In collaboration with
Boston Consulting Group

WORLD ECONOMIC FORUM

Fuelling the Future of Shipping: Key Barriers to Scaling Zero-Emission Fuel Supply

INSIGHT REPORT

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Foreword

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We are in the middle of what needs to be the decade of action if maritime shipping is to achieve net-zero emissions by 2050. Shipping is an industry that operates assets with a long life span and hence actions not taken today will affect us long into the future.

The global shipping industry facilitates the movement of 80% of goods around the world, but also accounts for 2–3% of global greenhouse gas emissions. We need to eliminate these emissions through the scaling of technologies that can power deep-sea vessels.

When the First Movers Coalition (FMC) was launched in 2021, shipping was one of the first four hard-to-abate sectors included (along with aviation, steel and trucking). Momentum has continued to grow as our members have started to move from commitment to action.

Many FMC companies are taking bold action, including orders for dual-fuel vessels, offtakes of zero-emission fuels and agreements to move cargo on zero-emission vessels. Despite all this positive momentum, our FMC shipping members have highlighted barriers in the maritime value chain and beyond that hinder decarbonization from progressing at the speed needed.

The nexus between demand and supply is an important dynamic: a stronger demand signal increases confidence to invest in the supply side, whereas conversely demand confidence is diminished by difficulties in securing zero-emission shipping fuel supply. While the FMC was launched to strengthen the credible demand signal, it is apparent that more needs to be done to overcome the barriers hindering projects seeking to scale zero-emission fuel supply to the final investment decision (FID) stage.

Through this insight report, the World Economic Forum, together with the Boston Consulting Group, intends to shed light on some of the key barriers for stakeholders working to get zero-emission shipping fuel projects past FID. Via qualitative interviews conducted in late summer 2023, combined with a roundtable discussion, we have collected input from more than 20 stakeholders with different vantage points along the maritime shipping value chain, including FMC members, as well as, importantly, stakeholders operating on the supply side. We thank them for taking the time to contribute to this work and for sharing their top concerns with us.

Further, in this report we offer an initial perspective on how to start addressing the barriers affecting zero-emission fuel projects today. These include, especially, the need to explore unconventional partnerships and business models with transparent cost and risk sharing, which extend beyond what is typically seen in the maritime shipping and energy industries. The solutions are by no means intended to be exhaustive, but rather to act as a conversation starter for stakeholders to come together to act, enabling the first few projects to get off the ground.

Executive summary

Understanding and addressing barriers to zero-emission shipping fuel project FIDs is key to accelerating maritime shipping's decarbonization.

To align with the Paris Agreement and aim for net-zero emissions by 2050, the shipping sector must reduce its emissions by around 15% by 2030 vs. 2022 levels. Among the available decarbonization options, zero-emission fuels such as methanol and ammonia are an important focus area. The demand for such fuels is on the rise, as indirectly indicated by 180+ dual-fuel ships on order, but on the supply side, more than 95% of projects centred on producing these fuels have not yet passed the final investment decision (FID) phase.

Discussions held for this report with maritime shipping decarbonization-focused decision-makers from more than 20 private, public and non-governmental organizations identified 10 barriers limiting zero-emission shipping fuel projects from getting past FID:

1. Lack of clear demand signals with sufficient willingness to pay to cover the green premium
2. Expectations gap between fuel producers and carriers on the length, volume and price of offtake agreements
3. Lack of credible third-party cost estimates, making it difficult for financiers and offtakers to assess options on a like-for-like basis
4. Venture-like risk but infrastructure-sized investment requirements means existing financial instruments and funds are not fit for purpose in terms of time horizons and risk appetite
5. Lack of strong near- to mid-term mandates or a global price on carbon
6. Standard definitions, methods and certifications still under development
7. Access to biogenic CO_2 in locations close to cheap renewables for methanol production becoming tougher; de-risking needed for the use of ammonia as a marine fuel and its handling at ports
8. Shipping's transition competing against other sectors, e.g. chemicals for methanol, fertilizers for ammonia and more broadly for low-carbon H_2 and CO_2 feedstocks
9. Storage and transport infrastructure for zero-emission fuels underdeveloped and responsibility for last-mile logistics uncertain; many promising e-fuel locations far from major ports and shipping routes
10. Decarbonization decisions and traditional department-specific business KPIs such as profit and loss (P&L) not always placed with the same team; risk appetite limited by a shortage of experts and/or decision-making mandates

Although daunting, these barriers need not all be overcome simultaneously. The important thing is to get the first few projects off the ground and drive the process of learning-by-doing at scale. For example, stakeholders from across the value chain – including fuel producers, project developers, carriers, cargo owners, bunkering companies, port authorities, financiers and governments – could come together in innovative ways to isolate, share and eliminate the risks by:

- Developing projects spanning the entire value chain with transparent cost and risk-sharing, ideally on green product development
- Consolidating shipping's demand for methanol and ammonia with other sectors (e.g. chemicals, fertilizers) to hedge end-market risk
- Driving offtake agreements through public-private demand aggregation, including via reverse auctions
- Developing strategic green corridors in the most attractive production locations and shipping routes, with reciprocal regulatory backing at endpoints
- Using innovative contracting and financing mechanisms, including capacity payments, dynamic contract pricing, offering equity stakes to strategic buyers

Complementary to actions that can get the first few projects off the ground, stakeholders also need to continue to proactively engage not only national/regional governments and maritime regulatory bodies such as the International Maritime Organization, but also multilateral bodies such as the International Organization for Standardization to help establish clear regulations and standards and articulate the requirement for greater regulatory support.

Collaborations to overcome the 10 barriers are under way, but first movers need to continue to take bold action to prevent progress from stalling and lay the foundations for a zero-emission future in shipping.

Introduction

Demand signals for zero-emission shipping fuel are on the rise, but are not providing sufficient confidence to fuel producers, as evidenced by the vast majority of zero-emission fuel production projects remaining in the pre-FID phase.

Today, maritime shipping is considered a hard-to-abate sector and accounts for 2–3% of global greenhouse gas (GHG) emissions.[1] Because more than 80%, or roughly 11 billion tonnes, of the world's traded goods travel by ship,[2] direct emissions from shipping is an integral part of supply-chain (Scope 3) emissions for almost every multinational business. For the sector to meet the goals set out in the Paris Agreement, emissions will have to decline by almost 15% by 2030 vs. 2022 levels to be in line with the International Energy Agency (IEA) Net Zero Emissions by 2050 (NZE) scenario.[3]

Since 2018, when the International Maritime Organization (IMO) adopted its initial strategy to reduce annual GHG emissions from ships by at least 50% by 2050 compared to 2008, there have been significant signs of progress, primarily in the form of scaling demand signals throughout the value chain. And in 2023 the IMO adopted an upwards revision of its GHG strategy, which now aims to reduce emissions by 20%, striving for 30% by 2030 compared to 2008, with the ultimate goal being to reach net-zero emissions in or around 2050.

