Accelleron

Accelerating to net zero

Deadlock:

What's stopping shipping's carbon-neutral fuel transition?

Foreword

Shipping's cross-sector journey to net zero

When Swiss engineer Alfred Büchi, Accelleron's forefather, invented the turbocharger in 1905, he set in motion a new era of maritime progress. By allowing marine engines to deliver greater power and range from the same amount of fuel, his innovation helped to establish shipping as the world's most energy-efficient form of transport. We have carried that spirit of engineering efficiency forward for more than a century.

Today, efficiency is also the industry's fastest decarbonization lever. Energy-saving technologies applied to the largest 50,000 ships in the global fleet could deliver emissions cuts beyond the International Maritime Organization's (IMO) 2030 reduction target of 30%. Leading operators are already cutting ship emissions by 30-40% with efficiency boosters such as turbocharger upgrades, digital tools, and wind-assisted propulsion.

But efficiency alone is no longer enough. In 2024, shipping emissions climbed to an all-time high[1] – precisely when science said they should have peaked and begun to decline. Last year also marked the first full year of global warming above 1.5°C[2] – not in 2050, as once hoped, but a quarter of a century early.

Indeed, the gap between climate goals and reality is no longer abstract or debatable. It is clear and present in fires, floods, droughts, and heat waves that are straining communities and disrupting supply chains worldwide.

While we cannot speak for climate progress in other sectors, we do have to ask: why, after nearly two decades of decarbonization innovation and investment, has shipping not yet managed to slow emissions or reverse the climate spiral?

The answer is twofold. First, the vast number of existing energy-saving technologies have yet to be applied to the majority of the global fleet. Less than 40% of the largest ships have implemented these measures.

Second, even if applied across the full global fleet, efficiency can only stretch the use of the fuels we are currently using, and slow the rise in emissions and temperatures. True decarbonization requires the use of new, carbon-neutral fuels.

And that is the industry's unanswered challenge: the energy transition. It remains unanswered, not because of technology – ships capable of running on carbon-neutral fuels like e-methanol and e-ammonia already exist – but because the fuels themselves are still nowhere to be found.

We built the ships. The fuels did not come. But why? And when can we expect them?

This report seeks to shed light on the energy transition challenge, and to propose a solution. In the process of investigating the challenge, we found stakeholder opinion converging on one guiding truth: green hydrogen is the foundation of shipping's net zero future. And yet, the economy of scale required to catalyze hydrogen production is beyond the reach not only of shipping, but of any single industry.

In fact, the scale required nearly defies imagination. To produce hydrogen at even remotely competitive costs, a single green hydrogen hub could span up to 30 times the landmass of Singapore, or one-tenth the size of the United Kingdom. This points to a future of hydrogen basins the size of small nations that will redefine the global energy landscape.

Hydrogen production itself is also an energy drain. By 2050, the annual green hydrogen needs of maritime alone will reach 100 to 150 million tons, requiring 4,900 to 5,800 gigawatts of renewable energy to produce. That equals nearly a decade's worth of today's annual renewable capacity.

And that is just for shipping. Then we have aviation, steel, cement, chemicals, power, and agriculture. Combined with shipping, these hard-to-abate sectors account for more than 70% of global emissions, and all of them will depend on the same green hydrogen building block to reach net zero. Together, they will require roughly 500 million tons of hydrogen annually by 2050,[3] and $9 trillion in cumulative investment to produce it.[4]

In contrast, only about 38 million tons of green hydrogen are currently in the pipeline, supported by less than $320 billion in committed investment.[5] What is missing is an entire order of magnitude, although we still have two decades to bridge the gap.

But that gap is, in fact, the fault line at the heart of shipping's stalled energy transition. The hardest part of our decarbonization journey turns out to be scaling green hydrogen as the building block for e-fuels, a task made exponentially harder, because no industry can achieve it alone. It is also the part of the journey that will determine whether we reach net zero on time, or at all.

To be clear, the task at hand is to undo the work of nearly two centuries of industrial emissions in 25 years. To meet the sheer scale of that challenge, we will need to muster an equal degree of collaboration, because shipping's energy transition cannot proceed in isolation. It will have to be part of a global, cross-sector energy transition spanning all seven hard-to-abate sectors. And it will depend on a tide of hydrogen investment powerful enough to lift the entire global energy system.

But we must also be clear about what is at stake. Shipping is the backbone of global trade and the energy system itself. If shipping fails to decarbonize, the rest of the world will struggle to do so, because the arteries of commerce and energy will still carry the carbon of the fossil era. For the world to achieve a net zero future, shipping must decarbonize.

However, we also believe that shipping is uniquely positioned to lead this cross-sector energy transition and the collaboration required to achieve it. We can lead, as the carrier of 80-90% of global trade, with the only binding global climate regulation of any sector, and with ports that serve as natural points of convergence, where energy meets cargo, and industries meet one another.

In fact, ports like Singapore, Açu, and Rotterdam are already taking the first steps in this cross-sector energy transition, aligning national policy with global maritime targets and aggregating cross-sector demand. In doing so, they have drafted the first blueprints of the cross-sector hydrogen economy.

In this report, we compare shipping's potential carbon-neutral fuel pathways, and identify hydrogen as the core energy transition challenge not only for shipping, but also for other hard-to-abate sectors. We then analyze systemic scaling deadlocks, arriving at the conclusion that these can only be solved by a cross-sector approach, largely orchestrated at the port-level. We then offer a basic set of criteria to help ports assess their roles in a new global port ecosystem, anchored in a cross-sector hydrogen economy.

It is clear from our research and analysis, and from the contributions of the many stakeholders who were good enough to share their expertise and insights for this report, that reaching net zero is not only about fuels or systems, but about forging a new paradigm of partnership.

Fortunately, partnership has always been one of shipping's great virtues. For thousands of years, shipping has connected cultures, carried science and progress across oceans, and overcome impossible odds through pragmatism, determination, and solidarity.

As an industry, we have already proven, in a relatively short time, that we can prepare our global fleet for a decarbonized world. Now, it is time to partner with other sectors to secure the fuels we all need to carry us, finally, to that net zero shore.

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67% increase in maritime fuel consumption by 2050, as maritime transport doubles

803 million tons of methanol,
or
859 million tons of ammonia,
or
333 million tons of
liquefied natural gas each year
required annually by 2050, to fully decarbonize shipping

100–150 million tons
green hydrogen feedstock required by shipping annually by 2050 to produce e-methanol or e-ammonia – competing directly with aviation, steel, power generation, agriculture, cement, and chemicals

500 million tons
annual green hydrogen demand required globally by 2050 to reach net zero

$9 trillion
required from now to 2050 to build the global green hydrogen supply chain

Executive summary

Accelleron's stake in the carbon-neutral fuel transition

Shipping has long been the backbone of global trade, moving 80–90% of the world's goods with unrivaled efficiency. Since the International Maritime Organization (IMO) launched its greenhouse gas working group in 2008,[6] the industry has shifted onto a net zero trajectory for 2050, investing in technologies that prepare fleets for carbon-neutral fuels and a decarbonized future.

Since becoming independent in 2022, Accelleron has also made decarbonization its North Star. Turbocharging, digital, and fuel injection technologies deliver the efficiency to cut emissions now and the flexibility to operate on tomorrow's carbon-neutral fuels. Fuel injection is also a critical enabler of the energy transition, ensuring safe and efficient combustion of new fuels with different properties, and allowing dual-fuel ships to use conventional fuels or carbon-neutral fuels as supply dictates.

Now, after nearly two decades of innovation and investment in decarbonization technologies, shipping stands at a turning point. The ships and the engines are more efficient than ever, and ready to run on carbon-neutral fuels like e-methanol and e-ammonia. What is missing is the fuel itself, produced at scale and at a competitive cost.

That is the challenge this report tackles: why fuels have not kept pace with ships, which barriers block their development, and how a new level of partnership across industries can break the deadlock and unlock the energy transition.

Maritime fuel pathways, the scale of the challenge, need versus reality

The scale of the energy transition required to get the maritime industry to net zero is immense. Maritime transport work will double by 2050, increasing energy consumption by 67%. Even if efficiency improvements reach 17%, demand will far outstrip savings.

To supply shipping's 2050 needs, any single carbon-neutral fuel would have to scale to levels that dwarf current global production. Each year, full decarbonization would require 803 million tons of methanol, 859 million tons of ammonia, or 333 million tons of liquefied natural gas. Ammonia alone would demand 6 times current global fossil-based production.

Biofuels, although useful as a bridge, are not scalable. Shipping's share is less than 1% of the 111 million tons of biofuels available today, with road transport using 98.9%, and aviation 0.5%.[7]

This is why, unlike the IMO, which permits biofuels in its 2030 checkpoint, the EU, under FuelEU Maritime, does not count crop-based biofuels towards the fulfilment of greenhouse gas intensity targets. This approach reflects a more comprehensive cross-sector view of biofuel constraints, and is intended to channel investment toward green hydrogen-based e-fuels that can scale.

E-methanol and e-methane hold potential, but their scale-up depends on direct air capture (DAC) of carbon dioxide, a technology still in its infancy.

But the real challenge for the maritime energy transition is revealed by the green hydrogen feedstock underpinning all e-fuel production.

By 2050, shipping alone will require 100–150 million tons of green hydrogen every year, estimated to cost around $3 trillion[8]. Producing it will also require 4,900 to 5,800 gigawatts of renewable electricity, nearly a decade of today's global capacity. That means that green hydrogen and e-fuels cannot be produced from the public power grid. They will require their own dedicated giga-scale renewable plants and carbon capture networks.

Meanwhile, fossil fuels will remain part of the mix for decades, making carbon capture indispensable both as a feedstock for e-fuels and as a safeguard to contain emissions.

The 5 deadlocks: how shipping's fate is tied to the wider, cross-sector energy transition

The ships are ready. The fuels are missing. Ships for ammonia and methanol are setting sail. Dual-fuel ships dominate orderbooks. But scalable carbon-neutral fuels are nowhere available, and emissions continue to rise. What emerges is not a single barrier to the maritime energy transition, but five interlinked deadlocks that extend beyond shipping into every hard-to-abate sector.

