timelines and potentially limited feedstock availability due to worldwide decarbonization. We expect varying demand for alternative fuels across geographical regions, making investments in producing alternative fuels risky, which may increase scarcity and fuel costs.

Alternative fuel production will be globally scattered and differ in availability, scale, and price over the coming decades. As a result, ports and vessel owners across the globe remain unsure about which alternative fuel technologies to invest in, with multiple options and little common technology across pathways. Investing in the 'wrong' fuels may leave ports with stranded assets if the fuel is not desired by the vessels calling at the port. Furthermore, vessel owners may be left with commercially unattractive or stranded assets if they invest in technology expecting to use a particular fuel, but that fuel is unavailable in the region where they operate.

First-moving vessel owners face much higher fuel costs for alternative fuels (2-8x higher than fossil fuels without subsidies),[68] higher operating costs, and upfront expenses from investing in new technologies. However, demand for green transportation is dispersed across different vessel segments, and willingness to pay varies.[69] Furthermore, there are currently no unified guidelines for quantifying, pricing, and selling green shipping services or quantifying and reporting shipping emissions. This all creates commercial risks for vessel owners and operators. However, GHG pricing, improved

Table 7: Technology, commercial, and regulatory risks for first movers in the maritime industry.

	Alternative fuel producers	Ports	Vessel owners and operators
Technology risks	Technologies unproven at scale Uncertain operation and efficiencies Uncertain product standardization	Uncertain safety standards and specifications for storing and bunkering alternative fuels	Uncertain alternative fuel pathways Dependencies on stakeholders and third party providers
Commercial risks	High and uncertain costs Uncertain, scattered demand	Uncertain demand and risk of stranded assets Uncertain role early in the transition	Unknown costs of new technologies Uncertain access to alternative fuels Uncertain how to cover the additional costs of alternative fuels
Regulatory risks	Uncertain fuel specifications and standards	Uncertain future fuel specifications and standards Risk from public perception of specific alternative fuel types (e.g. ammonia)	Uncertain future regulatory regimes Uncertain fuel specifications and standards

68 NavigaTE, MMMCZCS.
69 Global Shipping's Net-Zero Transformation Challenge, BCG, 2021.

ESG reporting (see Chapter 4), and new business models that aim to meet green service demands could help overcome these problems. Activating cost-sharing levers throughout the supply chain could also make green shipping economically feasible for first movers (see deep dive box for an illustrative example).

All stakeholders face regulatory uncertainties associated with undeveloped fuel specifications and standards, developing patchworks of local and regional regulation, and uncertain future regimes such as revised targets, new regulations, or market-based measures, as described in Chapter 4.

Deep dive:

How cost-sharing initiatives can make alternative fuels competitive

Table 8 outlines an illustrative example of how cost-sharing across the supply chain can make alternative fuels competitive with LSFO. This example uses published costs for sailing a 1,500 TEU ship from Hamburg, Germany to Kotka, Finland on LSFO.[69] As shown in the table, sailing on bio-methane or bio-methanol increases fuel costs by 50% or over 200%, respectively, compared with LSFO. This, and other additional costs associated with using alternative fuels, translates to an increase in cost per container of 75 USD for bio-methane and 182 USD for bio-methanol.

To assess the feasibility of cost sharing, in this example, we assumed the following discounts could be applied to share the costs of sailing on alternative fuels:

- Fuel producers offering 5% reduced fuel costs
- Shipowners offering charter costs on par with LSFO
- Ports offering a 50% reduction in port fees and free shore power
- Shipowners providing a 15% increase in energy efficiency on vessels

These discounts reduce the additional cost per container to 5 USD for bio-methane and 91 USD for bio-methanol. Using the relatively low 300 USD/TEU freight rate for sailing on LFSO reported in the publication, this equates to a 2-31% increase in cost for sailing on alternative fuels. With a more realistic freight rate of 500 USD/TEU, sailing on alternative fuels represents a 1-18% increase in costs.

Some cargo owners would be willing to pay this premium, but market-based measures or additional supply chain cost sharing may be needed to close the remaining gap. Sharing costs throughout the maritime value chain in this way would initiate a transition to green shipping with no single stakeholder having to carry all the costs alone.

Table 8: Cost per TEU for a 1,500 TEU ship sailing on different fuel types from Hamburg, Germany to Kotka, Finland.