Still, real progress in decarbonizing the industry will need a major shift away from the fossil fuels that currently power the vast majority of the world's ships and towards a variety of near-zero and zero-emission fuels. Among the possibilities gaining traction are biofuels (such as biodiesel), biogas (also known as renewable natural gas) and low-carbon hydrogen derivatives such as methanol and ammonia, as well as battery-powered electric vessels. For members of the First Movers Coalition (FMC) in particular,[4] the focus is on scalable zero-emission fuels,[5] which are currently in the demonstration and early-deployment phase – also known in the innovation literature as the "valley of death". Options meeting the FMC commitment thus include methanol, produced using low-carbon hydrogen and sustainable carbon dioxide (biogenic, recycled, CO_2 from direct air capture, etc.), ammonia, produced with low-carbon hydrogen and nitrogen, battery-powered electric vessels and low-carbon hydrogen as a fuel itself.

Methanol, in particular, has been gaining traction; in fact, carriers have placed orders for more than 180 methanol dual-fuel vessels, with more than 60% of the order being container vessels (illustrating that there are also still different challenges within each of the shipping segments, i.e. container ships, bulkers, tankers). The volume of fuel needed just for operating these 180+ vessels entirely on methanol fuel would be up to 21 million tonnes of methanol per year (see Figure 1). Separately, ammonia as a marine fuel is attracting attention, especially as the industry looks towards 2030 and beyond. MAN Energy Solutions, a prominent ship-engine manufacturer, is currently working on a two-stroke ammonia engine, which it expects to be on the market by 2025.[6] From a vessel-construction perspective, Seaspan, together with the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, recently received approval in principle for the design of a 15,000 twenty-foot equivalent (TEU)[7] ammonia-powered container vessel.[8]

FIGURE 1 | **Zero-emission methanol fuel supply emerging to power methanol dual-fuel vessels on order – but majority of projects remain pre-FID**

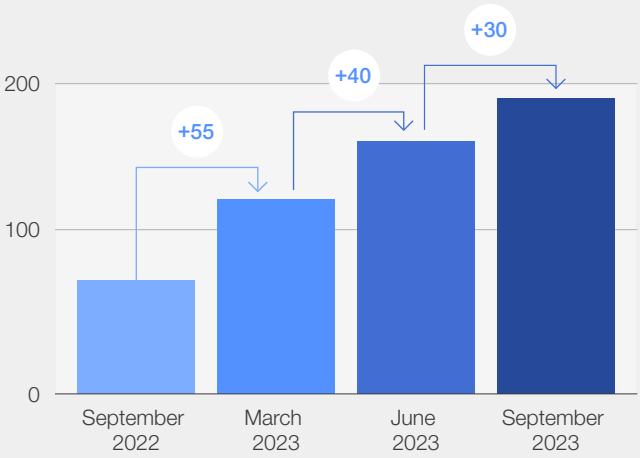
As of September 2023

Up to **21 mtpa** in potential methanol demand (assuming 100% consumption)

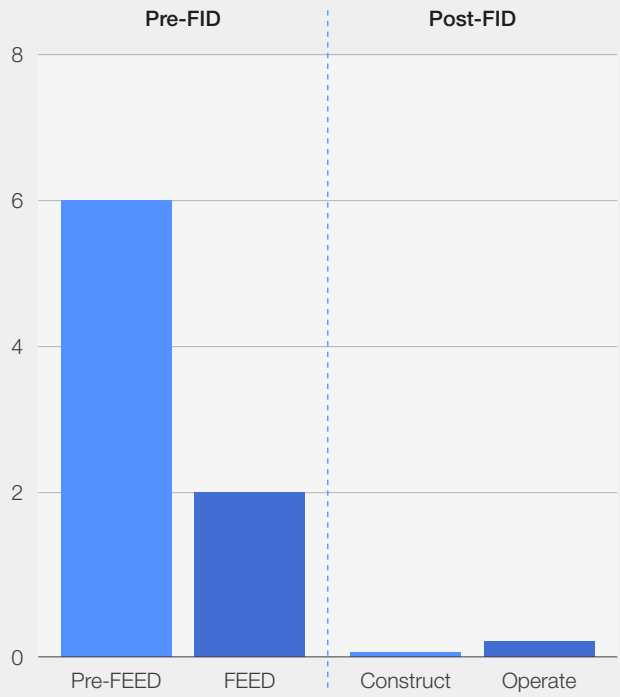
...to fuel **180+** methanol dual-fuel vessels on order, whose numbers continue to grow

~9 mtpa zero-emission methanol capacity announced; however, **>95%** remain pre-FID

Number of methanol dual-fuel vessels on order



Zero-emission methanol capacity in mtpa



Note: Methanol volume estimated, based on vessels currently in the fleet and order book only (not forecasts), assuming 100% consumption goes to methanol (despite dual-fuel engines). Consumption based on estimations of 2x consumption of regular fuel for methanol, based on data of average consumption per vessel type and size class.

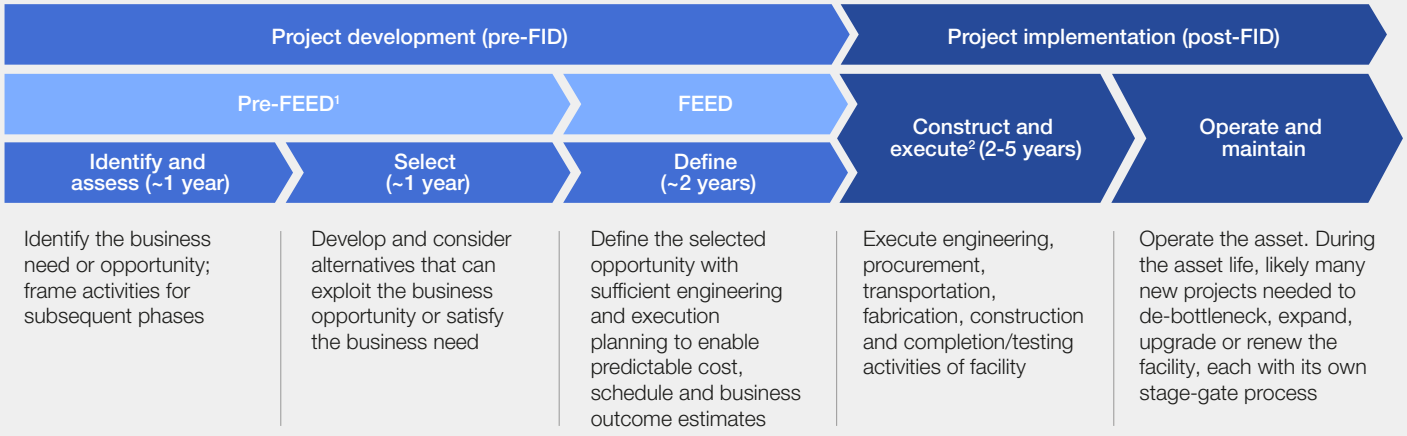
Source: World Fleet Register; press research; BCG hydrogen project database; BCG analysis

The sobering reality is that methanol and all other zero-emission fuels are in short supply already, and the shortage is projected to get worse in the future. In fact, more than 95% of plans to produce these fuels have not yet crossed the final investment decision (FID) phase.