Deadlock 1: Fuel pathway uncertainty fragments demand and dilutes investment in scalable net zero solutions

The proliferation of fuel pathways has created paralysis. LNG, biofuels, and e-fuels are all are being trialed, but none at scale. Shipping, historically the first in line for the leftovers of the fossil economy, now faces the reverse: competing for premium fuels.

Meanwhile the only truly scalable carbon-neutral fuel are e-fuels, based on green hydrogen. Shipping alone will need 100-150 tons of green hydrogen by 2050, and the total estimated green hydrogen need across sectors is 500 million tons by 2050.[9]

The economy of scale required for competitive green hydrogen production demands sizable, long-term offtake contracts, which neither shipping, nor any other industry can commit to, before a reliable, affordable supply is ready. Suppliers cannot commit without offtakes, and offtakers cannot commit without supply. Who will move first?

Deadlock 2: Concentrated fuel supply versus global fleet flexibility

In a hydrogen economy, carbon-neutral fuels are not just costly; they are geographically constrained. Green hydrogen hubs are, by necessity, the size of small nations. The Western Green Energy Hub in Australia alone will be 30x the size of Singapore, or one-tenth the landmass of the UK, and will use 70 gigawatts of renewables to produce 28 million tons of ammonia per year.

Such scale can drive costs down, but it also concentrates supply in just a handful of locations. Container lines with predictable rotations can plan for it; bulk and tramp operators cannot.

Deadlock 3: The green finance paradox

Finance exists but is not flowing at the scale required. Banks and investors are pouring trillions of dollars into ESG funds, but only a fraction of that goes to shipping.

Analysts estimate the total of global ESG assets under management at $3.5 trillion,[10] with only $14.5 billion earmarked for shipping since 2018.[11]

Shipping's fragmented ownership base, long vessel lifespans, hazy ESG reporting, and uncertain regulation make investors reluctant to award ESG funding.

Split incentives compound the problem: shipowners decide on engines, but charterers and cargo owners pay for fuel.

However, oil and gas majors, with the ready balance sheets to build such giga-projects, hesitate. A $10 billion investment in green hydrogen must compete with a $10 billion investment in LNG, where returns are clearer.

Consumer-facing cargo alliances like ZEMBA are demonstrating early offtake models that work for container lines. But bulk segments cannot absorb these green premiums.

Without aggregated, cross-sector commitments to boost returns and share the risk, the green finance gap will persist.

Deadlock 4: Regulatory ambition versus implementation reality

The International Maritime Organization (IMO) adopted its Net Zero Framework in April 2025, the first global carbon pricing system for an entire industry. It will raise $10–12 billion per year by 2030 for the IMO Net Zero Fund.

Ambition is historic. But incentives will not flow until 2028. That is too late for projects that must reach final investment decision now, to deliver fuels by the 2030s. Default factors also risk penalizing emerging lower-carbon technology with higher compliance costs.

Most crucially, national energy policies and incentives on the supply and demand sides must align with the IMO's net zero ambition, or investment in carbon-neutral fuels will remain stalled and the transition deadlocked.

Deadlock 5: Infrastructure bottlenecks at ports

Even if fuels are produced, they cannot flow without port infrastructure. Ports must connect shipping to grids, pipelines, water, and storage networks that also serve aviation, steel, power generation, and agriculture. Each ton of hydrogen requires 50–55 megawatt-hours of electricity[12] and 20–30 liters of water.[13] At hundreds of millions of tons, competition for electrons and water becomes acute.

Permitting adds further delays. Even after final investment decision, projects can take 5–7 years before production.

Ports also face a dual burden and opportunity: maintaining legacy bunkering while phasing in carbon-neutral fuels, without stranding assets.

Orchestrating a cross-sector, hydrogen-based energy transition can resolve the 5 deadlocks

Every deadlock shares a common cause: coordination failure which cannot be solved by shipping alone.

Every solution points to the same path: a cross-sector energy transition based on green hydrogen and e-fuels, with ports as the natural nexus between shipping and other sectors.

A cross-sector approach to fuel pathways provides a more comprehensive view of need, availability and scalability, and supports regulation and incentives at a national and global level that focus on green hydrogen and e-fuel development.

Shipping's 300 million tons of annual fuel demand looks vast, but even when it isn't spread out across multiple fuel pathways, it is too small to trigger green hydrogen development.

Aggregating cross-sector demand with aviation, steel, cement, chemicals, power, and agriculture transforms thin, fragmented signals into large, bankable commitments.

Aviation and steel also provide steady, high-value offtake. Ports where airports and shipping terminals converge, such as Amsterdam, can anchor joint demand.

Nation-sized hydrogen hubs, which could deliver green hydrogen and e-fuels at a competitive price, but only cross-sector collaboration will provide the offtake volume required to mobilize their development.

By producing their own renewable energy, such hydrogen hubs also alleviate ports of the burden of production.

Ports as platforms for the cross-sector energy transition

Ports are the natural nexus of maritime, industrial, and energy systems. They have long been central to energy trade.

Their role must now expand: from handling one or two fossil fuels to orchestrating the phase-in of carbon-neutral fuels, while legacy fuels phase out.

Ports cannot all play the same role. Geography and resources define their positions in a new archetype system. Producers generate fuels locally. Connectors distribute through pipelines and clusters. Receivers import at scale. Sources export from nation-sized hydrogen hubs with world-class renewables. Together, these archetypes map an interdependent hydrogen economy.

Scale is decisive. The Western Green Energy Hub in Australia, at 30 times the landmass of Singapore, illustrates this new reality. Hydrogen hubs the size of small nations will reshape trade flows, reducing the importance of some ports, while elevating others.

Ports that commit early to defined roles, readiness frameworks, and cross-sector offtake will capture opportunity. Those that hesitate risk obsolescence.

When ports can find their place in the green hydrogen economy as producers or export sources, receivers, or connectors for e-fuels, they can ensure that a greater portion of the global fleet will have access to those fuels. This will help shipping retain some level of the flexibility that has been its hallmark for centuries.

Key findings & recommendations: Breaking the deadlock & mobilizing a cross-sector energy transition

This report's analysis yields 8 key findings.

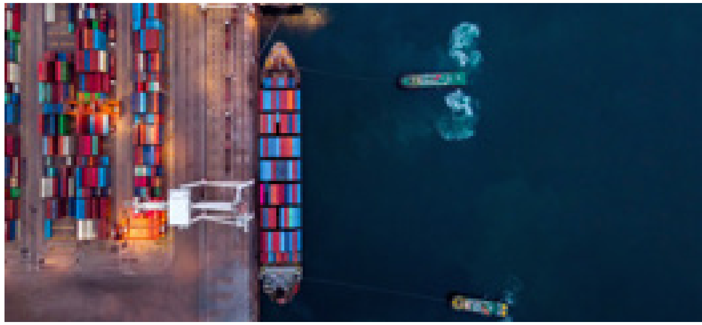
1. **Efficiency must 'go viral'.** Efficiency is the most abundant and cost-effective decarbonization lever today. Technical and operational efficiency measures could cut emissions over 30% by 2030. Efficiency is also a multiplier, amplifying the impact of every ton of scarce and expensive carbon-neutral fuels.
2. **The ships are ready. The fuels are missing.** Dual-fuel vessels dominate orderbooks, but planned e-fuels cover only 4–8% of the IMO's 2030 target.
3. **Green hydrogen is indispensable.** To achieve its energy transition, by 2050, shipping alone will require 100–150 million tons of green hydrogen, competing directly with six other hard-to-abate sectors for a total of 500 million tons needed by 2050, and requiring a total of $9 trillion to develop. Cross-sector alliances are the only way to trigger requisite production at scale.
4. **Biofuels are a stopgap, not a destination.** Under a cross-sector lens, , biofuels can supply only a tiny fraction of maritime demand. Investment in biofuels diverts money away from scalable e-fuels.
5. **Carbon capture is essential.** Direct air capture must be scaled to produce e-methanol and e-methane. Carbon capture and storage will also be indispensable to containing emissions from fossil fuels, which will remain entrenched across sectors for decades.
6. **The green finance gap must be closed.** ESG capital exists, but it cannot flow without consolidated demand, long-term contracts, and fit-for-purpose instruments. Without new structures to de-risk giga-projects, trillions in capital will remain idle. Digital emissions reporting from ships can also provide greater ESG certainty and support stronger investor interest.
7. **Global goals need local action.** The IMO Net Zero Framework is strong, but incentives only start in 2028, and $10-12 billion a year does not approach the trillion-dollar level of finance needed for e-fuels. Using a cross-sector lens, national energy policy must create corresponding incentives on supply and demand sides to stimulate hydrogen production and support the IMO's net zero goals.
8. **Ports provide the platform, but who will lead?** Ports are the backbone of global trade and energy. They must now aggregate cross-sector carbon-neutral fuel demand, to mobilize investment and unleash the global cross-sector energy transition, and ensure smaller ports and bulk operators can also participate in the hydrogen economy.

   As yet, the exact template for that action is nascent and will vary from one port to the next, based on both existing port roles and future geographic concentration of green hydrogen.

Conclusion

The report confirms a stark truth: shipping's net zero fate is inseparable from the cross-sector energy transition.

The industry has built the ships. But only by joining forces with other hard-to-abate sectors in need of the same green hydrogen and e-fuels for their own transitions, and by leveraging ports as the meeting point for solidarity and action, will shipping reach the net zero shore.



Accelleron's stake in the carbon-neutral fuel transition

974 million tons

Maritime emissions in 2024, the highest on record, surpassing previous peaks reported by the IMO and others

>1.5°C

The average global temperature in 2024, which was the first full year of global warming above 1.5°C, 25 years ahead of schedule

Nearly 50%

of all ship tonnage ordered in 2024 was alternative-fuel capable

The ships are ready, but the fuel is missing

The core barrier to achieving net zero by 2050

75%

of shipping's potential 2030 emission cuts will come from efficiency measures, up to a 35% global shipping emissions reduction by 2030, vs. 2008

6-14%

Average cost above business-as-usual for ship-wide energy-saving technologies in 2030 – forecast to be less than combined cost of fuel and carbon pricing.

