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Decarbonising Hard to Abate Sectors: Marine Fuels



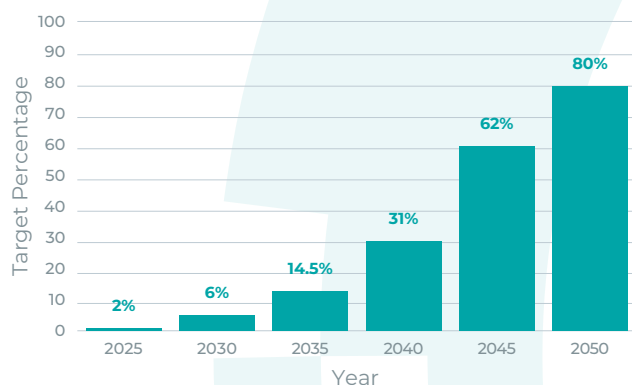


Introduction: The Problem

Annual emissions from the shipping industry are estimated at 940 million tonnes of CO₂¹. The International Energy Agency (IEA) estimates this was approximately 2% of global energy related CO₂ emissions in 2022² and the IEA Net Zero Emissions by 2050 (NZE) scenario requires approximately 15% reduction in shipping emissions from 2022-2030. The European clean transport not for profit, Transport & Environment, estimates shipping could represent 10% of global greenhouse gas (GHG) emissions by 2050³. On these numbers, the need to decarbonise shipping is clear. While the revised emissions reduction targets recently announced by the International Maritime Organisation (IMO) are now in line with the goals set out in the Paris Agreement⁴, these need to be supported through additional regulatory drivers to legislate for or incentivise the maritime shipping sector to decarbonise at the scale required.

In the European Union, the FuelEU Maritime initiative aims to decarbonise the maritime sector by promoting sustainable fuels and technologies through implementation of GHG Reduction Targets until 2050:

- The initiative sets progressive GHG reduction targets for the energy used in shipping, compared to 2020 levels.
- These targets increase over time:



If RFNBOs (renewable fuels of non-biological origin) amount to less than 1% in the fuel mix by 2031, the initiative plans to set a 2% renewable fuels usage target by 2034.

In addition to the FuelEU Maritime targets, industry body, the International Maritime Organisation (IMO) has proposed a Global Greenhouse Gas standard to reduce emissions from shipping as part of its emissions reduction strategy. This includes:

- **Net-Zero GHG Emissions by 2050:** The IMO aims to reach net-zero GHG emissions from international shipping by or around 2050.
- **Reduction in Carbon Intensity:** The strategy includes a reduction in carbon intensity of international shipping (to reduce CO₂ emissions per transport work), as an average across international shipping, by at least 40% by 2030.
- **Uptake of Zero or Near-Zero GHG Emission Technologies:** The strategy includes a new level of ambition relating to the uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources which are to represent at least 5%, striving for 10%, of the energy used by international shipping by 2030.
- **Phasing Out GHGs:** The IMO aims to phase out GHGs as soon as possible, while promoting a just and equitable transition⁵.

These governmental and industry initiatives are driving an increase in projects aiming to produce alternative, low carbon fuels for the maritime industry.

Deep sea vessels have large energy requirements and account for 80% of the total shipping emissions, currently the majority of these ships are powered by diesel internal combustion engines.

1 UK Research and Innovation (2021) Shipping Industry Reduces Carbon Emissions with Space Technology <https://www.ukri.org>
2 <https://www.iea.org/energy-system/transport/international-shipping>
3 <https://www.transportenvironment.org/topics/ships/climate-impact-shipping>
4 <https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx>
5 <https://www.imo.org/en/MediaCentre/PressBriefings/pages/Revised-GHG-reduction-strategy-for-global-shipping-adopted.aspx>

LNG and LPG are viewed as transitional fuels as they have lower emissions, but they are still carbon-based fuels, and will likely only be used in the interim, until 2030, while zero carbon fuels and technologies are developed. In the short to medium term, biofuels are viewed as an alternative fuel.