FID refers to the point in a project's development cycle when the company (or companies) owning and/or operating the project has secured sufficient funding and is now approving capital investments to commence construction. The decision to invest capital in construction is made based on a thorough evaluation of demand and revenue risks, i.e. the sponsor is confident of being able to sell enough of the project's output at a price sufficient to repay financiers and yield satisfactory returns.

Under the best of circumstances, moving a large-scale low-carbon fuel production project up to and past FID stage is a major undertaking (see Figure 2). Currently it can take four years or more to reach FID and then another two to five years to start producing the fuels. Yet 2030 is only six years away. If a significant number of projects do not cross FID in the next couple of years, there is a risk of dual-fuel vessels on order still predominantly running on emissions-intensive fossil-based heavy fuel oil in 2030. By understanding the many barriers in the way of reaching FID and moving past these, the marine shipping industry, together with key stakeholders and sectors contributing to the shipping industry, can progress and accelerate the path to decarbonization.

FIGURE 2 | **Large capital projects take six to nine years from start to finish with no challenges; FIDs need to happen as soon as possible to achieve operability by 2030**



	Key evaluative outcome[3]	Key evaluative input
Decision Gate 1	Business opportunity clearly defined, including a framing of subsequent activities	Pre-feasibility study
Decision Gate 2	Option that delivers optimal value selected for detailed design	Feasibility study
Decision Gate 3 (FID)	Decision to invest capital in construction made based on a thorough evaluation of demand and revenue risks, i.e. sponsor confident of ability to sell enough of the project's output at a price sufficient to repay financiers and yield satisfactory returns	FEED

Notes: 1. FEED = Front-End Engineering Design; **2.** Timeline varies based on scale and location of facility; **3.** Projects can also be stopped or paused at every decision gate.

Source: BCG analysis

1 Ten barriers limiting zero-emission shipping fuel project FID

Interviews with decision-makers from the shipping industry identified 10 key obstacles to financing and developing zero-emission fuel projects.

To obtain a better understanding of what prevents zero-emission shipping fuel projects from getting past FID, and what it will take to move forward, interviews were conducted with decision-makers from 12 private-sector companies with different vantage points along the shipping value chain, including traditional fuel producers, project developers, carriers and financiers. The interviews were combined with a roundtable discussion at the London International Shipping Week in September 2023, with participants from 15 private, public and non-governmental organizations.

The 10 identified barriers fall into five categories: customer and consumer demand; economics and finance; regulatory issues; supply-chain and infrastructure enablers; and organizational factors (see Figure 3).

FIGURE 3 **Ten key barriers across five categories surfaced in 1:1s and live roundtable discussions with stakeholders across the shipping value chain**

Customer and consumer demand	1 **Lack of clear demand signals with sufficient willingness to pay:** Methanol uptake volumes in dual-fuel ships remain uncertain. Companies struggle to absorb green premiums alone 2 **Expectations gap between fuel producers and carriers on terms of offtake agreements:** Friction on length (long term vs. spot), volume (how much) and price (what premiums are acceptable)
Economics and finance	3 **Lack of credible third-party cost estimates:** Makes it difficult for financiers and offtakers to assess investments and contract options for different zero-emission fuel pathways 4 **Lack of fit-for-purpose financing instruments:** Time horizons and risk appetite of existing financing options not suitable, e.g. PE fund life too short, infrastructure funds come in too late, insufficient pre-FID funding
Regulatory issues	5 **Lack of strong near- to mid-term mandates or a global price on carbon:** Policies emerging (e.g. EU, IMO) but need geographically reciprocal regulations to set a demand-side price and volume floor 6 **Lack of standard definitions, methods and certifications:** Hinders contracting terms, e.g. what defines "green"; how to measure, track and report emissions; how to assure quality
Supply chain and infrastructure enablers	7 **Methanol- and ammonia-specific risks:** Access to biogenic CO_2 for methanol, especially in locations close to cheap renewables, is getting tougher. Safety, especially for use as a marine fuel and handling at ports, is the biggest barrier for ammonia 8 **Competition and lack of alignment with other sectors:** Shipping competing against vs. collaborating with chemicals for methanol, fertilizers for ammonia and more broadly across sectors for H_2 and CO_2 9 **Zero-emission fuels infrastructure gap:** Uncertainties on responsibility for last-mile logistics. Physical gap between promising e-fuel locations and major ports – the infrastructure still needs to be expanded
Organizational factors	10 **Decision-making and risk appetite are limited by gaps in expertise:** Decarbonization decisions and P&L do not always sit with the same team, creating friction and requiring new ways of working together within companies

Source: Interviews with maritime decarbonization decision-makers from private-sector companies along the value chain; London International Shipping Week roundtable

1.1 Customer and consumer demand

Barrier #1: Lack of clear demand signals with sufficient willingness to pay

For all of the fuel producers and project developers interviewed it is still unclear how much methanol will actually be used in the dual-fuel ships on order today. If they all burned nothing but methanol, as much as 21 million tonnes per annum would be required. Depending on market dynamics, however, and the degree to which carriers (and eventually their end customers) are willing to pay, the lower limit could be much lower, making it difficult for fuel providers to have the confidence to make major investments.

At the same time, for carriers, it is unclear when the desired zero-emission fuel will be made available, at what locations and in what volumes, and at what cost. Given these perceived uncertainties, carriers may be hesitant to sign long-term fuel-offtake contracts.

Historically, carriers have been used to consuming the cheapest fuel available to minimize their operational costs and maximize competitiveness in a relatively tight-margin industry. Given the much higher current costs of zero-emission fuels over conventional fossil-based heavy fuel oil, absorbing the "green premium" remains difficult for carriers, unless they can credibly pass down the higher costs to their end customers.

Some acceptance by end customers of the need to pay a reasonable green premium is emerging, but the mechanisms are not developed, and transparency is lacking on price levels. The latter is important, as producers need greater reassurance that customers will pay the premium required to make a project viable, and the carriers who buy the fuel are concerned about their relative cost advantage in terms of maintaining competitiveness vs. other carriers.

> **An important factor for many carriers is not necessarily the higher cost of green fuel, but rather the need to ensure they can recover this cost from their customers – and subsequently a thorough investigation that they indeed land a competitive green fuel contract, keeping them cost competitive with the other green shipping providers.**
>
> Jens Andersen, Vice-President, and David Dupont-Mouritzen, Project Director, Copenhagen Infrastructure Partners

Barrier #2: Expectations gap between fuel producers and carriers on terms of offtake agreements

Given the current lack of market liquidity for zero-emission fuels and the hundreds of millions to billions of dollars required to construct new zero-emission fuel production projects, fuel producers typically expect to be able to secure financing for production facilities (through internal investment committees or banks) only if they can show secured long-term revenues/cashflows to their investors. Firm fuel-offtake agreements with carriers that last 10 years or more are a common way for fuel producers to show secured cashflows for a project. Shorter-duration agreements lasting seven to eight years with an option to negotiate are possible, but typically come with a price premium to account for the higher revenue risk for the supplier. This very quickly correlates with the barrier above on the willingness in the value chain to pay a premium and how to equitably split the additional cost the transition will represent, especially in its initial development phase.