"To unlock the added investment required, we need to find a better way to distribute the cost and gain, which points us towards ever increasing efficiency."

Martin Crawford-Brunt (Lookout Maritime)

"In 2023, we achieved a 10% reduction in GHG emissions compared to 2021, and are on track to meet our 45% reduction target by 2030, which aligns with the Paris Agreement's 1.5°C pathway."

Shingo Mizutani (NYK Shipmanagement)

Accelleron's stake in the carbon-neutral fuel transition

With decarbonization as its north star, Accelleron is channeling its investment **into three levers that cut fuel consumption and emissions at sea: turbocharging, digital optimization, and fuel injection. These levers are not only the foundation of Accelleron's business strategy. They also support the three time horizons for maritime decarbonization.**

Horizon 2030: Efficiency reigns

The fastest way to bend the emissions curve this decade is still efficiency.

The IMO-commissioned CE Delft study "Shipping GHG emissions 2030" analyzes the maximum technical abatement potential by 2030.[14] According to the study, efficiency measures alone could help the industry exceed the IMO's 2030 target of reducing emissions by 30%. The study quantifies what many operators know in practice: energy-saving retrofits are the fastest, most scalable lever for decarbonization through 2030.

However, to have that impact, the vast majority of the 50,000 largest ships in the global fleet would need to apply similar measures. To date, less than 40% have done so.[15]

Can the fleet afford it? According to the CE Delft study, a full suite of energy-saving retrofits could cost less than carbon exposure by 2030.

With 2024 marking the first full year of 1.5° global warming,[16] 25 years ahead of schedule,[17] it is time for the industry to pick up the pace and **"go viral" with efficiency**.

Efficiency will further gain in importance as future carbon-neutral fuels are used, serving as a multiplier to make every ton of expensive, scarce, low-density fuel go farther.

Horizon 2040: Bridging the 2030s and early 2040s with flexibility and carbon capture

Efficiency can take the industry far, but it will not deliver full decarbonization on its own.

At some point, efficiency meets its limit and only carbon-neutral fuels can drive deeper decarbonization. That is why the industry has turned its attention and investment to innovations that make ships ready for those fuels.

In 2024, nearly half of all tonnage ordered was alternative-fuel capable.[18] In 2025, that momentum has accelerated.[19]

The industry is also investing in flexibility to ensure that these ships are not stranded. This means dual-fuel engines that can be converted for e-fuels at scheduled drydocks, and investing in prelaid piping and other connectors to make it easier to integrate changes in the future. Engine and system designers are embedding flexibility into every platform.

Since thousands of vessels delivered between 2010 and 2030 will still be trading in the 2040s, retrofitting now for efficiency, and later for e-fuels, will remain critical. The success of decarbonization in this period will be defined by flexibility, ensuring today's vessels can bridge the energy transition.

Horizon 2050: The final stretch to net zero

The final test for shipping will be its ability to complete the energy transition. Deep decarbonization leading to net zero will depend on using carbon-neutral fuels at scale. Since the only truly scalable carbon-neutral fuels are e-fuels, this presents a dilemma.

It will not only require from $1.2[20] to over $3 trillion in investment,[21] depending on how much shipping must pay for the green hydrogen infrastructure underpinning its e-fuels, but it will also require a widespread economic, geographic, and cultural transformation. Shipping must move from being first in line for the leftovers of oil economy to competing for high-value carbon-neutral fuels based on expensive green hydrogen, probably e-ammonia, e-methanol, and possibly e-methane.

Uncertainty clouds this horizon. Of the many fuels explored, no single pathway has yet emerged as dominant, because the industry must use what it can get now, while still hoping for a better future.

This is where the wheels of innovation seem to meet their limits in shipping. Because the first e-methanol and e-ammonia ships are already setting sail.

After nearly two decades of investment and innovation, **the ships are ready, but the fuel is missing**.

Because carbon-neutral fuels are virtually absent, shipping has been forced into a divided fuel strategy.

Too many fuels, not enough scale.

And the underlying challenge that has forced this hedging across so many fuel pathways is this: scalable, green hydrogen and e-fuels are beyond the direct reach and control of shipping.

The challenge is not only bigger than shipping, but also bigger than any other single sector.

When such fuel supplies do finally become available, it will not be all at once, but in increments.

Who will be first in line remains uncertain, but most doubt shipping can compete against sectors already paying for premium fuels.

The maritime industry is stuck.

Shipping faces a 3-way carbon-neutral fuel deadlock between shipowners, fuel producers, and ports, each waiting for the other to move first.

- Ships wait for dependable fuel supplies in dedicated green corridors, if not at all of their favorite ports globally.
- Fuel producers wait for the necessary volume and duration of offtake contracts to move forward with investment and development.
- And ports wait for both; ships that will buy their expensive new fuels, and fuel producers that will supply them.

This stalemate blocks the scale-up of carbon-neutral fuels in shipping and stands as the greatest barrier to achieving a net zero maritime economy.

Report hypothesis: The success of the maritime energy transition hinges on a broader cross-sector energy transition.

Maritime fuel pathways, the scale of the challenge, need versus reality

101.6%

Increase in maritime transport work by 2050 (from 59.23 to 119.43 trillion ton-nautical miles)

67.4%

Increase in energy consumption by 2050, to 16.0 exajoules

5 - 10%

of shipping's energy consumption to be supplied as carbon-neutral fuels to reach IMO 2030 goals

152 million tons

of hydrogen feedstock required for ammonia by 2050

4,900 to 5,800

gigawatts annually = 1 decade of current annual capacity

of renewable electricity needed by 2050, to produce the green hydrogen required by shipping

1.37 billion cubic meters

of fresh water required annually by 2050, for green hydrogen electrolysis to produce e-ammonia for shipping

Maritime fuel pathways, the scale of the challenge, need versus reality

Our modelling, based on methodologies mirroring the IMO Fourth GHG Study (2020), reveals the magnitude of development needed.

i. Maritime transport work will grow 101.6% by 2050 (from 59.23 to 119.43 trillion ton-nautical miles)[22]

ii. Energy consumption will increase 67.4% to 16.0 exajoules by 2050[23]

iii. Efficiency improvements of 17% will only partially offset growing demand[24]

Year	**2018**	**2030**	**2040**	**2050**
Transport work	100%	139%	172%	202%
Energy consumption	100%	125%	146%	167%
Efficiency improvements	0%	10%	15%	17%

The CE Delft study[25] prior to the revision of the IMO GHG targets in 2023 envisions ship speed reduction, operational optimization, and energy-adding technologies offering the biggest potential for efficiency improvement.

To reach the IMO's 2030 goals, CE Delft estimated 5 to 10% of shipping's total energy consumption needed to be supplied as carbon-neutral fuels by the same year.

The study, however, does not specify the role of LNG as a marine fuel in the reduction of GHG emissions, which became highly debated in course of the creation of the IMO's Net-Zero Framework.

How much fuel does shipping need by 2050?

If any single future carbon-neutral fuel were to serve shipping's 2050 energy needs, the industry would require approximately:

i. **333 million tons of LNG or 320 million tons of e-methane** annually (current global production serves multiple sectors)[26]

ii. **803 million tons of green methanol** (7× current global production of fossil-based methanol)[27]

iii. **859 million tons of green ammonia** (6× current global production of fossil-based ammonia)[28]

iv. **596 million tons of ethanol**

v. **374 million tons of liquid biofuels** as substitute for HFO/MDO (vs. current 111 million tons available for all sectors, and 0.7 million tons available based on shipping's current share; expected to grow to 2.8 million tons by 2030)[29]

The required amount of liquid biofuels in 2050 serves only as guidance, as the potentially accessible feedstock for biofuels remains scarce, if we respect sustainability criteria and the food vs. fuel dilemma.[30]

Biofuels are finite, a stop-gap, not a destination

Shipping's share of global biofuels is less than 1% of the 111 million tons of biofuels available today, with road transport using 98.9%, and aviation 0.5%.[31]

Though electrification of land transport may release some liquid biofuels for shipping, aviation is expected to compete heavily for this supply given its limited carbon-neutral fuel options.

Another potential biofuel is bioethanol. It shares similar chemical properties with methanol but is less toxic, hypothetically making it a viable option for marine fuel.

Currently, first-generation bioethanol is used in Brazil as a locally produced automotive fuel. However, the conversion of bio-ethanol for aviation use presents a competitive disadvantage for shipping, given aviation's purchasing power.

Given its availability, it could potentially be adopted for shipping in that region. In contrast, second-generation bioethanol is more expensive than biodiesel and is therefore not considered a practical alternative for marine use.

Globally, bioethanol is not yet seen as a broadly viable marine fuel due to limited large-scale availability and competition with land-based transport and food production.[32]

E-methane challenges and opportunities

E-methane production presents both compelling infrastructure advantages and formidable complexity and scaling challenges.

E-methane, also known as synthetic methane, is produced by combining green hydrogen with captured carbon dioxide through a methanation process.

This cost of production is comparable to e-methanol, and the pathway offers the strategic advantage of being a drop-in replacement for liquefied natural gas, enabling compatibility with existing LNG infrastructure and dual-fuel engines.

However, the complexity related to the handling and storage of e-methane as a subcooled liquid adds to the overall technical challenge.[33]

Infrastructure compatibility could represent an opportunity for ports and shipowners who have invested in LNG capabilities.

E-methane can utilize the existing global LNG bunkering network, storage facilities, and operational expertise.

In addition, methane itself is a potent greenhouse gas. Regulation is still developing, but the continued use of either LNG or e-methane will require strict mitigation of this impact.

But can e-methane benefit from cross-sector synergies?