Several biofuels exist on the commercial market today, including first- and second-generation biofuels. The two main commercially available biofuels are Fatty Acid Methyl Esters (FAME) and Hydrogenated Vegetable Oil (HVO).

Biofuels offer some advantages as a short-term decarbonisation option:

- Drop-in biofuels are fuels that can be directly substituted in place of an existing fossil fuel with minimal alterations to equipment.
- While Tank-to-Wake emissions are similar to MGO, biofuels offer reductions on the upstream Well-to-Tank emissions.

Production of biofuels is expected to increase over the next decade; however, the maritime industry is likely to face significant competition from other sectors when securing supply contracts. This may lead to fuel price increases and slow eventual uptake of biofuels among vessel owners and operators. There are also concerns regarding the long-term availability and sustainability of bio feedstocks.

Unlike previous fuel transitions, where the shipping industry transitioned from one fuel to another: wind to steam to fossil, both DNV and the Maersk McKinney Moller Center for Zero Carbon Shipping predict a mix of fuel types will be used to decarbonise the shipping industry.

This is reflected in the IEA's modelling with ammonia supplying 45% of the total shipping fuel by 2050 in the Net Zero by 2050 model.

While traditional production of methanol and ammonia exists, these are primarily reliant on natural gas as a feedstock and for these fuels to be considered carbon neutral their production must include carbon capture processes. However, there is an emerging dynamic where alternative production pathways are being developed. Having executed over 35 power-to-x and power-to-liquid projects globally, including projects where e-methanol and "green" ammonia has been produced for shipping, io consulting is supporting the decarbonisation of the maritime industry by bringing these alternative fuel projects to market.

The Solutions:

Hydrogen

Hydrogen may have a role to play in shipping, either as a fuel itself or as a feedstock to produce other fuels such as ammonia or e-fuels, including e-methanol. However, hydrogen is currently primarily produced from fossil feedstocks and incorporating it into the fuel system can lead to higher lifecycle greenhouse gas emissions than conventional marine fossil fuels. Lower carbon "blue" hydrogen can be produced from legacy fossil fuel pathways through implementation of carbon capture processes. Alternatively, "green" hydrogen can be produced via electrolysis of water using renewable electricity and can be considered carbon free.

While hydrogen can be used as a fuel in specialised internal combustion engines or gas turbines or in retrofit engines where the fuel injection system has been converted, it still requires blending of the hydrogen with conventional fuels to aid combustion. Furthermore, combustion of hydrogen in air can produce NO_x, which are potent greenhouse gases themselves. An alternative approach is to use hydrogen to generate electricity in a fuel cell, which releases energy from the hydrogen via a chemical reaction.

The significant challenges facing the direct use of hydrogen as a fuel are the storage, transportation and handling complexities. Hydrogen can be stored as compressed gas (GH₂) at 450 - 700 bar, as a cryogenic liquid (LH₂) at -253°C, or a combination of both. Each option poses significant challenges for vessel design and operation. This is further complicated by the size of the hydrogen molecule being so small as it has a propensity to leak. While these leaks may be small hydrogen is itself an indirect GHG with significant global warming potential. To mitigate these challenges, alternative hydrogen derived fuels are being explored by the shipping industry.

Ammonia

As a compound, ammonia (NH₃) is well understood with a mature and proven production process: the Haber-Bosch process in which hydrogen is reacted with nitrogen in the presence of a catalyst. At atmospheric pressure, ammonia is liquid below -33°C, so does not require high-pressure or cryogenic storage. Furthermore, as a larger molecule it is less leak prone than hydrogen. In this regard it is an attractive fuel for the maritime applications and dual-fuel engines that are in development. However, it is not without its challenges:

- Given ammonia production requires a hydrogen feedstock, it faces the same need for a low carbon production hydrogen.
- The need to produce low carbon hydrogen and then use that to synthesise ammonia adds complexity and cost to the production process, making it economically challenged in comparison to traditional fuels.
- It has a lower energy density than traditional fuels, so larger onboard tank storage solutions are required.
- It is highly toxic, while protocols are in place to safely transport it as a cargo using it as a fuel, it introduces new risks to crew that will need to be managed.
- Similar to burning hydrogen in air, ammonia produces nitrogen oxides. A recent MIT study claims this could result in approximately 600,000 additional premature deaths should the global fleet be switched to ammonia fuel⁶.