Carriers today generally buy fuel on the spot market and are not used to entering into long-term fuel-offtake agreements. Many carriers also expect the cost of zero-emission fuel to drop significantly in the future, which further limits their appetite to sign long-term contracts. There is some precedent of producers and carriers in the liquefied natural gas (LNG) world agreeing to long-term contracts, but such deals have largely been driven by government support and energy-security concerns. The length of offtake agreements thus ends up being a major point of contention between fuel producers and carriers, which, in turn, limits investment decisions.

1.2 Economics and finance

Barrier #3: Lack of credible third-party cost estimates

Given that both the zero-emission fuel industry and the enabling technologies required are new, forecasting future costs is difficult, and confidence in such forecasts is low. The absence of credible estimates makes it difficult for carriers and financiers to assess different contracts and investments on a like-for-like basis. Because no engineering, procurement and construction (EPC) company has history or precedents in executing projects from end to end, any estimate of future costs is highly uncertain. Some developers end up revising the estimates, and this creates disparities among developers. The differences can create confusion across the value chain on what the real cost will be. Ultimately, overly optimistic estimates negatively affect conversations among developers and offtakers, creating concerns about credibility and deliverability of the end product, particularly at that cost.

> **As the green hydrogen and e-fuels business begins to grow, we are seeing a lack of consistency in supply-chain costs, feedstock costs and EPC costs. While the cost of projects will decrease with time as the industry is scaled, there is currently confusion among buyers on the credibility and deliverability of projects. To solve this situation, some of the same changes are required that we at Ørsted saw when scaling the offshore wind industry 20 years ago. This includes predictable financial support for the first wave of projects, infrastructure buildout and offtake incentives.**
>
> Olivia Breese, Senior Vice-President and Chief Executive Officer, Power-to-X, Ørsted

A few specialized zero-emission methanol developers have created standardized plant concepts with original equipment manufacturers (OEMs), which could potentially reduce cost uncertainties. However, these initial standardized plants will not be operational before 2026 at the earliest. This limits the short-term opportunities for other projects under development, especially those with a 2030 target operation date, to use the findings and implement them in their own projects. These discrepancies can thus make it difficult for developers of more mature projects to attract investors and enter into long-term contracts with potential customers. A credible third-party view on the range of expected costs to construct and operate a zero-emission fuel production plant as well as set up distribution would be extremely helpful for financiers and offtakers to assess different contract and investment options on a comparable basis.

Barrier #4: Lack of fit-for-purpose financing instruments

Finding sources of funding with the appropriate risk appetite and dollar investment size to develop zero-emission fuel projects remains a challenge. Venture-capital funding (with a high risk appetite but small dollar investment size) is typically available at the pre-development stage exclusively for start-ups, and traditional project financing (with a large dollar investment size but low risk appetite) can be found post-FID. But that leaves a gap in the middle. To close it, conventional investors such as private equity (PE), commercial banks and infrastructure investors have to go beyond their investment expectations and risk appetite to invest and thus accelerate the market. For PE firms, that means extending their funding periods beyond the typical exit cycle to account for the long development timelines of these capital-intensive projects. And commercial banks, as well as infrastructure funds, will need to invest earlier in the cycle – ideally before FID – to get a better deal and possibly the right to run the project's finances. Meanwhile, current macroeconomics and the high-interest rate environment is not making the financing situation any easier.

Some companies are starting to explore innovative financing options to spread the risk, including tax-equity partnerships, blended finance and special-purpose vehicles (SPVs), but it remains a relatively nascent space. Some others have also explored the possibility of combining concessional lending, such as is available from development banks and/or export credit agencies, to bring down the overall cost of capital. However, many are still hesitant about concessionary lending, as they perceive that the requirements are not always fit for purpose and fear such capital will add extra bureaucratic complexity.

> **Project developers should not shy away from exploring multilateral development banks like IFC, IDB, EBRD, FMO, etc. as they can remove political and country risk to make the projects more bankable. In addition, export credit agencies like EKF of Denmark or NEXI and JBIC of Japan not only provide low-interest loans (particularly for green development equipment), but they can fund high-risk feasibility studies and are important when it comes to mitigation of political and commercial risks and the provision of trade, investment and loan insurance. Ironically, as global warming progresses, insurance is becoming harder to secure to make a project bankable.**
>
> Alicia Eastman, President, InterContinental Energy

1.3 Regulatory issues

Barrier #5: Lack of strong near- to mid-term mandates or a global price on carbon

There are several policy mandates in place governing the decarbonization of the shipping industry, including: FuelEU Maritime's GHG reduction goal of 2% by 2025 and 6% by 2030; the IMO's goal of increasing the uptake of zero or near-zero GHG emission technologies, fuels and/or energy by 5%, striving for 10%, by 2030; and the European Union's Emissions Trading System for shipping, which will come into effect in 2024. These efforts remain in their infancy, however, and, except for the IMO mandates, are largely regional. This hinders firming up demand for zero-emission shipping fuels and the required supply.

Without a price on carbon or policy mandates that cover the industry and take its global nature into account, there is limited incentive for the shipping industry to decarbonize. Having the certainty that a global price on carbon would come into force at a given point would also help early zero-emission fuel projects to get off the ground by setting a price and volume floor, and thus acting as a firm backstop for demand.

> **A significant global IMO-led carbon tax on fossil fuels will enable deep-sea shipping decarbonization. Unfortunately, without a carbon tax that unlocks demand, we are unlikely to see sufficient green fuel projects materialize in time for industry decarbonization requirements.**
>
> Rasmus Bach Nielsen, Global Head of Fuel Decarbonisation, Trafigura Group

As part of its Marine Environment Protection Committee (MEPC 80) resolution, the IMO has committed to developing a maritime GHG emissions pricing mechanism by 2027. Hence, for the next 18 months or so, stakeholders need to work together to identify and define a fit-for-purpose instrument that helps to accelerate shipping's transition.

> **We need the proactive support of governments around the world to close the cost gap through supply-side and demand-side actions. First, by providing incentives that lower the cost of green fuel production, this will promote the rapid scaling-up of these new technologies. And second, by creating a strong and visible demand-pull through mandates and clear carbon-pricing signals. Together this can kick-start the industry to drive faster scale-up and better climate outcomes.**
>
> Brian Davis, Chief Executive Officer of C2X, a global green methanol developer backed by A.P. Moller Holding and A.P. Moller – Maersk

Even regional mandates and/or directives could play a role in the long and short term by forcing carriers to test how much more customers would be willing to pay.

> **For example, if the Nordic countries were to insist that any cruise ship coming into the region had to be low-carbon or electric, then the carriers would likely go out and start testing how much more the customers would be willing to pay for it.**
>
> Claes Fredriksson, Founder and Chief Executive Officer, Liquid Wind

Barrier #6: Lack of standard definitions, methods and certifications

A further cause of uncertainty among carriers and investors is the lack of industry-standard definitions for the resulting zero-emission fuels. For example, it is possible that the definitions and requirements of low-carbon sources of feedstock for zero-emission fuels, including CO_2 (whether biogenic, from direct air capture [DAC] sources, fossil-fuel-based or recycled from e-fuels) and H_2 (additionality, temporal and geographic correlation)[9] could change over time.[10] This could risk the zero-emission status of the planned fuels after a project has gone past FID and entered construction.