Unlike hydrogen, methanol, and ammonia, which serve as essential feedstocks in other industries, it is unclear which sectors, beyond shipping, would use e-methane in a decarbonized world.

Carbon capture immaturity puts e-methanol and e-methane in question

The outlook of green carbon capture, and thus of e-methanol and e-methane production, remains limited.

A recent Zero Emission Maritime Buyers Association (ZEMBA) report on e-fuel availability found that among the e-methane projects submitted to their request for information, none had reached final investment decision (FID) stage, due to high production costs, uncertain demand, lack of regulatory clarity, limited access to renewable carbon sources, and the early-stage maturity of key technologies like direct air capture.[34]

The current production pipeline suggests limited availability of e-methanol or e-methane for shipping, compared to the scale of vessel capacity under development.

The underlying feedstock need: green hydrogen

Given the scale of fuels required, a deeper challenge becomes clear: green hydrogen is in scarce supply.

Without green hydrogen, green ammonia, methanol, and methane, cannot scale.

Under the assumption that the supply of methanol and ammonia can only be scaled up to the required quantities via synthesis from green hydrogen and carbon dioxide (for e-methanol and e-methane) from direct air capture, the required quantities of feedstock can be roughly estimated below.

The following requirements for hydrogen and carbon dioxide are projected for 2050 (excluding further use of hydrogen for processes in fuel production and potential hydrogen slip):[35]

i. **100 million tons of green hydrogen feedstock for methanol or 152 million tons for ammonia**[36]

ii. **1,105 million tons of green carbon dioxide from direct air capture (DAC) as feedstock for e-methanol**[37]

Note that biogenic sources of green carbon exist, but their limited availability makes them negligible in meeting the scale of shipping's energy demand.

The electron competition

Vast amounts of electricity are needed for feedstock and fuel production.

With a power utilization factor of 20% for renewable energies, required capacity can be estimated at **4900 GW of installed power from renewable energies for methanol or 5800 GW for ammonia**.

At the current pace of installation, the full decarbonization of shipping with e-methanol or e-ammonia would absorb the current annual capacity of renewable electricity in 8-10 years.

Meanwhile, the electrification of transport, heating, and industry, and the explosive growth of data centers is also driving demand across every sector.

According to the IEA Net Zero Emissions by 2050 (NZE) Scenario, global electricity demand is projected to grow 150% by 2050, so demand will be 2.5x current consumption.[38]

At ports, onshore power is also driving increased demand. Combined with municipal needs, this is already placing strain on power grids in port communities, leaving no spare capacity.

The production of future carbon-neutral fuels in international shipping cannot depend on tapping into new renewable power plants built for the public grid.

It will require the development of additional, dedicated renewable energy facilities to produce green hydrogen and e-fuels at the scale needed for maritime use.[39]

The water competition

In addition to consuming electrons, green hydrogen and e-fuel production consume vast amounts of fresh water.

The production of the above quantities of green hydrogen via water electrolysis results in the following global demand for fresh water:

i. 0.9 billion cubic meters of fresh water annually for methanol or 1.37 billion cubic meters annually for ammonia.

ii. That's the equivalent of fresh water for between 8 and 13 million households.[40]

The 5 carbon-neutral fuel deadlocks: where pathways meet reality

The maritime fuel pathway analysis reveals too many pathways on paper, too little scale in practice, and deep resource dependencies.

The foremost challenge is to secure green hydrogen.

- The quantities of carbon-neutral fuels required are staggering.
- The world's current green hydrogen base is almost non-existent.

In addition, carbon capture is needed both to mitigate fossil fuel emissions and to produce e-methanol and e-methane, but neither have scaled materially, presenting another significant technology and investment hurdle.

Meanwhile, the competition for renewable electricity is also severe, particularly at ports.

Together, these barriers reveal interdependencies that extend beyond shipping.

This report identifies 5 deadlocks that tie shipping's fate to the broader global energy transition, and can only be solved through cross-sector collaboration.

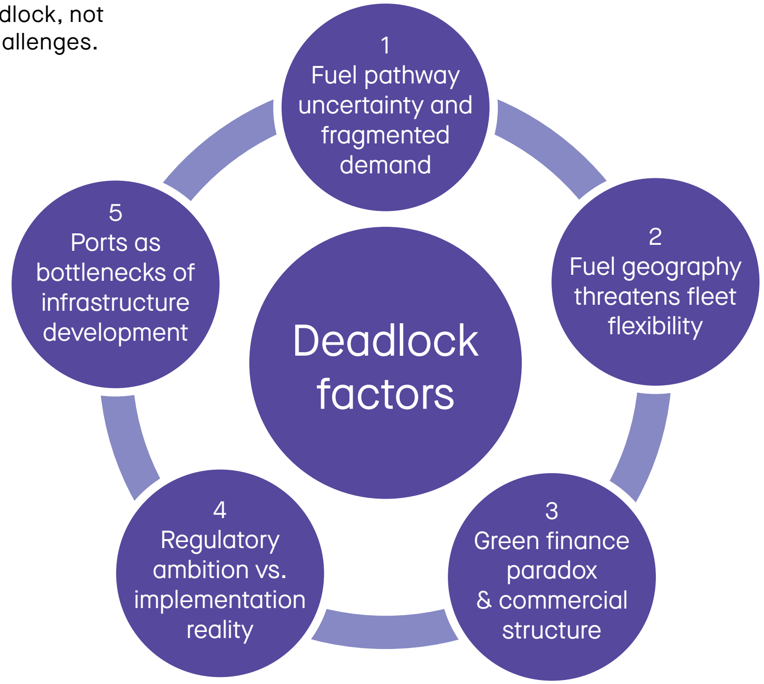
The 5 deadlocks: how shipping's fate is tied to the broader cross-sector energy transition

If the ship technology is ready and fuel need is clear, why has progress toward carbon-neutral fuel adoption remained so limited?

Shipping's paradox: The ships are ready. The fuels are missing.

The maritime energy transition faces a deadlock, not from one barrier but from five interlinked challenges.

1	First, uncertainty over the long-term success of any carbon-neutral fuel pathway is fragmenting shipping's already limited demand across multiple competing pathways, preventing the scaleup and reliability of any single carbon-neutral fuel.
2	Second, fuel availability constraints threaten to fracture shipping's traditional operational flexibility and reshape the industry's fundamental business model.
3	Third, green finance capital remains inadequate to the scale of investment required, and inaccessible due to fundamental mismatches between shipping's commercial structures and investor requirements.
4	Fourth, the misalignment between ambitious regulatory frameworks and the reality of implementation creates investment uncertainty around carbon-neutral fuels and decarbonization technologies, precisely when long-term certainty is essential.
5	Fifth, even if capital and regulatory clarity align, fuels cannot flow without infrastructure. Ports, pipelines, storage, power grids, renewable energy, and bunkering facilities put extreme stress on port resources and logistics, requiring more support from a broader cross-section of industries.



Deadlock 1: Fuel pathway uncertainty fragments demand and dilutes investment in scalable net zero solutions

1.07 million tons

Shipping's e-fuel commitments for 2030 vs 13.7 million tons needed for IMO's 5% GHG reduction target

0.7 million tons

Shipping's current share of the 111 million tons of biofuels currently available globally

19% of IMO 5% minimum carbon-neutral fuel target in 2030

Combined biofuel and e-fuel production commitments by 2030

"Shipping companies are used to operating in a world where energy is abundant and nobody else wants it.
That's no longer the case."

Bo Cerup-Simonsen (Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping)

"If shipping and aviation could work together... that would be a game changer. I think shipping alone is too small."

Dominik Schneiter (WinGD)

Stakeholders agree on one essential truth: green hydrogen is the foundation of the long-term maritime energy transition

Yet fragmented fuel choices and sectoral silos prevent it from scaling

Deadlock 1: Fuel pathway uncertainty fragments demand and dilutes investment in scalable net zero solutions

Stakeholders agree on one essential truth: green hydrogen is the foundation of the long-term maritime energy transition.

Yet fragmented fuel choices and sector silos prevent it from scaling. The absence of a clear winner among future carbon-neutral fuels creates planning paralysis that extends beyond shipping.

- Every fuel pathway has champions and drawbacks, but none has yet achieved the scale needed to meet IMO's 2030 and 2050 targets.
- In practice, this has resulted in three overlapping investment horizons: LNG and biofuels as near-term bridges, grey or blue methanol and ammonia as mid-term bets, and green hydrogen as the long-term foundation of the net zero scenario.
- Individually, these choices are rational. Collectively, they fragment demand and delay investment in the requisite green hydrogen infrastructure to reach net zero.
- The result is a dispersion of capital, time, and innovation spread too thin across sideways options that have yet to produce a material reduction in maritime emissions, which reached an all-time high at the end of 2024.[41]

The industry is valiantly exploring every conceivable decarbonization path.

However, unless this evolves into focused, aggregated demand and investment in the few viable, long-term options, shipping could lose out to other hard-to-abate sectors like aviation in securing scalable e-fuel supplies. This is not just a maritime problem. All hard-to-abate sectors face similar deadlocks. Each knows hydrogen is indispensable, but none is able to shoulder the cost of scaling it alone.

Cross-sector demand aggregation is therefore the only pathway to break the deadlock.

Without such alignment, capital and infrastructure will flow toward whichever sector can promise the clearest and most consolidated demand.

Multiple fuel pathways fragment demand signals

Multiple fuels are being trialled simultaneously.

Each potential pathway demands vast capital and infrastructure.

Fragmented demand prevents any single option from reaching the scale required to provide a long-term global supply.

The hydrogen economy requires daunting economy of scale

Hydrogen electrolysis alone could require as much as 25,000 terawatt-hours of electricity[42] in optimistic scenarios, exceeding even the tripling of global renewables pledged at COP28.[43]

New hydrogen hubs represent some of the largest renewable energy investments ever conceived, but they require guaranteed cross-sector demand to justify capital intensity.

Shipping's new fuel paradigm: competition

No longer is shipping the exclusive patron of its own supply of the cheapest remaining fuel in the global oil economy.