Fuel type (2025)	**LSFO**	**Bio-methane**	**Bio-methanol**
Fuel cost (USD/GJ)	16	23	36
Emission reduction (WTW,%)	-	(-) 93%	(-) 98%
Cost per container			
Fuel cost (USD/TEU)	116	177	288
Vessel charter cost (USD/TEU)	50	58	56
Port costs (USD/TEU)	42	49	47
Cost compared to LSFO (USD/TEU)	-	**+75**	**+182**
Supply chain discounts (USD/TEU)		-70	-91
Cost Increase after discounts (USD/TEU)	-	**+5**	**+91**
Cost Increase after discounts (% of a USD 300 freight rate)		2%	31%
Cost Increase after discounts (% of a USD 500 freight rate)		1%	18%

Calculated using public information about the costs of sailing on LSFO.[70]
Fuel cost per TEU incorporates pilot fuel needed for bio-methane and bio-methanol. Port costs assume three port calls.

70 Research on feeder network design: a case study of feeder service for the port of Kotka, by Yisong et al, European Transport Research Review (2020) 12:61.

Despite all these risks and uncertainties, the maritime industry cannot afford to wait for them to be resolved to initiate the transition. We must find ways for first movers to manage uncertainties and minimize their risks now. While awaiting greater systemic efforts, we can limit uncertainty for first movers with dialogue, coordinated action, and sharing costs across the value chain. Based on our experiences in ongoing first mover projects and the experience of our partners, who are first movers, we have developed recommended actions for each part of the shipping value chain to enable first movers (Table 9).

Table 9: Recommended actions for selected stakeholders across the shipping value chain to enable first movers.

Transition drivers			Market enablers		
Alternative fuel producers	Ports & terminals	Vessel owners & operators	Regulation and policy making	Financing	Cargo owners & customers
Unlock barriers to enable all alternative fuel pathways Promote and scale commercially available alternative fuels	Re-purpose existing infrastructure to support uptake of alternative fuels Share learnings and develop blue-prints on safe handling of all alternative fuels	Order dual-fuel ships Maximize energy efficiency Send demand signals to fuel producers Deepen dialogue and green service offering with customers	Focus on removing barriers and closing cost-gaps Present long-term regulatory roadmaps and experiment with regulatory sandboxes to find solutions fast Introduce carbon pricing	Mobilize capital to decarbonization technologies Engage in private-public partnerships De-risk investments by providing e.g., cheaper capital, governmental guarantees, subsidies	Be transparent about green shipping demand Be willing to share some of the costs of alternative fuels Work to find solutions to aggregate fragmented supply and demand

Green corridors bring together first movers to share risk

The Clydebank Declaration[71] was launched at COP26 to facilitate rapid decarbonization of the shipping industry. It represents a commitment by its signatories to support the establishment of "green shipping corridors – zero-emission maritime routes between 2 (or more) ports" and aims to establish at least six corridors by 2025 and "many more" by 2030.

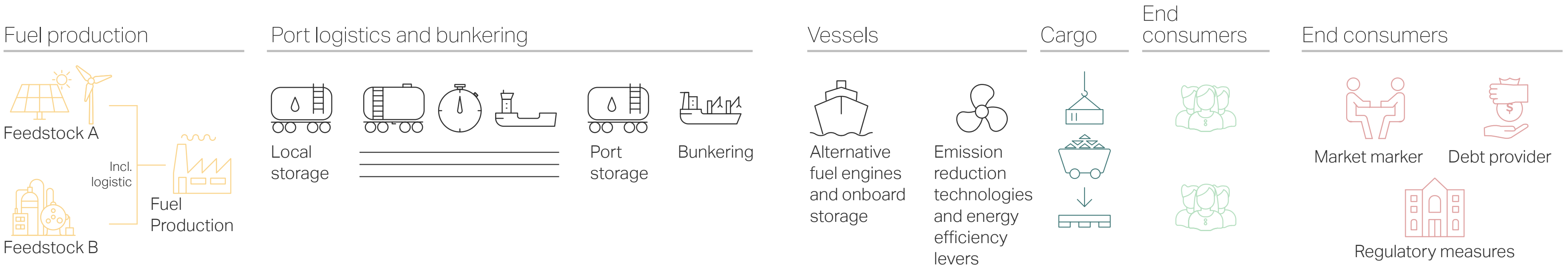
Since COP26, the number of green corridor studies initiated has grown steadily. There are now at least 21 worldwide, with prominent examples in Latin America, Northern Europe, and North America-Asia.[72,73] Green corridor projects provide an approach to consolidating individual first mover actions and embarking on an accelerated decarbonization process in a specific geographical area. They bring together first movers across the maritime value chain (see Figure 20) with a common desire to reduce emissions by sailing on alternative fuels.