There is also an urgent need to pivot from the often vague green/blue/grey colour schemes now commonly used to define sustainability to more scientific frameworks based on emissions intensity. This could also help harmonize differences in requirements among emerging regional policy frameworks such as the EU RED II and US IRA to account for shipping's global nature. The IMO is currently working on a goal-based marine fuel standard regulating the phased reduction of the marine fuel's GHG intensity, which can solve this problem for the long term, but this is not expected to be ready until 2025 – and would then come into force by 2027. Broader consensus on this issue will be essential to boost investor confidence and get projects off the ground.

> **Lack of clear definitions and requirements could render projects obsolete or result in significant scope changes to meet new zero-emission requirements and thus risk investments in a project.**
>
> James Walsh, Senior Development Manager, Power-to-X, Mainstream Renewable Power

Finally, accurate emissions-accounting methodologies and certification schemes for measuring, tracking and reporting emissions will be needed to back up emissions-reduction claims and provide quality assurance of the fuel itself. Approaches to assuring the GHG chain of custody of zero-emission fuels are also not ready or fully accepted. The current incompatibility between transitory tools such as carbon attribution mechanisms through, for example, book-and-claim, and the GHG Protocol[11] creates uncertainty with carriers as well as shippers if they cannot claim the GHG benefits of zero-emission fuels in their sustainability reporting.

1.4 Supply-chain and infrastructure enablers

Barrier #7: Methanol- and ammonia-specific risks

For methanol, access to biogenic CO_2 as a feedstock, particularly in locations close to where cheap renewables are also available, is a known challenge. Until recently, developers of zero-emission fuels were able to access biogenic CO_2 (e.g. from a bioethanol facility or pulp and paper mill) cheaply or even at no cost. Now, however, they are competing with developers of carbon capture and storage (CCS) technology for tax incentives in the United States and elsewhere. Adequate supplies of biogenic CO_2 are likely to remain available until 2035, after which the sector will have to consider using recycled CO_2 or adopting emerging technologies such as DAC.

In the case of ammonia, access to CO_2 is not a problem. However, ammonia is toxic, and safety is the biggest concern, especially when it comes to its use as a marine fuel and issues associated with its handling at ports. On the vessel design front, several sea trials are in the works, including Seaspan's 15,000 TEU ammonia-powered container ship, to be launched by 2030.[12] In terms of using ammonia as a fuel, the Global Center for Maritime Decarbonization is conducting a number of pilot studies on ammonia bunkering safety.[13] More time and positive sea trials are needed, however, before ammonia can be considered fully safe to use as a fuel in marine environments.

Additionally, there is the broader question regarding the preferred long-term fuel choice for maritime decarbonization: methanol vs. ammonia vs. something else. Given the magnitude of the problem, it is likely that all options will be needed, but, unfortunately, due to the limited availability of financing and resources, these options end up competing with each other.

Barrier #8: Competition and lack of alignment with other sectors

The shipping sector is already competing with several other hard-to-abate industries for scarce supplies of feedstocks and end-molecules. For example, the chemicals sector is able to directly substitute fossil methanol with zero-emission methanol as a way to remove fossil-carbon inputs in its value chains, and the agricultural sector needs low-carbon ammonia to produce fertilizers. The biogenic CO_2 needed as a feedstock for zero-emission methanol could also be sequestered to generate carbon credits or used to make other competing products such as synthetic aviation fuel. And the supply of low-carbon hydrogen needed could have alternative uses in, among others, the aviation, iron and steel and chemicals industries.

If other sectors have a larger appetite and are willing to pay higher prices than the shipping industry, this could potentially limit the supply available for zero-emission shipping fuel buyers. However, on the flip side, it will have a positive impact on supply development. Other industries interested in the same product can increase producers' confidence in their investments by diversifying offtaker risks – especially appealing to those who find investing only in shipping fuel too risky. For example, it is possible to imagine a blended set of offtakers where the baseload of production output goes to a customer in shipping, and the remaining production volumes are fed to more cyclical end users in chemicals.

> **Although the potential demand for ammonia in multiple sectors as a key element to decarbonize said sectors has been raised by some as a concern regarding availability of clean ammonia, the reality is that large-scale production investments are actually facilitated by combining demand in multiple sectors. The synergetic effect between sectors should be seen as a positive towards the availability of ammonia and scalability of clean ammonia production.**
>
> Magnus Ankarstrand, President, Yara Clean Ammonia

Barrier #9: Zero-emission fuels infrastructure gap

Getting zero-emission fuels onto ships remains a complex challenge. The industry standard for determining whether suppliers or offtakers handle last-mile logistics has not yet been fully established. Offtakers currently do not engage in this and lack the capability to do so. Traditional bunkering companies could play a key role here with respect to bridging the gaps, but this logistics element for zero-emission fuels is still far from developed or tested.

> **In today's conventional fuel world, the commercial practice is supplier arranging the logistics to deliver the fuel onto the vessel. However, with the zero-emission fuel industry still in its infancy, it is not decided whether the fuel producers or carriers will arrange the logistics from the production site – adding another difficulty when discussing offtake agreements.**
>
> Tatsuro Watanabe, Chief Environment Sustainability Officer, Mitsui O.S.K. Lines (MOL)

Many customers and offtakers worry that unreliable last-mile logistics could significantly affect the security of their fuel supplies. Another concern is the often considerable physical distance between the most promising locations for zero-emission fuel production – such as Chile, South Africa or Morocco – and the major ports where network-based shipping lines (container and cruise) and shipping segments such as tanker and bulk are bunkering today. Changes in these patterns can occur, but in all cases there would still be a need to transport either hydrogen derivatives or finished fuel products to other locations, similar to the way bunker fuel oil is transported today. The international transport of hydrogen derivatives is already part of international maritime trade, so there is already a basis to build upon – and expand much further.