Shipping is now forced into direct competition with sectors that have stronger balance sheets and the ability to pay for premium fuels.

The cross-sector coordination challenge

Shipping cannot create sufficient demand signals to unlock the $3 trillion required in green hydrogen investment from now to 2050, just to generate sufficient e-fuels to meet the IMO 2050 net zero goal.[44]

However, aggregating demand and sharing the risk with the other hard-to-abate consolidates fragmented signals into bankable offtakes.

Deadlock 2: Concentrated fuel supply impacts global fleet flexibility

30x the landmass of Singapore = 1/10 the size of the UK

The largest planned hydrogen hub for green ammonia production

$650 per ton

Projected cost of green ammonia from hydrogen hubs with economy of scale the size of small nations, vs $500 per ton for conventional fuel

70-80%

of the global merchant fleet are bulk ships with business models dependent on flexible routing

"Am I going to stop in Cape Town on my way from Brazil to China, just because it has all the infrastructure built for bunkering the fuels I need?"

Paolo Tonon (Berge Bulk)

The concentrated geography of green hydrogen and e-fuels impacts the flexibility that has long defined global shipping

Container operators adapt to hub-based supply, bulk operators face new business challenges

Deadlock 2: Concentrated fuel supply impacts global fleet flexibility

One of the industry's defining strengths has been its ability to operate flexibly across global trade routes, with different segments adapting their business models to shifting cargo and market demands.

Shipping's traditional flexibility is now challenged by the geographic constraints of carbon-neutral fuel availability.

This is not only a maritime issue.

Aviation's fuel demand is naturally concentrated at airports, while steel plants anchor continuous energy demand in industrial hubs.

If ports can align fuel production and logistics around these cross-sector anchors, shipping can preserve a greater degree of flexibility, without losing access to supply.

Without such alignment, hubs will serve sectors with stronger balance sheets first.

However, different fleet segments must adapt to the new carbon-neutral fuel landscape.

Predictable container services can adapt more easily to such constraints, while the irregular and opportunistic trading patterns of bulk shipping will require more attention and support to navigate the transition.

The economics of energy density

The average energy density of new e-fuels is half that of conventional fuels, which means ships will need twice as much fuel to travel the same distance.

Energy density matters, because different shipping segments take on fuel in different ways.

For container services on fixed routes, lower energy density can be managed by planning more frequent bunkering at regular hubs.

For bulk shipping, which often operates on irregular and unpredictable routes, lower energy density translates into operational risk, higher costs, and reduced flexibility to pursue cargo opportunities.

Nation-sized hydrogen hubs

Hydrogen developers avoid reliance on public grids, and instead focus on building their own renewable electricity hubs in geographies with abundant natural wind and solar resources.

Some developers, such as InterContinental Energy, are betting on an economy of scale which will consolidate production into a handful of regional hydrogen hubs the size of small nations (e.g., 30x the size of Singapore, or one-tenth the size of the United Kingdom).

The aim is to deliver green hydrogen and its derivatives at volumes that drive costs down, with the Western Green Energy Hub targeting under $650/tonne of green ammonia in its first phase, with further reductions for future phases.

These colossal regional hubs are strategically positioned to serve major container and bulk trade routes.

Fuel transition divide: containers adapt, bulkers struggle

Container and bulk operators face different challenges in a regionalized hydrogen economy.

Containers can adapt to geographically concentrated fuel hubs.

Bulk operators face reduced flexibility, longer voyages, higher costs, and missed cargo opportunities.

This can create a significant disadvantage for bulk operators, and will require a dedicated approach to ensuring that a greater number of smaller ports are able to participate in the hydrogen economy.

Market and charter impacts

The impact of fuel geography extends beyond operations to charter rates and broader shipping economics.

Container operators benefit from long-term contracts, making it easier to incorporate fuel costs into freight rates and negotiate infrastructure investment at major ports of call.

Bulk fleets, conversely, operate in volatile spot markets where margins are thin and charterers are reluctant to pay premiums for uncertain fuel availability.

The combined need for both economy of scale and more widely dispersed carbon-neutral fuel availability speaks once again to the need for smaller ports to have a way to access these fuels.

Deadlock 3: The green finance paradox

$14.5 billion

Amount of ESG funds earmarked for shipping since 2018, out of $3.5 trillion total global ESG assets under management

"Without long-term offtake and cost visibility, financiers simply won't take the risk. We've seen this again and again."

Eman Abdalla (Cargill)

"In the past the energy companies and the bunker traders have been dealing with the risk, since fuel is today a commodity. They do this confidently, but we are stepping into a new territory where nobody is willing to take that risk."

Bo Cerup-Simonsen (Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping)

"There's a lot of green money wanting to be invested but constantly changing government policies create additional investment uncertainty."

Didier de Beaumont (Port of Amsterdam)

"Investments in hydrogen or synthetic fuels are on scales that require decades of certainty. You simply don't get that in shipping, where even contracts of a few years are rare… We need aggregated demand and long-term certainty, otherwise projects will simply not go ahead."

Alexandra Ebbinghaus (Shell Marine)

Deadlock 3: The green finance paradox

Banks and investors are pouring trillions of dollars into ESG funds, but only a fraction of that goes to shipping.

Analysts estimate the total of global ESG assets under management at $3.5 trillion,[45] with only $14.5 billion earmarked for shipping since 2018.[46]

Investors are reluctant to award ESG capital to shipping companies, due to shipping's:

- fragmented ownership base
- long vessel lifespans
- uncertain regulation
- unreliable ESG disclosure, compared to other sectors like aviation and power generation.

This, combined with the fragmentation of demand across multiple fuel pathways, makes it challenging to access the trillions of dollars needed to scale carbon-neutral fuel development.

Green capital exists, but shipping's overall business model is ill-suited to securing it

Global finance has been mobilized for the energy transition and banks face mounting pressure to demonstrate climate-aligned portfolios.

Yet maritime decarbonization projects repeatedly fail to qualify.

For investors, predictable returns and proven decarbonization technologies are essential before capital can flow.

Shipping's energy transition offers neither.

The abundance of green money does not translate into finance for carbon-neutral fuels in shipping, because the sector cannot yet deliver the long-term certainty, transparency, and commercial alignment that investors require.

In addition, compared to other sectors, shipping's ESG reporting has been less comprehensive and standardized, making investors question the impact of decarbonization measures.

Split incentives across the shipping value chain exacerbate the gap

The financing gap is also rooted in how responsibilities and incentives are divided across the shipping value chain.

In many cases, the party making long-term investment decisions is not the same as the one paying for the fuel.

This creates a split incentive that undermines investment in efficiency improvements and new fuelcarbon-neutral fuel technologies.

Furthermore, financing hydrogen at scale requires aligning the balance sheets of multiple industries.

Without coordinated commitments across shipowners, charterers, and cargo owners, supported by parallel demand from other sectors, shipping will remain unable to translate capital abundance into to fund scalable fuel investment.carbon-neutral fuels at scale.

Hedging strategies fragment demand signals

Large shipping companies hedge against uncertainty by ordering dual-fuel vessels across LNG, methanol, and ammonia.

While rational at the corporate level, this fragments demand and prevents the concentrated offtake producers need to reach final investment decisions.

The hesitation of oil and gas majors underscores the weakness of today's business case for hydrogen and e-fuels. Most majors have slowed or shelved large-scale green hydrogen ventures, not only because shipping cannot afford it, but because no single sector can.

The ripple effect of a wait-and-see approach is paralysis.

Fuel producers will not build without offtake guarantees. Shipowners will not sign offtake without price and availability clarity. Banks will not lend without ESG clarity and long-term certainty.

Green premium effectiveness relies largely on consumer proximity

Demand signals are beginning to emerge in areas of the value chain where companies are close enough to end consumers to pass on a green premium.

Retailers and cargo owners with visible sustainability commitments can justify paying more for carbon-neutral shipping.

For containerized goods with high value-to-weight ratios, the added cost of zero-emission shipping is minimal once it is distributed across the final product.

This explains why cargo owners in retail and consumer sectors are taking the lead in driving early carbon-neutral fuel uptake.

At the same time, these green premiums remain limited in scope. Bulk cargoes and industrial commodities cannot absorb those premiums in the same way.

Deadlock 4: Regulatory ambition versus implementation reality

$10-12 billion annually
Expected revenue from the IMO Net Zero Fund starting 2028

$3 trillion
Investment needed by 2050 for green hydrogen production and infrastructure, just for shipping's complete energy transition

85%
of international shipping emissions covered by the Net Zero Framework

"Whether incentives or penalties, you need something to address the gap. You can have the stick or the carrot, but without those you cannot make it work."
Alexandra Ebbinghaus (Shell Marine)

"The incentives can't wait until 2027/2028. We have already seen green fuel projects halted due to a lack of demand drivers."
Dominik Schneiter (WinGD)

Deadlock 4: Regulatory ambition versus implementation reality

Ambition is high, but harmonization and clarity are essential.

The IMO's Net Zero Framework represents a historic breakthrough. It is the first global carbon pricing system for an entire industry. Its ambition is not in question.

The challenge lies in translating that ambition into bankable signals for fuel producers and investors.

Governments have also launched subsidy regimes and hydrogen strategies with ambitious decarbonization programs. These initiatives are designed to guide industries toward a 2050 net zero target.

Yet ambition is not the same as implementation.

Multiple potential fuel pathways, fragmented timelines, and the scale of capital required to build new fuels, infrastructure, and vessels expose clear weaknesses in the timing mismatches, default factor distortions, and misaligned fragmented regulatory landscape.

This creates uncertainty, amplifies the perceived risk, and undermines investment just when fuel producers need long-term clarity needed to move forward with hydrogen and e-fuels.

By matching ambition with clarity and alignment, regulators can accelerate the development of hydrogen and e-fuels that shipping and other industries depend on.

Could delayed incentive clarity and implementation hinder investment decisions?

Regulatory ambition is there. The next step is to translate it into bankability and impact.