Green corridors have several purposes. Firstly, they activate and scale up first mover activities. Secondly, they are a tool to identify and solve the challenges discussed in this report, such as cost gaps, regulatory approval, and alternative fuel availability. And thirdly, they can catalyze the global transition by contributing to fuel supply chain development, informing regulation, and finding solutions that can be magnified across the globe.

The collaborative nature of green corridors and the defined geographical areas they cover help mitigate some of the uncertainties and risks faced by first movers. They create a space for pre-competitive testing and commercial trials of technologies and market solutions. Furthermore, they can use a partnership approach that promotes collaboration across the supply chain, so all stakeholders share risks, costs, and benefits. Concentrating efforts around a corridor allows targeted support mechanisms (e.g., public support) to incentivize the supply chain, reducing the risks to first movers.

Green corridors lay the foundations for scalable long-term decarbonization solutions by demonstrating what it takes to build alternative fuel supply chains, providing platforms for further scaling technologies, and

Figure 20: Green corridors can involve the entire maritime supply chain.



71 Clydebank Declaration for green shipping corridors - UN Climate Change Conference (COP26) at the SEC – Glasgow 2021 (ukcop26.org).
72 Climate Shipping in Action, UMAS, 2022.
73 Annual progress report on green shipping corridors, Getting to Zero Coalition & GMF, 2022.

showcasing new business models for operating zero-emission vessels at scale. They also offer opportunities to try out de-risking mechanisms and exemplify safety standards and prerequisites for using new technologies and alternative fuels.

Realizing green corridors hinges on leveraging opportunities and competencies across the entire supply chain in a coordinated manner. Stakeholders across the chain – from fuel producers through cargo owners, must form a consortium of first movers to ensure a smooth development process. Due to the complicated nature of planning the production, distribution, and use of alternative fuels across multiple ports, green corridor projects require thorough planning and a coherent project framework (Figure 21). As stakeholders progress through the different stages and the corridor moves from concept to execution, uncertainty decreases, and stakeholder commitments and investments increase.

Green corridor projects must start with pre-feasibility and feasibility analyses that identify and assess potential corridors. Selected corridors should not only target routes with high emissions, but also be viable across technical, economic, and regulatory spheres. Furthermore, assessments should consider the likelihood of actual implementation based on stakeholder commitment to the corridor.

Figure 21: Stages of a green corridor project.[74]

Green Corridor Project Phases	Pre-Feasibility	Feasibility	Select	Define	Execute	Operate
Purpose	**Identify corridors**	**Assess corridors**	**Select final concept**	**Detail concept**	**Execute the concept**	**Realize the concept**
	High-level screening of potential green corridors to identify corridor(s) warranting further maturation	In-depth assessment of a green corridor's feasibility to determine its viability and actions to mitigate potential gaps and risks	Further assessment of value chain elements in order to rank and select final concept	Detailed engineering and commercial design of the final concept for the green corridor	Final detailing and execution of projects culminating in handover to operators	Operation of green corridor

For more information about how to form a green corridor project, see our recently published Green Corridors: Feasibility Phase Blueprint and our Pre-feasibility Phase Blueprint, which will be published soon.