> **From a cargo-owner perspective, the security of supply, location of bunkering and last-mile delivery are all quite critical. Addressing these barriers is essential to raise the level of confidence in investing in offtake projects.**
>
> Rashpal Bhatti, Vice-President Maritime and Supply Chain Excellence, BHP

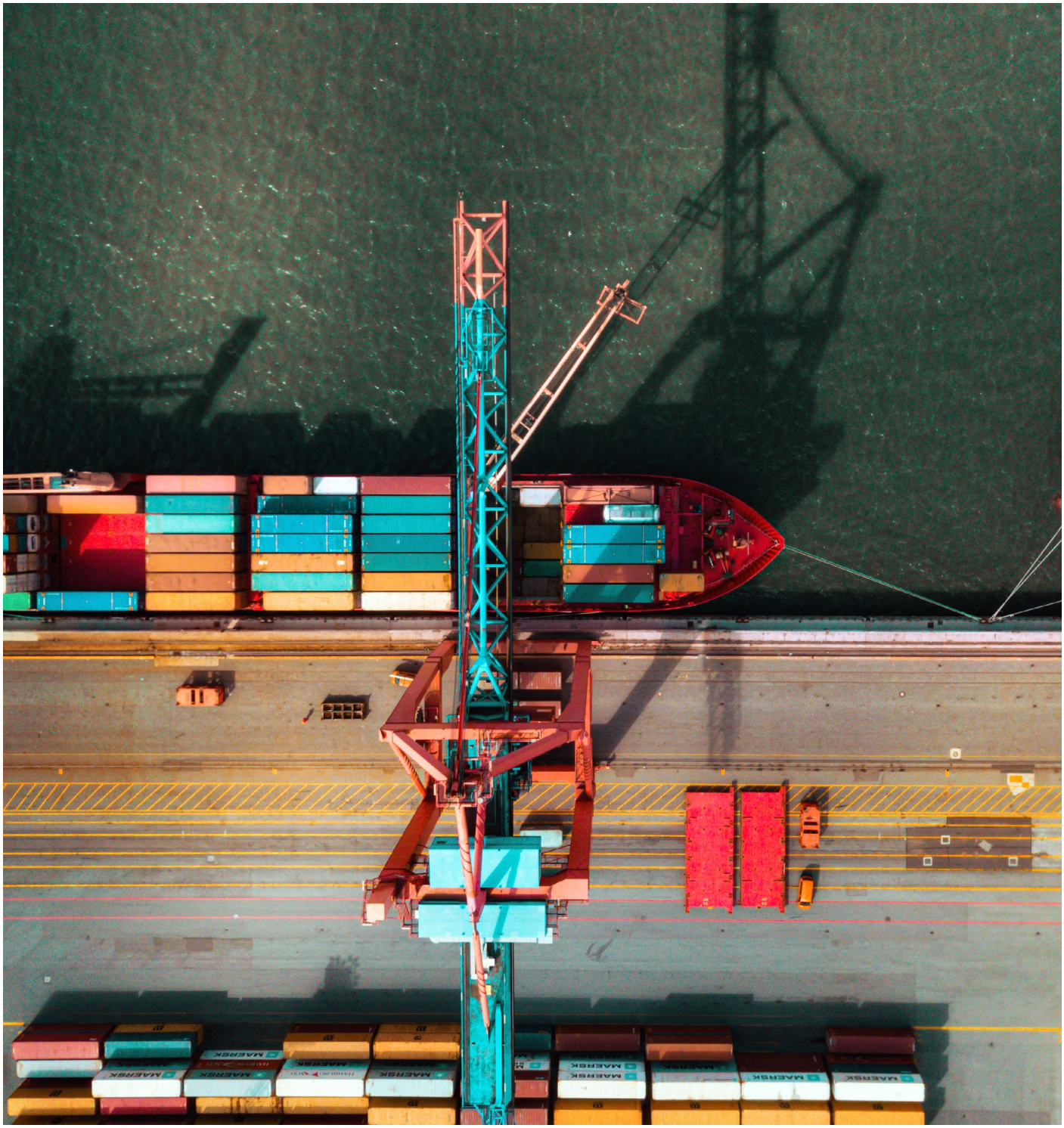
1.5 Organizational factors

Barrier #10: Decision-making and risk appetite are limited by gaps in expertise

In several instances, organizations that have an ambition to engage with maritime decarbonization or have made a pledge to do so lack the expertise to engage with the complexities of developing, procuring and financing zero-emission shipping fuels. Without the right level of expertise, the risks associated with funding and procurement can be poorly managed, posing barriers to investment. Further, in many cases decision-making on decarbonization occurs within specialized sustainability teams, creating conflicts and misalignment with commercial teams that might be responsible for profit and loss (P&L). As such, organizations transitioning from ambition to execution will require a significant change in organizational mindset (sustainability should be included as an inherent component of everyone's day-to-day work), operating models (ideally, leaders making zero-emission shipping fuel decisions should be fully empowered; GHG reduction should be a part of leadership key performance indicators [KPIs]) and upskilling of employees (what are the different options? how do they compare? what is the best way to market, price and sell green products at a premium?). Enhancing collaboration among various business functions will be critical in navigating the transition.

2 Charting the course

The list of barriers should not be seen as a reason to do nothing but as an opportunity for first movers and fast followers to act in new collaborative ways to isolate, share and eliminate risks and turn lessons learned and relationships built into a competitive advantage.



Barriers are not presented as a reason to do nothing but rather as an opportunity to collaborate in new ways to shape the green shipping market of the future.

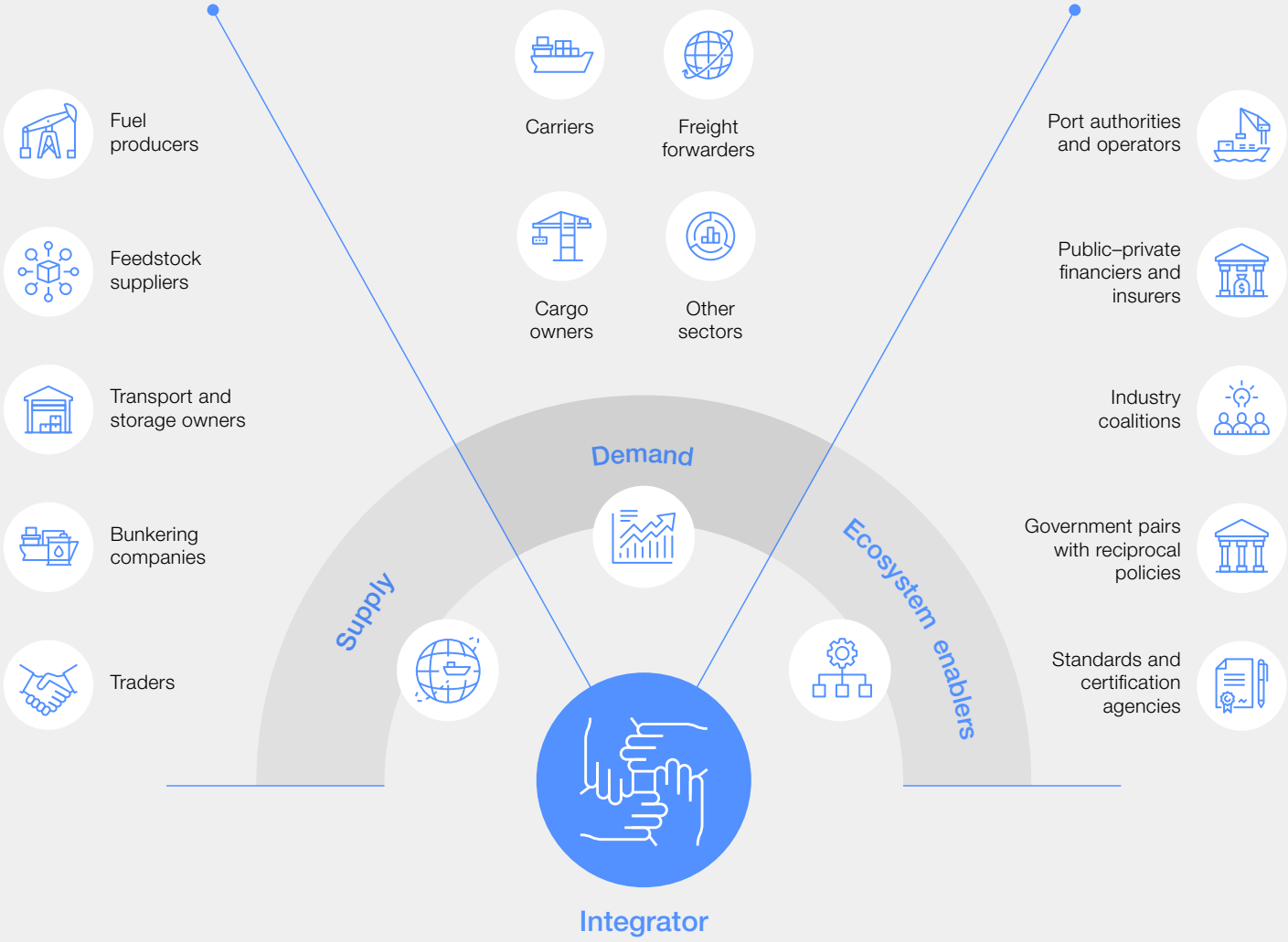
The barriers to developing and scaling zero-emission shipping fuels pose a daunting challenge, particularly given the many pieces that must come together in terms of investment, procurement and policy. Ultimately, however, these barriers are not presented as a reason to do nothing but rather provide an opportunity – early adopters of solutions can collaborate in new ways to shape the green shipping market of the future to their advantage, and to everyone else's.