The IMO framework is expected to be adopted in a special session of the IMO Marine Environment Protection Committee (MEPC) in October 2025. However, it will not enter into force until March 2027, and pricing incentives and the IMO Net Zero Fund begin only in 2028.

Delayed incentives and uncertainty over fund allocations risk leaving projects stranded at precisely the moment when investment decisions must be taken.

Earlier clarity on incentives, rewards, and allocations can help shipping companies, ports, and fuel developers to make critical, long-term investment decisions.

Will the IMO default factors foster deeper decarbonization?

The IMO Net Zero Framework was designed to be technology-neutral.

In practice, the current default GHG factors raise questions about whether the system will unintentionally favor existing technologies over emerging technologies with deeper decarbonization benefits, by placing a complex and expensive compliance burden on emerging technologies.

When default GHG intensity factors are applied instead of measured performance, technologies that achieve lower total emissions but have higher emissions per unit of energy can face higher penalties than less efficient alternatives.

Updating default factors regularly, based on measured well-to-wake data, would give innovators confidence that improvements will be recognized and adopted in good time, without onerous delay and expense.

Do global and regional regulations and incentives require harmonization?

Harmonization between global and regional fuel systems is vital. One significant reason for this is that regional systems provide an essential cross-sector lens to carbon-neutral fuel development.

The IMO's and EU's different approaches to biofuels are evidence of that. The IMO permits biofuels to count towards the 2030 emissions checkpoint. The EU, calculating availability for all sectors, does not.

In addition, the IMO regulation can only set standards of achievement and funding in the billions. Corresponding national energy incentives on both the supply and demand side will be critical to achieving the trillions in funding needed to catalyze green hydrogen production for all hard-to-abate sectors.

Without global-regional regulatory alignment, the broader investment case for hydrogen remains fragmented. Investors in hydrogen and e-fuel hubs look at the aggregate demand picture across sectors. If global and regional regulations diverge, the demand base fragments, and capital cannot flow at the scale required.

Clear, consistent, and coordinated regulatory frameworks across sectors and geographies can unlock the scale of capital required to achieve net zero in all hard-to-abate sectors.

Deadlock 5: Infrastructure bottlenecks at ports

"If people are looking to have product by 2030, there is a requirement for planning and commitment [now], for it to come online by that time."

Isabelle Ireland (InterContinental Energy)

5 to 7 years

Typical time taken for e-fuel and biofuel projects to move from planning into production after a final investment decision (FID)

"One of my concerns with hydrogen and hydrogen derivatives from renewables is that there's substantial competition for that electricity... Shipping tends not to be first in line for these products – they're usually further down the priority list."

Tore Longva (DNV)

"We are preparing comprehensive training programs for seafarers to ensure safe and effective handling of new fuels. Training is the most critical factor for the successful adoption of new marine fuels."

Shingo Mizutani (NYK Shipmanagement)

"Ammonia cannot be bunkered in busy city ports; safety risks are too high. Floating bunkering islands offshore are more suitable, and portable if needed."

Paolo Tonon (Berge Bulk)

"We're strong proponents that guidelines need to be in place before commercial bunkering happens, so we can build ecosystem confidence."

Lynn Loo (GCMD)

Deadlock 5: Infrastructure bottlenecks at ports

Even if finance and regulation align, fuels can only flow with the proper infrastructure.

This makes ports the final gatekeepers of maritime's energy transition.

Ports are where shipping demand meets the power grids, pipelines, storage, and logistics networks that also serve aviation, steel, chemicals, cement, and agriculture.

The challenge is not limited to shipping. The port network forms the backbone of both global trade and energy.

The entire cross-sector hydrogen economy will rely on that global port ecosystem.

Unless ports, utilities, and industries expand these systems in step, bottlenecks will constrain the scale-up of carbon-neutral fuels.

The competition for power, water, space, and money

Fuel production, storage, and bunkering depend on stable access to electricity and water.

National grids face competing demands from electric vehicles, heat pumps, industrial electrification, and data centers.

New shore power requirements add an additional strain on the municipal power grid at ports.

In addition, electrolysis requires significant quantities of freshwater, which is in short supply at some ports.

Land is equally scarce, with limited port space available for fuel storage, pipelines, and infrastructure.

The challenge is not whether bunkering will take place, but whether ports can secure sufficient electricity, manage the complexity of new fuel systems, and aggregate cross-sector demand to guarantee offtake, avoid stranded bunkering assets, and reduce financial risk.

Accelerating permitting and governance to match technology readiness

Even when technology is available, the permitting process can slow projects for years.

Safety assessments, land-use planning, and political caution often extend timelines well beyond what the energy transition requires.

For fuel producers, permitting is often a significant bottleneck.

This is not just a maritime issue. Large-scale hydrogen projects for industry face similar delays.

Permitting that is stable, transparent, and aligned across governance levels can give fuel developers and ports the confidence to commit.

Safety and workforce readiness are preconditions for adoption

The introduction of carbon-neutral fuels like ammonia requires safety standards and operational protocols that are still in development.

Ports require clear rules and trained people to scale bunkering of carbon-neutral fuels.

Establishing harmonized global safety standards, embedding cross-sector expertise, and investing in workforce training will make it possible to manage new fuels at scale.

Pilots like the Global Centre for Maritime Decarbonisation ammonia bunkering and transfer project are already providing templates for safe adoption.[47]

Geography will shape port roles in the transition

Not every port can or should become a production hub for hydrogen and e-fuels.

Some regions are advantaged by vast renewable resources and are likely to become export hubs.

However, geography, access to renewable resources, and inland industrial demand will determine which ports emerge as exporters, which act as import hubs, and which primarily serve as bunkering and distribution points.

With clear roles, ports can complement rather than compete, giving shipowners the confidence that fuel will be available where and when it is needed.

Orchestrating a cross-sector, hydrogen-based energy transition could resolve the 5 deadlocks

43 million tons vs 11 million tons

Potential green hydrogen projects by 2030 versus actual committed demand due to fragmented signals

28 million tons annually

Green ammonia capacity planned at Western Green Energy Hub – supporting cross-sector offtake

"While 300 million tons of fuel oil seems like a lot, when you convert that to future carbon-neutral fuels, it's not that much. With different sectors you can aggregate demand. That's where the signal becomes much stronger."

Lynn Loo (CEO, Global Centre for Maritime Decarbonisation)

"Shipping companies just don't have the balance sheet to get these large-scale infrastructure investments going, so either the public sector needs to step in, or shipping needs to go in together with other big sectors in getting these fuel production plants established."

Bo Cerup-Simonsen (Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping)

Cross-sector collaboration can transform today's deadlocks into tomorrow's opportunities

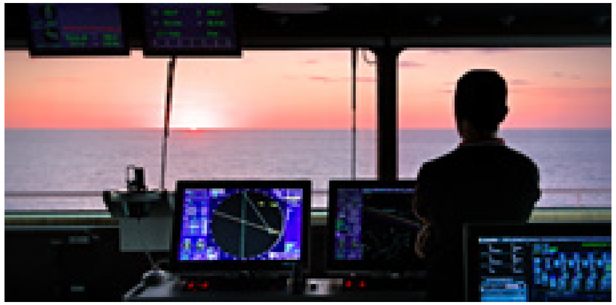
Aggregated demand across industries creates the critical mass investors require

Orchestrating a cross-sector, hydrogen-based energy transition could resolve the 5 deadlocks

The 5-deadlock analysis clearly shows why shipping cannot solve its carbon-neutral fuel transition in isolation. Each deadlock stems from coordination failure involving multiple sectors.

However, the solution becomes equally clear: **cross-sector collaboration and aggregated demand**.

Shipping's 300 million tons of annual fuel demand looks vast, but even when it isn't spread out across multiple fuel pathways, it is too small to trigger green hydrogen development.



Aggregating cross-sector demand with aviation, steel, cement, chemicals, power, and agriculture transforms thin, fragmented signals into large, bankable commitments.

By aggregating demand across these sectors, shipping can help create the critical mass of offtake that investors and developers require.

Collaboration across sectors can significantly resolve each of the 5 deadlocks identified in the previous chapter.

Deadlock 1: Fuel pathway uncertainty across fragmented, cross-sector demand

A cross-sector lens shows which fuel pathways will be most viable in the long-term and helps channel demand and investment to scale them earlier.

1. Clearly identifies green hydrogen as the backbone
2. Clarifies biofuel as a finite stopgap
3. Ensures critical mass and economy of giga-scale projects

Deadlock 2: Concentrated fuel supply impacts global fleet flexibility

Cross-sector demand aggregation:

1. Achieves economy of scale for import and export
2. Allows smaller ports and bulk operators to participate in the hydrogen economy
3. Cross-sector demand preserves traditional trade corridors

Deadlock 3: The green finance paradox

Cross-sector demand aggregation can mobilize green capital.

1. Large cross-sector bankable contracts
2. Unlocking trillions in idle ESG capital
3. Catalyzing oil and gas majors
4. Green carbon capture and storage can also scale as part of the aggregation logic
5. ESG standardization on hydrogen, carbon capture, and e-fuels

Deadlock 4: Regulatory ambition versus implementation reality

Cross-sector collaboration can align regulatory intent with implementation.

1. Mitigating the single-sector burden of incentives
2. Harmonizing frameworks to send a clear investment signal
3. Integrating shipping and energy strategies to unlock shared infrastructure and incentives
4. Providing stable, consistent regulation to give investors long-term confidence

Deadlock 5: Infrastructure bottlenecks at ports

Cross-sector collaboration can help resolve port infrastructure bottlenecks and make efficient use of scarce resources.

1. Shared electricity supply
2. Shared water resources
3. Shared bunkering and storage systems
4. Robust safety and workforce readiness

Cross-sector collaboration can transform today’s deadlocks into tomorrow’s opportunities for accelerated carbon-neutral fuel development.

Ports as platforms for the cross-sector energy transition

"You need the financiers, the insurers, the regulators, the port authorities, the ship owner. You need everybody".