6 <https://news.mit.edu/2024/study-finds-health-risks-switching-ships-to-ammonia-fuel-0711>

E-Fuels

E-fuels, particularly e-methanol and e-methane, are also attractive solutions for the maritime industry due to their equivalence with the fossil counterparts meaning they are compatible with existing infrastructure and engines. However, they have other positives:

- E-fuels have a higher energy density compared to batteries. This characteristic makes them particularly relevant for applications where weight and volume constraints are critical.
- In maritime applications, where long distances are covered and energy storage space is limited, e-fuels offer a viable alternative to batteries.
- Batteries, while suitable for short-haul flights and land-based vehicles, face limitations in terms of weight and capacity for extended marine journeys.
- Large cargo vessels operate globally, often far from charging infrastructure.

E-Methanol

E-methanol is produced via a one-step CO₂ hydrogenation process that uses CO₂ directly as a feedstock or via a two-step synthesis process (Reverse Water Gas Shift and CO Hydrogenation). Due to the inclusion of oxygen within the methanol chemical formula, the mass production rates of methanol are significantly higher than other e-hydrocarbons. E-methanol is a key product in the chemical industries. Global methanol production has grown from approximately 98.3 Mt in 2019 and is expected to rise to more than 120 Mt by 2025, 137 Mt by 2030 and 500 Mt by 2050. There is expected to be a significant market for e-methanol in the coming years, and the technology for its production is at Technology Readiness Level (TRL) 9. The analysis performed indicates a strong preference for e-methanol over bio-methanol in Europe.

As part of this dynamic, e-methanol offers an attractive solution for the marine industry offering the following benefits:

- Methanol is a proven marine fuel.
- Methanol has a higher volumetric energy content than alternative fuels like ammonia or hydrogen, making it a better choice for a wide range of vessel types and longer voyages, as it requires less frequent bunkering.
- Existing methanol dual-fuel engines can function with green methanol, including bio-methanol and e-methanol.
- E-methanol is a liquid fuel under ambient conditions, making it easier to transport, store, and bunker using standard safety procedures.
- Cost of storage and supply of e-methanol is significantly lower than other alternative fuels that require pressurisation or cryogenics.

Based on existing orders, Methanex predicts there will be over 250 methanol fuelled ships on the water by 2028⁷.

⁷ <https://www.methanex.com/about-methanol/marine-fuel>

E-Methane

E-methane is produced via methanation (the Sabatier reaction). At the time of writing, there is a single commercial e-methane facility in operation (Audi e-gas), and the product is assigned a TRL of between 7 and 8. There is a developing market for e-methane, primarily due to its identical chemical composition to methane enabling it to be a “drop-in” replacement supplying the existing offtakers. Koppö Energy Oy, a joint venture company between Prime Green Energy Infrastructure Fund and CPC Finland Oy, is developing a 200MW e-methane facility in Kristinestad, Finland. The project will produce 50,000t e-LNG per year and export it to Germany via an existing route and infrastructure.

The global methane market is dominated by oil & gas majors, who produce fossil methane at a fraction of the cost of e-methane. Furthermore, the production of e-methane for use as a combustion fuel is inherently inefficient: in an interview with Hydrogen Insight, the developer of the Kristinestad e-methane project claims electricity produced by a project's wind farms will lose around 30% of its energy content during electrolysis; a further 40-50% during the Sabatier methanation process; with energy losses in the combustion engine leaving just 20-30% of original energy content⁸.