74 Green Corridors: Feasibility Phase Blueprint, MMMCZCS, 2022.

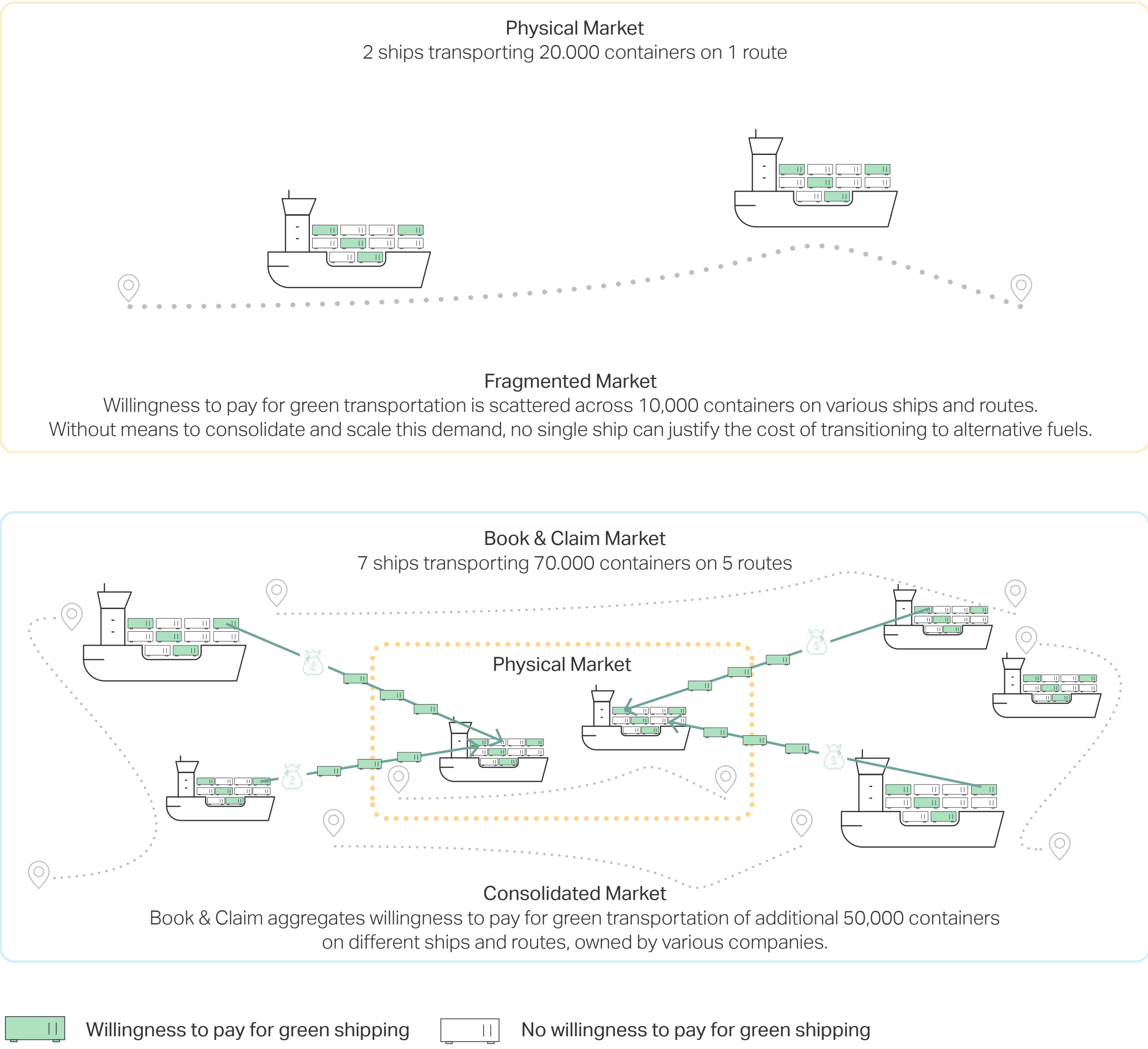
Book & Claim provides credibility and consolidates demand

For customers to be able to purchase green shipping services, we need a robust model ensuring transparency, accountability, and credibility. Book & Claim systems deliver these features using a so called 'chain of custody' model. Chain of custody models track specific product characteristics as they travel through a supply chain from their source to the end consumer (e.g., their emission profile). These models provide transparency and credibility to an end consumer that the purchased product has specific characteristics. While most chain of custody models track the product characteristics alongside their physical flow, Book & Claim takes a different approach and decouples the characteristics from the physical product.

To participate in a Book & Claim system for green shipping, shipowners/operators would certify their emissions with an independent authority and receive a certificate. They would then "book" certificates on a registry. Cargo owners can then pay a premium to "claim" low-emission shipping that fits their decarbonization strategy.