Lynn Loo (Global Centre for Maritime Decarbonisation)

Producer port: Port of Açu

Brazil's green hydrogen production port

The Port of Açu is emerging as Latin America's largest port for green hydrogen and e-fuels, with exceptional solar and land availability, deep-water access on major shipping routes, and aggregating cross-sector demand from shipping, power generation, steel, and agriculture.

Connector port: Port of Rotterdam

Regional green hydrogen connector

The Port of Rotterdam is transforming from a traditional petrochemical hub into the central node of Northwest Europe's green hydrogen pipeline network.

Receiver port: Port of Singapore

Global fuel import specialist

For over five decades, the Port of Singapore has been the world's largest bunkering hub, now transforming into a sophisticated import terminal for next-generation shipping fuels.

Source port: Port Bonython

A purpose-built green hydrogen export powerhouse

Drawing on South Australia's exceptional wind and solar potential, Bonython is one of the lowest-cost green hydrogen sources worldwide.

Ports as platforms for the cross-sector energy transition

Collaboration needs a physical platform, and ports are that platform. They are where maritime, industrial, aviation, and energy systems converge.

Ports have long been central to energy and trade. What is new is the remapping of fuels, carriers, and cross-sector offtake at a system level, and the expanded role that follows.

Many ports are not starting from zero. They are extending established capabilities in chemicals, refining, storage, and hazardous logistics to the handling of green hydrogen and e-fuels.

Ports will remain the backbone of the global energy system.

By convening carbon-neutral fuel offtake across multiple sectors, they can create the infrastructure, investment, and supply chains needed for the transition from fossil fuels to a green hydrogen economy.

At the same time, scale will be decisive.

This initiative began with the hypothesis that there would be four clear types of ports in a future hydrogen economy: producers, connectors, receivers, and sources.

However, given the nation-sized economies of scale required for cost-competitive hydrogen production, many potential producer ports may, in practice, become either receiver ports or exporting source ports.

This will depend on whether land, renewable energy, and other resources are constrained or abundant.

The archetypes provide a structured way to map roles, manage overlaps, and reduce the risk of stranded capacity. But they should not be read as evenly distributed or permanent categories.

Not every port can or should play the same role. Geography, resources, industrial base, and existing trade positions will help determine what each can contribute.

Four port archetypes

- **Producers** generate green hydrogen and e-fuels locally, drawing on strong renewable resources.
- **Connectors** distribute green hydrogen from nearby supply regions to industrial and maritime demand centers.
- **Receivers** import fuels at scale, supplying global trade networks.
- **Sources** specialize in nation-sized giga-scale exports from the world's most abundant renewable regions.

Port archetype comparison

Criteria	Producers	Connectors	Receivers	Sources
1. Proximity to renewable resources	Within 50–100 km of abundant wind, solar, or hydro capacity.	Within 2,000–3,000 km pipeline-feasible distance from renewable-rich regions.	Limited domestic renewable resources; rely on imports.	Located in regions with world-class solar, wind, or hydro capacity factors.
2. Access to water resources	Desalination and water reuse in existing water systems can avoid bottlenecks during scale-up. Leverage current utility channels to shorten new-build timelines.	Moderate requirements; largely handled upstream but with some conversion needs.	Minimal on-site requirement.	Substantial freshwater or large-scale desalination to support giga-projects.
3. Land availability	Brownfield integration and shared-use allows parallel legacy and new-fuel assets, reducing the risk of half utilization during transition.	Adequate land for pipeline terminals and conversion facilities.	Limited land, often dense urban hubs.	Expansive coastal land with few competing uses.
4. Grid and industrial expertise	Can update ammonia and methanol handling as an extension of existing chemical competencies, rather than introducing new operating models.	Strong grid links and regulatory frameworks for cross-border pipelines.	Expertise in logistics, hazardous materials, and large-scale trading.	Often greenfield, though some leverage existing export expertise.
5. Cross-sector demand aggregation	Naturally co-located with steel, aviation, chemicals, power, and other industries.	Aggregate regional demand from multiple inland and maritime users.	High-volume aviation and trade hubs can reinforce bunkering economics.	Primarily export-oriented but may serve emerging regional industries.
6. Bunkering and refueling infrastructure	Established bunkering integrated with local green hydrogen production.	Strategic bunkering nodes tied to pipeline distribution.	Largest global bunkering hubs, ensuring continuity of supply.	Secondary role: focus is bulk export, though some integrate bunkering.
7. Strategic trade advantage	Local energy sovereignty and verifiable low-carbon supply strengthen competitiveness in regulated and premium markets.	Pipeline economics deliver lower costs and enhance regional energy diplomacy.	Continuity of bunkering and trading scale stabilize global markets and pricing.	Lowest-cost global exports secure long-term supply positions in international trade.
8. Investment profile	High upfront capital, offset by renewable partnerships and strong policy frameworks.	Very high investment in pipelines and conversion, often multinational.	Investment in import, storage, and distribution infrastructure.	Greenfield mega-projects requiring substantial international financing.
9. Supply chain role	Independent producer and regional distributor.	Regional distributor and intermediary hub.	Import hub and global trading platform.	Dedicated exporter to global markets.

Key findings and recommendations: Breaking the deadlock and mobilizing the cross-sector energy transition

Efficiency is not only a bridge to 2030 targets but also a multiplier of the impact of every scarce ton of green hydrogen and e-fuel that arrives in the 2030s and 2040s.

The industry has built dual-fuel-ready ships at record pace, but without scaled supply, those ships wait for fuels that do not yet exist.

Green hydrogen is the indispensable feedstock for future carbon-neutral fuels.

The supply of biofuels is finite, and investment should be rechanneled into the viable carbon-neutral fuels of the future.

Green funds are available, but not at the scale needed, and new financial instruments are needed to unlock them for shipping's transition.

Where policy alignment is strong, capital flows. Harmonize national energy policies and incentives to support the green hydrogen economy and the IMO global net zero goals.

Ports can play a decisive role in breaking shipping's carbon-neutral fuel deadlock by becoming the orchestrators of cross-sector demand.

If ports and their partners anchor cross-sector demand, capital will flow, green hydrogen will scale, and efficiency will multiply the impact.

↖

1 | Efficiency must 'go viral'. It is the first fuel in shipping's decarbonization race.

2 | The ships are ready. The fuels are missing.

3 | Green hydrogen: Indispensable feedstock and strategic energy security resource.

4 | Biofuels are a stopgap, not a destination.

5 | Carbon capture is essential, both for e-fuels and fossil mitigation.

6 | Green finance gap: Unlocking capital at the scale shipping needs.

7 | Global goals need local action: Align energy incentives with IMO net zero.

8 | Ports provide the platform, but who will lead?

Key findings and recommendations: Breaking the deadlock and mobilizing the cross-sector energy transition

This report's analysis – from mapping fuel pathways, to synthesizing stakeholder interviews, to examining port archetypes and global trade dynamics – converges on a single truth.

Ports have always been the backbone of the global energy system.

Now that backbone is being remapped, as nation-sized green hydrogen hubs become the vertebrae of a new global hydrogen economy.

Ports can play a decisive role in breaking shipping's carbon-neutral fuel deadlock by becoming the orchestrators of cross-sector demand.

Fragmented initiatives and voluntary coalitions cannot generate the certainty investors require.

As **Didier de Beaumont (Port of Amsterdam)** explains,

"The regulation needs to be clear for a long period, because these investments are huge sums of money."

Ports that commit early to specific roles, develop readiness frameworks, and convene cross-sector offtake platforms will be the ones that unlock the first wave of green hydrogen and e-fuel investment.

Global trade realities reinforce the urgency. The United Nations Conference on Trade and Development (UNCTAD) warns that the shift to carbon-neutral fuels will increase costs and redistribute flows across ports and regions.[48 49]

Professor Lynn Loo (Global Centre for Maritime Decarbonisation) note,

"the energy transition will naturally reshape port dynamics, allowing for ports that don't exist yet to come into existence, and for ports that are in operation today to be significantly less important."

The operational flexibility that has defined shipping for centuries will not survive unaltered in the net zero era.

Lower energy density and uneven geography of new fuels will force more frequent bunkering stops, creating entirely new strategic positions, while potentially rendering others obsolete.

However, ports can play a role here, too, in retaining that flexibility, by using cross-sector demand to pull e-fuels to smaller ports, enabling more of the bulk and tramp segment to participate in a hydrogen economy.

The long-standing risk-management strategy of "diversify across all fuels" will no longer work.

It is precisely that fragmentation which has stalled investment at scale.

The industry has built dual-fuel-ready ships at record pace – e.g., fuel injectors are flying off production lines – but without scaled supply, those ships wait for fuels that do not yet exist.

Breaking deadlocks and mobilizing a cross-sector energy transition is not optional.

It is the only way to assure shipping's own energy transition, and to strengthen rather than fragment global trade in a net zero, green hydrogen-based economy.

In the process, shipping and the other hard-to-abate sectors will have the chance to build a net zero future by 2050.

If ports are to take on this leadership role, the full stakeholder ecosystem must move with equal urgency.

From this foundation, the following key findings and recommendations set out the practical actions that industry, policymakers, investors, and ports can take to mobilize the cross-sector energy transition for a net zero future.

1 | Efficiency must ‘go viral’. It is the first fuel in shipping’s decarbonization race.

Efficiency is the most abundant and cost-effective lever for decarbonization that we have today. Shipping must ‘go viral’ with efficiency, to reduce emissions now, and prepare for efficient use of future carbon-neutral fuels.

- The International Energy Agency (IEA) has long called energy efficiency “the first fuel”, emphasizing that it is “abundantly available and cheap to extract” and provides some of the quickest, most cost-effective emissions mitigation opportunities.[50]
- Technical and operational efficiency measures could cut emissions over 30% by 2030.
- Efficiency is not only a bridge to 2030 targets but also a multiplier of the impact of every scarce ton of green hydrogen and e-fuel that arrives in the 2030s and 2040s.