The growth in the e-methane market is shown in Maersk Mc-Kinney Moller Center for Zero Carbon Shipping's Fuel Pathway Maturity Map, which grades e-methane as mature for fuel storage, logistics & bunkering: onboard energy storage & fuel conversion and onboard safety & operations⁹. MOL aims to have 90 LNG ships on water by 2030¹⁰, NYK expects to have 20 LNG fuelled car carriers on the water by 2028¹¹, CMA CGA has 9 LNG fuelled vessels on order¹² and Hapag-Lloyd expect to stake synthetic LNG as bunker fuel from 2026. Similarly, Nordic road and maritime fuel provider Gasum identifies the interchangeability of

e-methane with natural gas, biogas and, when it's liquefied, with LNG and bio-LNG. In January 2024, Gasum announced an offtake agreement with Nordic Ren-Gas where they will buy all of the e-methane produced at the Tampere plant from 2026 onwards. This is estimated to be e-methane equivalent to 160 GWh per year.

Again, Koppö highlights the drop in nature of e-methane and argues that e-methanol ships still need to be built while ships and heavy goods trucks already run on LNG. This assertion can be substantiated by looking at maritime providers, for example The CMA CGM Group has 28 ‘e-methane ready’ dual-fuel, LNG-powered containerships and will have a total of 44 vessels of this type in service by the end of 2024¹³.

8 <https://www.hydrogeninsight.com/transport/interview-this-is-why-were-producing-e-methane-from-green-hydrogen-even-though-its-so-inefficient/2-1-1495170>

9 <https://www.zeroarbonshipping.com/fuel-pathways>

10 <https://www.mol.co.jp/en/pr/2022/22094.html>

11 <https://ingprime.com/asia/japans-nyk-to-further-expand-its-large-lng-fleet/97182/#:~:text=NYK%20currently%20has%2013%20LNG-fueled%20vessels%2C%202%20LPG-powered,The%20firm%20also%20has%20one%20LNG%20bunkering%20vessel>

12 <https://www.cma-cgm.com/news/2749/world-premiere-launching-of-the-world-s-largest-lng-powered-containership-and-future-cma-cgm-group-flagship>

13 <https://www.cleanshippinginternational.com/cma-cgm-joins-french-hydrogen-and-e-methane-project>

Beyond Liquid Fuels

Battery Energy Storage Systems (BESS)

BESS is emerging as a popular power delivery option for short-sea routes, particularly for ferries and small vessels with relatively low power demand. Energy density of lithium-ion BESS is very low compared to conventional marine fuels and other alternative low-emissions fuels, limiting the application of full-electric energy storage system propulsion systems to larger vessels. Some lower-TRL options are emerging which may offer alternative solutions, including Lithium-Titanium-Oxide (LTO), Sodium-Metal-Chloride, and other solid-state architectures.

Emissions abatement from the use of BESS depends upon the source of the electricity used for charging. If the electricity is from a renewable source (e.g. wind turbines, tidal turbines), lifecycle emissions can potentially be reduced significantly.

The uptake of BESS has been especially fast in Scandinavia and the Baltic states, where short-sea ferries are common. As of July 2024, 84 full-electric vessels have been delivered globally, of which 73% are Ro-Pax or Ro-Ro car & passenger vessels¹⁴.

Nuclear

Nuclear power solutions are emerging within the maritime sector, with several promising designs in development. Small Modular Reactors (SMRs) offer high-density power delivery with extremely long refuel periods. Several reactor architectures are available, which typically differ on cooling methodologies.

Nuclear power offers potential “zero-emission” propulsion, however, the additional complexity of the power generation system, along with the strict training requirements for onboard crew, means that uptake is likely to be slow. These solutions are currently low- to medium-TRL and significant development is required to reduce the levelised cost of energy (LCOE) from these systems, particularly for maritime applications. The primary barrier for nuclear power in the maritime sector is likely to be the slow development of regulations, at both a governmental level within each flag-state, but also globally within IMO and classification society rules and guidelines. Power to x applications may be more advantageous than direct propulsion, as floating nuclear barges could provide high-power industrial applications. This application is also low-TRL, however, and requires additional development.