To achieve a decarbonized shipping industry in the long term, it is paramount to formulate regulations, standards and government incentives. Ideally, any actions taken should drive economic certainty for projects and enable the mobilization of investments and funds. While the sector is engaging with and supporting national and regional initiatives and governments, as well as regulatory bodies such as the IMO and the International Organization for Standardization (ISO), it is evident that greater clarity in standards and increased regulatory support is urgently required.

It is important to remember that getting the first few projects off the ground will be critically important for long-term success, as doing so drives learning by doing at scale. There is no need to tackle every barrier simultaneously to kick-start pioneering projects.

Stakeholders – including fuel producers, project developers, carriers, cargo owners, bunkering companies, port authorities, financiers, governments and others along the value chain, as illustrated in Figure 4 – can unite under the leadership of a visionary integrator. Their mission: to identify and eliminate risks in innovative ways, and uncover collaborative approaches that position them strategically for the future not just of shipping but of a transformed global low-carbon market.

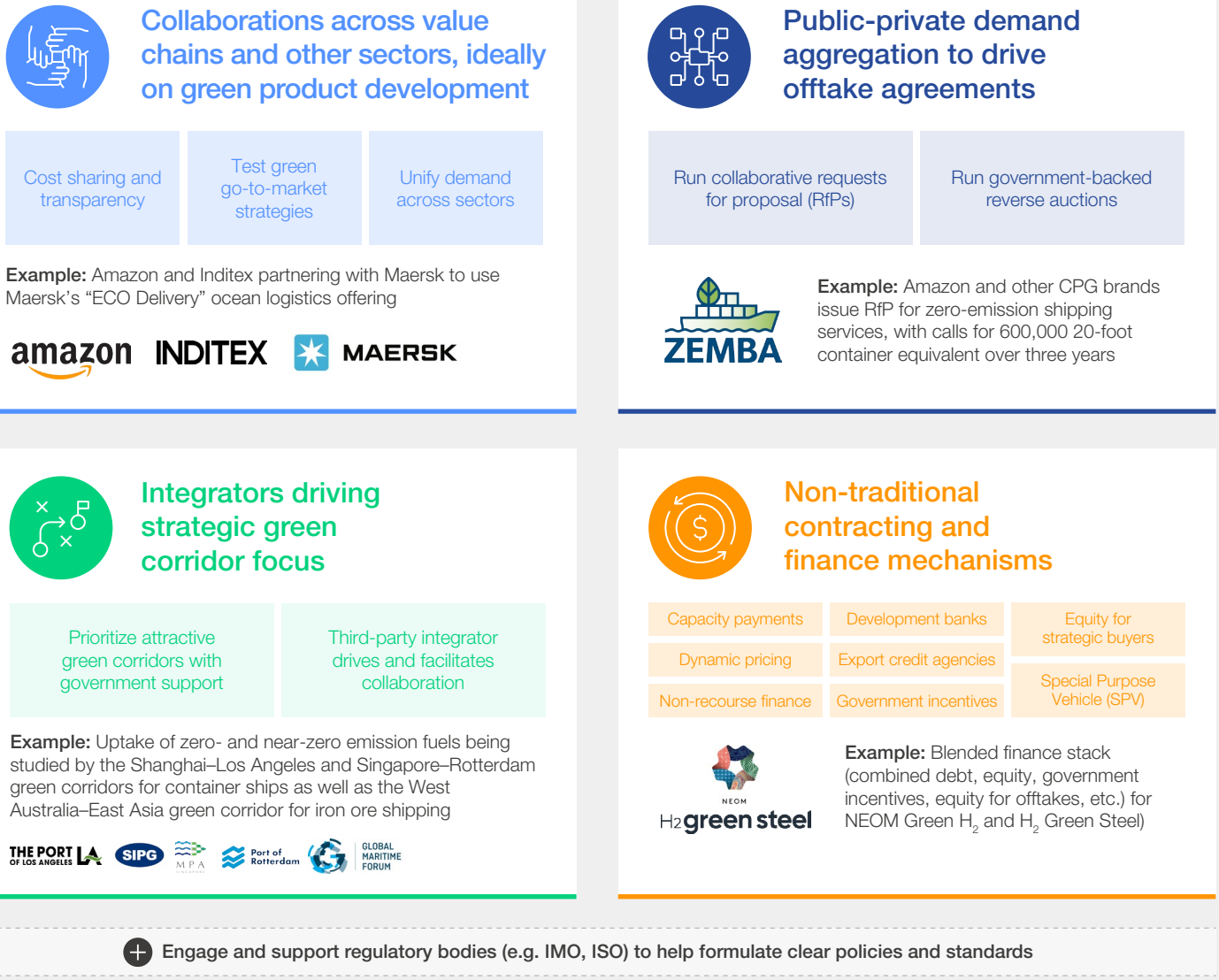
FIGURE 4 **Collaborations among public–private actors across the value chain needed to catalyse the first few zero-emission shipping fuel projects**



Source: BCG analysis

New types of collaboration are starting to take place but need first movers to take bold action to accelerate the decarbonization of shipping. Some of the collaborative solutions emerging to overcome the identified barriers are outlined in Figure 5.