A Book & Claim system for green shipping would give cargo owners flexibility to claim lower emissions where physical green shipping routes are unavailable. Furthermore, first mover shipowners/operators sailing with alternative fuels could recover some of their additional costs.

Figure 22: Physical market vs. Book & Claim market for low emission shipping services.



Book & Claim activates first movers by consolidating demand and creating additional revenue streams. In this way, Book & Claim systems address some of the challenges faced by first movers, including:

- Limited access to alternative fuels: Physical access to alternative fuels is no longer a constraint as companies can “claim” low emissions transport service from outside their physical supply chain.

- High vessel cost: The additional costs from investing in alternative fuel technology and sailing on alternative fuels is covered by end users willing to purchase “claims” for low-emissions transport.

- Fragmented demand for low-emission shipping: Demand is aggregated across segments and geographies into a common registry. Without Book & Claim, a small shipping company may have demand for green shipping but cannot meet this demand because it is scattered across their ships. However, with Book & Claim, the same company can aggregate its internal demand and expand its access to other cargo owners willing to pay a green shipping premium, helping justify investments in alternative fuel ships.

- Investment uncertainty: Fuel producers receive a strong demand signal and more certainty around revenue.

Book & Claim allows first-moving shipping and fuel companies to access a broader market for their services, leading to more certainty around revenue streams. It will enable large and small shipping companies to finance their fleet’s transition via the additional revenue generated. Furthermore, first-moving cargo owners can use their capital to support alternative fuel supply chains. In this way, a Book & Claim system could be used alongside market-based measures like carbon pricing to share the cost of the transition. When Book & Claim and green corridors are used in combination, the uptake of alternative fuels can be funded through cargo owners who are not even active in the specific geographic area where the green corridor is operating.

The potential impact of Book & Claim has generated significant interest in the maritime industry. Book & Claim is a new concept, and several organizations, including the MMMCZCS, are exploring the best way to design these systems. There are currently a variety of approaches across organizations and projects being analyzed and discussed, each with their own advantages and challenges. We must collaborate to bring a universal, industry-standard Book & Claim system into operation as soon as possible.

We must support first movers and fast followers

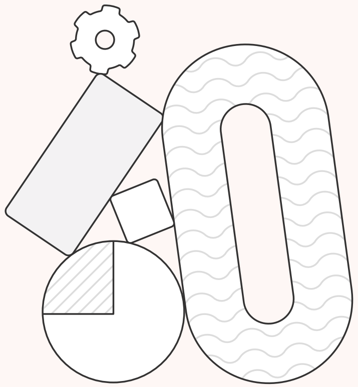
First movers are playing an essential role in initiating the transition to low-emission shipping. They are transformation entrepreneurs from across the value chain, identifying opportunities and risks, evaluating solutions, and catalyzing cost reductions. We are already seeing action from first movers across the industry. However, the uncertainties and risks associated with the transition to alternative fuels are limiting their opportunities.

The risks to first movers can be counteracted by public sector involvement, collective action, and cost-sharing. Importantly, when enabling first movers and starting the transition, we should not let perfect be the enemy of good. Decarbonizing to align with the Paris 1.5°C trajectory will be a gradual transition linked to implementation and demonstration learning curves. Therefore, we must support first movers who are making incremental step changes, even if they are not perfect.

Key actions by 2030

The industry must drive **collective action** across the supply chain to share costs, benefits, and risks for first movers. This means:

- Alternative fuel producers, ports, and vessel owners must work together to prove technologies, demonstrate business concepts, and share challenges and opportunities.
- Regulatory, policy, financial bodies, and customers must de-risk first mover investments and decarbonization activities.
- All stakeholders must support first mover initiatives that drive collective decarbonization and share costs, benefits, and risks, such as green corridors and Book & Claim systems.



Conclusion

Aligning with the Paris 1.5°C trajectory requires immediate collective action on an unprecedented scale, and everyone reading this report can contribute to the effort. Some of the most important actions we must take as an industry in the coming decade include the following:

Summary of key actions

- The maritime industry must take immediate collective decarbonization action on an unprecedented scale to bring us closer to the Paris 1.5°C trajectory, including:
  - Reducing emissions by 45% in 2030 compared with 2010
  - Limiting the fossil fuel consumption of the global fleet to 6 EJ in 2030
  - Reaching net zero by 2050

Elevating onboard energy efficiency

- Shipowners and operators must take immediate action to increase energy efficiency. This should include installing energy efficiency technologies when dry-docking and asking for state-of-the-art designs when ordering new vessels.
- Businesses across the maritime value chain must develop collaborative business models driven by transparency to reduce emissions from ship operations.
- The industry must support the IMO in increasing their regulatory ambitions around energy efficiency.
- The IMO must provide clear enforcement mechanisms, tighten compliance levels, and find regulatory solutions for sharing responsibility among all those who influence vessel emissions.