¹⁴ www.clarksons.net/wfr/fleet



The Complexities

Transportation & Storage

Complex storage methodologies are required for hydrogen and ammonia, which make transportation costs more expensive per tonne carried. The relatively low energy density of hydrogen, methanol and BESS mean that significant modifications to vessel design may be required to provide the required vessel operational range. Safe operational methodologies must be built into upstream transportation and handling processes.

Loading & Offloading

Bunkering methodologies for low-flashpoint alternative fuels require significant de-risking, especially in ports with high passenger and crew throughput. Risks associated with explosion and fire, particularly for hydrogen and methanol, require mitigation in line with the as low as reasonably practicable (ALARP) principles. Ownership of the risk is not yet defined and may fall somewhere between the vessel owner/operator and the port authority. Decoupling the human factor from operations through autonomy may offer significant risk mitigation, however, this adds additional complexity to existing bunkering methodologies and represents a step change in approach.

Safe Operations at Sea

Spillage or leakage of alternative marine fuels, particularly ammonia, represents a major hazard for both human and marine life. The high toxicity of ammonia means that leakage to the marine environment is particularly damaging and should therefore be mitigated as far as possible.

Additional training will be required for future vessels crews, particularly around leakage response and fire suppression. This represents a large operational barrier to the uptake of low-flashpoint marine fuels and can have indirect effects on vessel operating expenditure (OPEX).

Economics

In addition to the technical challenges, the cost of producing alternative fuels make them economically unattractive in comparison to fossil alternatives.

Considering that fossil-based fuels are currently (October 2024) in the following price ranges:

- VLSFO: ~USD 500-600/mt¹⁵
- LNG: ~USD 790/mt¹⁶
- Grey Methanol: ~USD 300-385/mt¹⁷
- Grey Ammonia: ~USD 350-550/mt¹⁸

They are significantly less expensive than alternatives:

- E-methane: A paper titled "Production costs for synthetic methane in 2030 and 2050 of an optimized Power-to-Gas plant with intermediate hydrogen storage," published in the Applied Energy journal in 2019, calculated e-methane production costs at 175-290EUR/MWh in 2030 dropping to 75-120 EUR/MWh in 2050. It must be noted these ranges are based on a range of assumed electricity prices, which significantly influence the production costs¹⁹.
- E-methanol: The current production cost of e-methanol is estimated to be in the range USD 800-1600/t assuming CO₂ is sourced from bioenergy with carbon capture and storage (BECCS) at a cost of USD 10-50/t. With anticipated decreases in renewable power prices, the cost of e-methanol is expected to decrease to levels between USD 250-630/t by 2050²⁰.
- Green ammonia: recent io studies have calculated the levelised cost of green ammonia (LCOA) to be in the range of USD 650-900/mt.

Why are projects not reaching FID?

The technical complexities, combined with the relatively low TRLs for the production pathways and the nascent adoption of alternative fuels, results in a risk profile that is often prohibitive to making a Final Investment Decision (FID). This uncertainty is exacerbated by the seeming lack of a clear choice of fuel of a future: while the range of options eases risk that comes from a single choice of product where feedstocks and production pathways may be constrained, it also introduces uncertainty and hinders investments with investors reluctant to back the "wrong" fuel.

From the economic perspective, as indicated in the introduction of this paper, there is a regulatory drive to decarbonise shipping and the target quota for RFNBOs as part of the fuel mix that are included in FuelEU Maritime may move to reduce some of the uncertainty. However, in addition to these regulations and potential penalties for shipping companies, it is likely that there will need to be financial incentives to encourage developers and investors to produce alternative fuels, which are currently more expensive than existing fuels, in the required quantities.