FIGURE 5 **A set of interrelated actions could address demand uncertainty, discover price premiums, share risks and unlock the first few projects**



Source: Interviews with maritime decarbonization decision-makers from private-sector companies along the value chain; London International Shipping Week roundtable; press releases; company websites; BCG analysis

2.1 Collaborations across value chains and other sectors, ideally on green product development

Third-party integrators could pull together demand as well as drive transparent cost sharing across the value chain for projects in fuel production and bunkering. Such arrangements could help test new "green go-to-market" product strategies and the green premiums available for them – resulting in believable price signals, which are currently lacking. This could also help bridge gaps and address friction points between stakeholders in the value chain around prices, contract lengths and overall terms.

> **Collaboration along the value chain is essential so that we can distribute the cost of zero-emission fuels to the customers willing to pay.**
>
> Olivia Breese, Senior Vice-President and Chief Executive Officer, Power-to-X, Ørsted

As a starting point, companies could pursue regions (e.g. EU, US), sub-segments (e.g. container vessels) and end sectors (e.g. consumer-packaged goods, retail, e-commerce) with the most favourable regulatory and market conditions. Some leaders in this space are already pursuing opportunities along these lines. Amazon and Inditex (the parent company of fashion brands such as Zara and Massimo Dutti), for example, have formed a partnership with Maersk to use Maersk's "ECO Delivery" ocean logistics offering for their cargo.

Further, working with potential customers for zero-emission methanol and ammonia outside the shipping industry, including chemicals and fertilizer companies, could help hedge end-market risk and make investments more palatable for investors who do not want to bet fully on zero-emission shipping fuels just yet.

2.2 Public–private demand aggregation to drive offtake agreements

Bringing collaborative fuel-procurement agreements from conception to request-for-proposal (RfP) processes in order to increase offtake volumes could help drive demand and price discovery, especially as potential purchasers remain hesitant to sign long-term contracts. Examples include ZEMBA, a purchasing consortium that recently released an RfP to source green shipping services for cargo owners; a similar collaborative approach could be used for zero-emission fuel procurement. Reverse auctions, where fuel producers bid for the prices at which they are willing to sell different volumes of their zero-emission shipping fuel, backed by governments, could be another powerful approach to volume and price discovery, and associated policies could mitigate any anti-trust risks that might potentially arise when big carriers start aggregating their demand.

2.3 Integrators driving strategic green corridor focus

The continued development of green corridors in the most attractive production locations and shipping routes, with reciprocal government and policy backing at end points, linked with the development of infrastructure that supports this approach, will be critical to success.

> **Bringing value-chain partners together through green corridors – working with a coordinated approach towards infrastructure and policies, as well as transparent cost-sharing across all partners, is a way forward.**
>
> Laure Baratgin, Head of Commercial Operations, Rio Tinto

The key port locations and the corridors themselves enable multiple stakeholders to participate, test and align on decarbonization options, logistical details and policy enablers across jurisdictions. Some current examples include the Shanghai–Los Angeles and Singapore–Rotterdam green corridors for container ships and the West Australia–East Asia green corridor for iron ore.[14,15,16]

The role of green corridors, also related to demand aggregation, is significant and, besides the other benefits highlighted above, can help create more certainty about what volume of fuel is needed and at what locations for which vessels, sending a very strong demand signal to fuel producers in a specific geographic location.

2.4 Non-traditional contracting and finance mechanisms

Most industry leaders engaged in this study expressed a willingness to explore novel risk/reward-sharing mechanisms to get the zero-emission shipping fuel market going.

A wide range of innovative approaches to contracting and financing for zero-emission shipping fuels are possible. These include: minimum revenue or capacity payments combined with a volume-based payment (similar to the approach used for power plants and pipelines for natural gas), dynamic contract pricing (where, for example, an input factor such as electricity is used to recalibrate the contract price, thus better sharing the cost uncertainties and risks between suppliers and offtakers), offering equity stakes to strategic buyers in lieu of debt or contract payments, combinations of senior and junior debt,[17] non-recourse financing, SPVs and government incentives such as supply-side subsidies to reduce production costs, loan loss guarantees, etc.

In fact, most industry leaders engaged in this study expressed a willingness to explore novel risk and reward-sharing mechanisms to get the zero-emission shipping fuel market going. In some cases, they were also willing to open up and explain their cost structures to offtakers, to provide greater transparency on the green premium – which, in turn, could help persuade offtakers to sign long-term deals, thereby making up for the lack of a market index, something that will be needed as the market develops.

Interviewees also pointed to the possibility of tapping into concessionary lending available through public–private institutions – these are currently an underused resource due to lack of awareness and difficulty in navigating the process. Examples include development banks such as the US International Development Finance Corporation, the International Finance Corporation, the European Investment Bank and the Inter-American Development Bank, as well as export credit agencies (ECAs); such funds could come not only at lower-than-market rates but also stimulate further public- and private-sector investments by lending credibility to the project. In some cases, development banks might also be able to provide extra resources to project developers and be willing to write off the cost of pre-FID phases, further minimizing risk.

As an example, the NEOM, ACWA Power and Air Products green H_2 project in Saudi Arabia and the H_2 Green Steel project in Sweden have explored some of these combinations and could serve as an inspiration for participants in the shipping sector. In the first project, an SPV was established, with Air Products committing to a 30-year offtake agreement, and a combination of 23 local, regional and international banks and investment funds participated with the finance stack, split into 20% equity and 80% debt. For H_2 Green Steel's large-scale green steel plant in Sweden, more than 30 public–private investors participated through a combination of equity investments into H_2 Green Steel as a company and debt finance for building the plant in Sweden. Some offtakers were enticed by the equity upside, with the Swedish and German government grants supporting the overall deal structure.

3 Full speed ahead

Cross value-chain collaboration, including the sharing of innovative finance and contract models, is needed to reduce investment risks and drive the development of zero-emission shipping fuels.

Overcoming barriers to the development of zero-emission shipping fuels will be no easy task. It will take willingness on the part of all public–private stakeholders to band together not only to reduce the long-term risk of their investments but also to act before all risks have been eliminated.

The persistent plea to work across the value chain to solve what is one of the maritime industry's most significant challenges is justified. Many of the barriers outlined in this paper require unprecedented collaboration across unconventional partnerships. Overcoming these obstacles involves going beyond mere calls for cooperation and partnership; there is a need to actively share concrete models, such as innovative contract and finance structures, to drive the industry towards success.

The shipping industry's decarbonization goals are clear, and virtually all stakeholders, especially the first movers, are agreed on the urgent need to meet them by facilitating development of the first few projects. Now is the time to weigh anchor and set sail.

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Endnotes

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10. So far, the European Union, through its Delegated Act pursuant to RED II Article 27 (3) and 28 (5), has led the field in providing definitions for H_2 and CO_2 sources in scope for e-fuels. However, they are only regionally binding and do not account for the global nature of shipping. The IMO is expected to come up with industry-wide shipping-specific definitions and guidance, but not until 2025.
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17. Senior and junior debt refers to differences in repayment priority if a firm faces bankruptcy or liquidation. Senior debt is often secured and more likely to be paid back whereas junior debt is not secured and is more of a risk. This also means that senior debt comes in at a lower rate than junior debt, given the lower risk factor.

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