Stakeholder actions

- **Shipowners and operators:** Treat efficiency as a fuel in its own right. Prioritize retrofits and operational upgrades across the fleet and use digital monitoring to verify results and strengthen compliance.
- **Regulators:** Ensure that IMO, EU ETS, and FuelEU frameworks immediately credit verified efficiency measures, and harmonize methodologies to avoid compound compliance costs.
- **Investors and insurers:** Link financing and risk products to efficiency outcomes, so that verified emissions reductions become investable and generate reinvestment momentum.

2 | The ships are ready. The fuels are missing.

The global fleet is becoming carbon-neutral-fuel-ready, but the supply of e-fuels in 2030 will cover just 4–8% of the IMO’s 5% minimum target, making accelerated production essential.

Dual-fuel and fuel-ready vessels already dominate orderbooks, yet fuel supply reaching final investment decision falls far short of what is required.

Stakeholder actions

- **Fuel producers:** Accelerate projects to final investment decision in line with IMO and EU compliance timelines, by prioritizing and collaborating with ports serving multiple sectors.
- **Charterers and cargo owners:** Assess whether pooling offtake demand for bankable volumes and shared risk would allow you to commit to long-term offtake agreements for e-methanol, e-ammonia, or e-methane.
- **Ports:** Where possible, convene shipping and other hard-to-abate industries to aggregate demand and align infrastructure. Use this dispersed cross-sector pull to establish earlier bunkering and storage for e-fuels and carbon, ahead of a full-scale energy transition and demand.

3 | Green hydrogen: Indispensable feedstock and strategic energy security resource.

Green hydrogen is the indispensable feedstock for future carbon-neutral fuels, and also a strategic energy security resource that shipping cannot access without cross-sector collaboration.

- Every viable pathway converges on green hydrogen. By 2050 shipping will require 100–150 million tons as feedstock, competing with aviation, steel, cement, agriculture, power generation, and chemicals.
- Alone, shipping lacks the purchasing power to drive projects of this scale.
- Beyond decarbonization, green hydrogen is already being treated by governments as a foundation of industrial competitiveness and energy sovereignty, making cross-sector alliances essential.

Stakeholder actions

- **Fuel producers:** Work with investors, shipping and energy regulators, ports, shipping, aviation, and industry leaders to aggregate demand, establish standards, and achieve economy of scale for accelerated development and competitive pricing.
- **Cross-sector net zero alliance:** Build joint procurement and investment platforms across shipping, aviation, and industry with common timelines, pricing floors, and risk-sharing structures.
- **Governments and flag states:** Integrate shipping into national green hydrogen strategies, ensuring the sector is allocated a share of incentives, production, and import capacity rather than left last in line.

4 | Biofuels are a stopgap, not a destination.

The supply of biofuels is finite, and investment should be rechanneled into the viable carbon-neutral fuels of the future.

- Biofuels, although useful as a bridge, are not scalable. Shipping's share is less than 1% of the 111 million tons of biofuels available today, with road transport using 98.9%, and aviation 0.5%[51]
- Even under optimistic projections, biofuels can only supply a fraction of maritime demand by 2050.
- As one stakeholder put it, "Eat the food, don't burn it."
- Most available production is already constrained by land, water, and food system limits, while aviation is expected to claim the lion's share due to its lack of alternatives.
- Investing in biofuels as a long-term solution risks channeling critical funds towards a low-impact decarbonization path, and delaying the shift to scalable green hydrogen-based pathways.

Stakeholder actions

- **Governments and industry:** Avoid policies or investment strategies that lean heavily on biofuels for shipping.
- Direct subsidies and capital instead toward developing green hydrogen, e-fuels, and carbon capture as the real foundations for scale.
- Harmonize the IMO 2030 5-10% carbon-neutral fuel requirements with the cross-sector, long-term focus of those in EU regulations.FuelEU Maritime, which does not count crop-based biofuels towards the fulfilment of greenhouse gas intensity targets.
- **Cross-sector net zero alliance:** Establish clear allocation frameworks so that scarce sustainable biofuels go where they are genuinely indispensable, such as in aviation or certain regional transport niches, rather than being locked into shipping at the expense of longer-term solutions.

5 | Carbon capture is essential, both for e-fuels and fossil mitigation.

Carbon capture is essential both as a feedstock for e-fuels and as a safeguard against continuing fossil emissions, serving on a parallel track to green hydrogen.

The historical energy curve shows that new fuels rarely displace older ones completely. Oil, coal, and gas will continue for decades, which means carbon capture will be needed in two distinct roles.

First, direct air capture (DAC) is required to provide green feedstock for e-fuels like e-methanol and e-methane. Without captured CO_2, these green hydrogen-based fuels cannot scale.

Second, carbon capture and storage (CCS) is needed to capture and sequester fossil emissions from ships and industrial facilities during the long transition when hydrocarbons remain in use.

Both tracks must advance in parallel to keep the 2050 net zero target in reach.

Stakeholder actions

- **Industry and governments:** Accelerate investment in both DAC for fuel feedstocks and CCS for fossil emission mitigation.
- **Regulators:** Establish regulatory recognition so that DAC-captured carbon used as e-fuel input, and CCS permanently stored, both count as verified compliance under the IMO Net Zero Framework and national systems.
- **Cross-sector net zero alliance:** Build shared infrastructure for carbon capture, transport, and storage, including pipelines, terminals, and geological storage hubs.
- Collaboration with power, steel, and cement sectors can lower costs and create economies of scale that make DAC and CCS viable for shipping.

6 | Closing the green finance gap: Unlocking capital at the scale required.

Green funds are available, but new financial instruments are needed to unlock them for shipping's transition.

- Of the $3.5 trillion[52] in ESG assets under management, only $14.5 billion has been earmarked for shipping since 2018.[53]
- This is insufficient to meet the $3 trillion required to scale green hydrogen for shipping.[54]
- To unlock these funds at scale, investors need high-volume, consolidated cross-sector demand, and transparent, long-term contracts, and reliable ESG reporting.
- Current shipping models do not provide that, but new financial instruments can.
- Expanding frameworks such as the Poseidon Principles to cover green hydrogen infrastructure and carbon capture, linking loans to verified carbon savings, and creating pooled funds across sectors would channel capital into shipping's transition.
- Digital optimization and emissions reporting from ships can also support stronger investor interest.

Stakeholder actions

- **Investors:** Develop blended finance instruments and pooled funds that spread risk across government, shipping, aviation, and heavy industry. Link financing terms to carbon intensity reductions verified under IMO and regional schemes.
- **Shipowners and cargo owners:** Work with investors to structure bankable offtake agreements that tie repayment to avoided carbon costs and verified emissions savings. Participate in cross-sector financing platforms to secure affordable access to fuels and infrastructure. Use digital optimization and emissions reporting to provide greater ESG certainty.
- **Governments:** Support private investors by reducing risk, for example through loss guarantees, co-investment, or low-cost public loans. This will help direct ESG capital into shipping projects rather than leaving it on the sidelines.

7 | Global goals need local action: Align energy incentives with IMO net zero.

Where policy alignment is strong, capital flows. Harmonize national energy policies and incentives to support the green hydrogen economy and the IMO global net zero goals.

- Europe, Australia, and the Middle East are advancing with clear green hydrogen frameworks that give investors confidence, while recent policy reversals in the United States have slowed momentum there.
- Fragmented regional rules and competing certification schemes create uncertainty, undermine national energy security, raise compliance costs, and risk delaying final investment decisions.
- The IMO Net Zero Framework offers the best chance for a level global playing field, provided certification and carbon pricing standards harmonize internationally.

Stakeholder actions

- **Governments and flag states:** Align national energy and industrial incentives with the IMO Net Zero Framework so that supply- and demand-side measures support the attainment of global net zero standards and goals.
- Provide long-term stability across election cycles to attract investment.
- Establish green hydrogen and e-fuel certification systems that are compatible with IMO methodologies and interoperable across borders.
- **Multilateral institutions:** Use the IMO as an anchor to foster bilateral and regional partnerships to connect fragmented green hydrogen and carbon markets into a coherent global system.
- Promote the harmonization of certification, carbon pricing, and fuel standards to reduce complexity and unlock investor confidence.

8 | Ports provide the platform, but who will lead?

The missing piece is a forum for cross-sector collaboration, with ports as the natural nexus of activity.

Shipping, aviation, steel, cement, chemicals, power, and agriculture all need the same green hydrogen-based fuels.

Ports are the natural meeting points for both energy and industry, yet no single forum or institution currently coordinates cross-sector demand at this scale.

Without a trusted orchestrator, the risk is that promising infrastructure plans stall for lack of alignment.

Such a forum must go beyond demand aggregation to also address handling, safety, and business models. Its purpose would be to ensure both energy security and net zero progress through coordinated access to green hydrogen, carbon capture, and e-fuels.

Stakeholder actions

- **Ports:** Step forward as conveners by creating structured forums that bring together maritime customers and industrial users inland. Use these platforms to develop shared offtake agreements and coordinated infrastructure plans.
- **Governments and flag states:** Align national energy and industrial policies with the IMO Net Zero Framework so that supply- and demand-side incentives reinforce one another. Support ports with grants, guarantees, or co-investment schemes that make cross-sector aggregation financially viable.
- This reduces the risk of fragmented approaches and helps create the scale and certainty fuel producers and investors require.
- **Existing industry alliances:** Consider whether new or expanded coalitions are required to complement ports' facilitation role, ensuring that aggregated demand signals reach the scale producers and investors require to commit capital.

Shipping has already demonstrated that preparing the fleet for decarbonization is possible. The next step is participation in a cross-sector energy transition that secures the fuels and infrastructure no single industry can deliver alone.

Ports emerge as the natural focal points for this effort: by aggregating demand, aligning policies, and anchoring investment, they can turn fragmented signals into the scale and certainty needed for a net zero economy.

In the end, shipping's role will be defined not only by its own progress, but by its ability to engage in a cross-sector energy transition that determines the resilience and prosperity of the global economy.

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