15 <https://shipandbunker.com/prices>

16 <https://shipandbunker.com/prices/emea/nwe/nl-rtm-rotterdam#LNG>

17 <https://shipandbunker.com/prices>

18 <https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/051023-interactive-ammonia-price-chart-natural-gas-feedstock-europe-usgc-black-sea>

19 Jachin Gorre, Felix Ortloff, Charlotte van Leeuwen, Production costs for synthetic methane in 2030 and 2050 of an optimized Power-to-Gas plant with intermediate hydrogen storage, Applied Energy, Volume 253, 2019, 113594, ISSN 0306-2619, <https://doi.org/10.1016/j.apenergy.2019.113594>.

20 https://www.methanol.org/wp-content/uploads/2020/04/IRENA_Innovation_Renewable_Methanol_2021.pdf

The Opportunities

New Frontiers

Production costs for green hydrogen and, by extension its derivatives, including ammonia and e-fuels is driven by low power costs. This in turn is driving these projects to be developed in areas with more abundant renewable energy resources: the north of the Nordics; Spain and Portugal; North and West Africa; South America; Canada and Australia. While some of these locations have a legacy fossil-based industry, with the associated infrastructure, some are new entrants to fuel production. This brings opportunity for diversifying economies and labour markets; and has the potential to shift terminal, bunkering and re-fuelling hubs across the globe. This dynamic creates opportunities such as a terminal for hydrogen derivative fuels on the Suez to distribute relatively low-cost product from North African and Middle Eastern electrolysis facilities.

Sector Coupling (Cement, Hydrogen & E-methanol)

One way to offset the cost of producing e-fuels is to consider opportunities for integration with other sectors where the waste streams can be minimised and value maximised. io has previously discussed this in an article focussed on sector coupling discussing multiple use cases, including an example for e-methanol.

Considering the cement industry, one of the most impactful ways of reducing the emissions from cement production is to introduce an oxy-fuel kiln to the clinker. The benefit of oxy-combustion is that when fuel is combusted in pure oxygen the flue gas contains mainly CO₂ and water vapour with only trace amounts of other combustion products. Capture of CO₂ from this highly pure stream is significantly easier than from flue gas produced in conventional combustion, which contains significantly more impurities. This compatibility with existing fuel sources and the ease of capture makes oxy-combustion an attractive potential solution for the cement industry. This process requires a source of pure oxygen, which is often obtained by the introduction of an Air Separation Unit (ASU) to the process. However, combining this with a hydrogen electrolysis facility presents the opportunity to use the "waste" oxygen as a feedstock for the oxy-kiln, thus increasing the utility of the electrolysis process. Furthermore, the CO₂ captured from the cement facility can then be used as a feedstock to produce e-fuels such as e-methanol or e-methane. In this scenario the waste streams from hydrogen and cement production are integrated to take advantage of a compelling synergy. This is particularly pertinent for cement facilities located in the proximity of ports.

Conclusion: Why Houlder & io consulting?

The development of alternative fuels is critical for the decarbonisation of the marine industry. However, projects for the production of these fuels are challenged economically and technically. These challenges bring uncertainty to investors and developers who require the projects to be significantly de-risked before they are willing to take FID.