Enabling alternative fuel pathways

- Over the next five years, the industry must focus on enabling all alternative fuel pathways by:
  - Achieving technological readiness for alternative fuel production and vessel operations.
  - Developing regulatory standards to unlock use of alternative fuels.
  - Ensuring uncompromised safety onboard and on-land for bunkering and operation on alternative fuels.
- To be ready to scale up alternative fuels this decade, the industry must:
  - Address the mismatch between planned alternative fuel production supply and demand.
  - Build infrastructure and establish competencies that can support scaling of all alternative pathways.
  - Make alternative fuel pathways commercially attractive by closing the cost gap with fossil fuels.

Promoting abatement action with regulation, policy, and commitments

- Members of IMO need to reach consensus on ambitious absolute emission targets to reduce global GHG emissions from a well-to-wake perspective and reach net zero by 2050, aligning with the Paris 1.5°C trajectory.
- These targets must be accompanied by supplementary emissions intensity and efficiency targets, intermediate targets for 2030 and 2040, global GHG pricing, and transparent emission reporting.
- The IMO must fast-track the development of international rules and standards supporting alternative fuels and decarbonization technologies.
- Shipowners and operators should set ambitious decarbonization targets, embrace transparency, and use clear, comparable ESG reporting.
- Regional, national, and local policymakers must develop roadmaps encouraging dedicated investments in green energy and fuel infrastructure for the maritime industry transition and engineering capacity to build these facilities.

Supporting bold first movers and fast followers to unlock the transition

- The industry must drive collective action across the supply chain to share costs, benefits, and risks for first movers. This means:
  - Alternative fuel producers, ports, and vessel owners must work together to prove technologies, demonstrate business concepts, and share challenges and opportunities.
  - Regulatory, policy, financial bodies, and customers must de-risk first mover investments and decarbonization activities.
  - All stakeholders must support first mover initiatives that drive collective decarbonization and share costs, benefits, and risks, such as green corridors and Book & Claim systems.

Here at the MMMCZCS, over the next year, we will continue our work on maturing solutions that can provide a real impact for decarbonizing the industry. Amongst other things, we are working on ammonia safety studies, design concepts for vessels sailing on alternative fuels, emission reduction technologies and solutions, life cycle analysis frameworks, green corridors, and many more. See the project page on our website for more details.

Currently, we are far from aligning with the Paris 1.5°C trajectory. However, despite the seriousness of our current situation and the enormity of the task ahead, we cannot afford to be paralyzed by hopelessness. We must get started now.

After all, “you can’t cross the sea merely by standing and staring at the water”
- Rabindranath Tagore.

Abbreviations

CapEx	Capital expenditures
CO_2	Carbon dioxide
CII	Carbon Intensity Indicator
EEDI	Energy Efficiency Design Index
EEXI	Energy Efficiency Existing Ship Index
EPC	Engineering, procurement, and construction
ESG	Environmental, social, and governance
EU ETS	EU Emissions Trading System
GHG	Greenhouse gas
IEA	International Energy Agency
IMO	International Maritime Organization
ILCD	International Reference Life Cycle Data System
IPCC	Intergovernmental Panel on Climate Change
LCA	Life cycle assessment
LNG	Liquified natural gas
LSFO	Low sulfur fuel oil
MMMCZCS	Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping
N_2O	Nitrous oxide
OECD	Organisation for Economic Co-operation and Development
RORO	Roll-on/roll-off
SEEMP	Ship Energy Efficiency Management Plan
TTW	Tank-to-wake
UN	United Nations
UNEP	United Nations Environment Programme
WTT	Well-to-tank
WTW	Well-to-wake

Visit our website for more

www.zerocarbonshipping.com

Mærsk Mc-Kinney Møller Center
for Zero Carbon Shipping