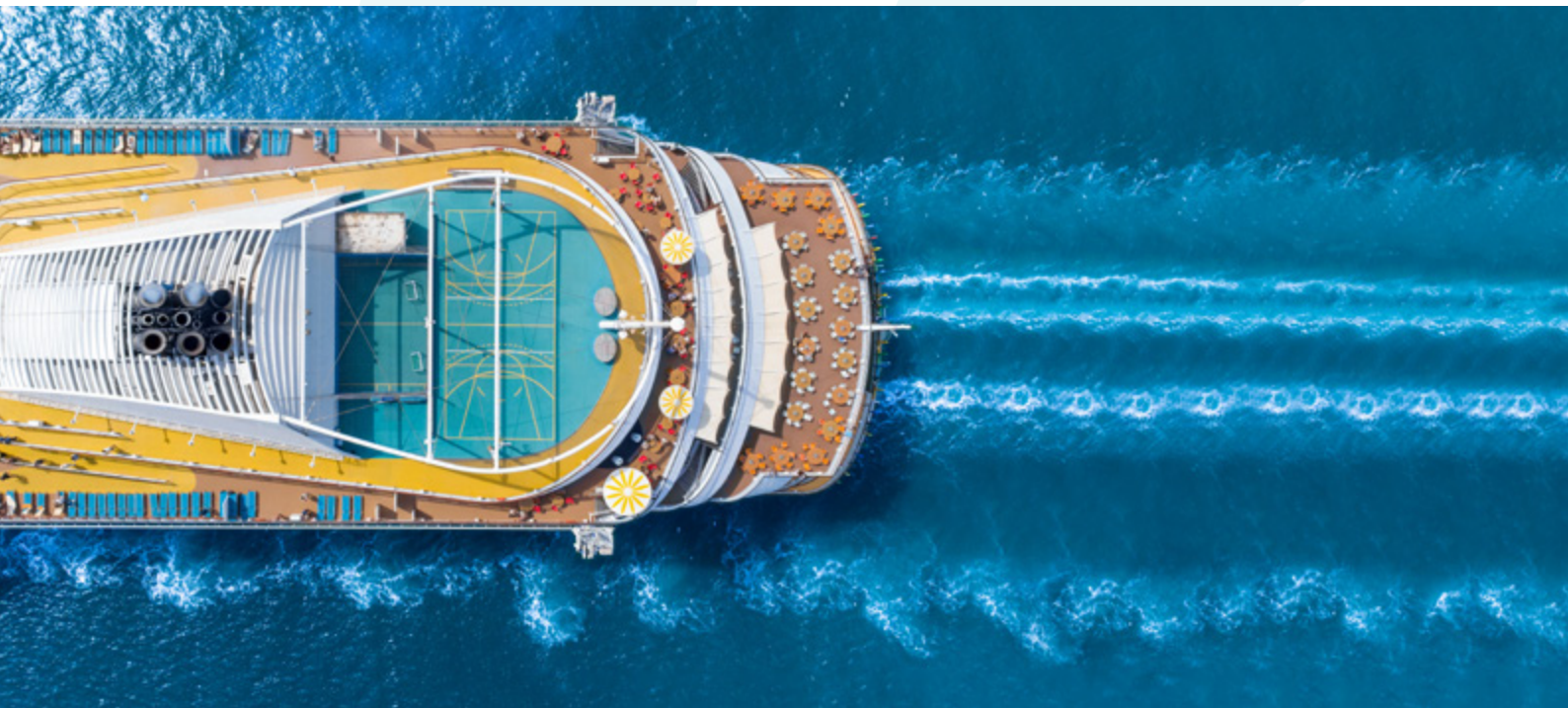
io consulting and Houlder bring a complementary skillset that can deliver this derisking and enable projects to move forward at the scale and pace industry requires. As a project architect and system integrator, io is uniquely positioned to shape the optimal solution for the development of alternative fuel projects and has done so for over 35 power-to-x / power-to-liquid projects including ammonia and e-methanol. Houlder's technical understanding of vessel design and supply chain requirements to support the safe uptake of low-emissions alternative fuels complements these capabilities offered by io.

Houlder offers comprehensive, well-to-wake technical and commercial expertise. This integrates well with io's emerge tool, which is a powerful suite of linked technical and commercial modelling tools designed specifically for hydrogen, e-fuels, power-to-x and other complex projects.

io and Houlder de-risk alternative fuel projects by:

- Reducing Development Costs: Tailored optimisation targeting the core drivers of project efficiency, without unnecessary simulations.
- Integration Excellence: Seamlessly integrates meteorological conditions, energy generation, chemical processes and more to offer a holistic project view.
- Dynamic Modelling: Utilises dynamic simulation frameworks and visualisation tools to create bespoke solutions for every project phase.
- Deep Domain Expertise: Backed by io's extensive experience across over 50 large-scale projects, ensuring best-in-class project outcomes.

By focusing on what truly matters and delivering a streamlined approach to project design, emerge empowers developers to achieve technically feasible and bankable projects ready for final investment decisions and beyond.



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