Availability of E-fuels and E-fuel-capable Vessels from 2027–2030

KEY FINDINGS FROM A REQUEST FOR INFORMATION FOR THE ZERO EMISSION MARITIME BUYERS ALLIANCE

OCTOBER 2024

ZEMBA
ZERO EMISSION MARITIME BUYERS ALLIANCE

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1 Lloyd's Register Maritime Decarbonisation Hub

2 The Aspen Institute. Note, the Aspen Institute serves as the Secretariat of the Zero Emission Maritime Buyers Alliance (ZEMBA)

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Highlights

- In May 2024, the Zero Emission Maritime Buyers Alliance (ZEMBA) in collaboration with Lloyd's Register Maritime Decarbonisation Hub launched a request for information (RFI) to assess the **near-term (2027–2030) market readiness of e-fuels for commercial deployment** in the maritime shipping sector to inform the design of ZEMBA's next collective tender process. **32 fuel suppliers and 15 ship operators** participated in the RFI.
- The majority of respondents predicted that commercial e-fuels deployment in the maritime sector would be feasible between **2027 and 2028**, with limited deployment as early as **late 2026**.
- For e-fuel volume projections, the RFI results suggested that **391,000 metric tonnes of heavy fuel oil equivalent (tHFOe) of e-fuel** (e-ammonia, e-methane, and e-methanol) production could be expected by 2027 across multiple sectors. **304,000 tHFOe** (78%) of that projected e-fuel production was reported from fuel suppliers who ranked the maritime sector as their top target market.
- For e-fuel-capable vessel projections, in 2027, the RFI found for the containership segment specifically, there are projected to be 27 e-methane-capable vessels, 68 e-methanol-capable vessels, and 4 e-ammonia-capable vessels. This equates to **985,700 TEU of e-fuel-capable vessels**.
- In comparing the supply of e-fuel production and e-fuel-capable vessels from 2027 to 2030, the RFI results suggested a **mismatch between the projected supply of different e-fuels and the projected availability of e-fuel-capable vessels**, potentially limiting the near-term availability of certain e-fuel-powered shipping services in the container segment.
- Based on these projections, for a next e-fuel tender, ZEMBA can remain focused on aggregating demand for the environmental attributes associated with **container shipping services**. For containership services launching in 2027, **e-methanol-powered container shipping services** represent the most likely bid pathways. ZEMBA remains open to **any qualifying e-fuel-powered bid**.
- Crucially, the RFI **did not ask about potential costs or prices** associated with e-fuel-powered shipping services, which will have **major implications** on both the timescales for deployment and the overall uptake of e-fuel in the maritime sector.
- While the RFI projections suggest that e-fuel-powered shipping services could be available by 2027, ZEMBA learned through its inaugural tender process that **projections do not always equate to deployment**. One of the key considerations as part of the design of ZEMBA's next tender is how its forward procurement processes can help **facilitate actual offtake of projected e-fuel production** to support the deployment of e-fuel-powered shipping services.
- While comparisons to existing literature suggest the RFI captured a **representative view** of the developing e-fuel and e-fuel-capable vessel market, the results from the RFI represent a **snapshot in time of constantly evolving markets** and a subset of the overall fuel production and ship operator communities. The supply of e-fuel and availability of e-fuel-capable vessels for ZEMBA's next tender depends on many global, regional, and national factors outside ZEMBA control.

About ZEMBA

The Zero Emission Maritime Buyers Alliance (ZEMBA), a non-profit organization, is a first-of-its-kind buyers group within the maritime sector, the aim of which is to accelerate commercial deployment of zero-emission shipping, enable economies of scale, and help cargo owners maximize emissions reduction potential beyond what any one freight buyer could accomplish alone. The Aspen Institute's Energy and Environment Program serves as the Secretariat. More information is available at www.shipzemba.org.

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The Aspen Institute is a global nonprofit organization committed to realizing a free, just, and equitable society. Founded in 1949, the Institute drives change through dialogue, leadership, and action to help solve the most important challenges facing the United States and the world. The Institute has campuses in Aspen, Colorado, and Washington, D.C. It also maintains offices in New York City and has an international network of partners. Visit www.aspeninstitute.org to learn more.

About Lloyd's Register Maritime Decarbonisation Hub

The Lloyd's Register Maritime Decarbonisation Hub is an independent, not-for-profit social purpose organisation, working towards our vision of a safe, sustainable, and human-centric decarbonised shipping industry for the benefit of society.

Formed in 2020 with a grant from Lloyd's Register Foundation, and in partnership with Lloyd's Register Group, we are an evidence-led research and action unit. Our team of specialists in economics, fuels, risk & safety engineering, human factors, and analytics deliver research, insights, and implementation pathways to future fuels across the maritime supply chain.

For more information, go to www.maritimedecarbonisationhub.com.

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Executive Summary

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This report summarizes the key findings of a Request for Information (RFI) that the Zero Emission Maritime Buyers Alliance (ZEMBA) and Lloyd's Register Maritime Decarbonisation Hub (LR MDH) launched in May 2024 to assess the market readiness of e-fuels for commercial deployment in the maritime shipping sector from 2027 to 2030.

ZEMBA is a first-of-its-kind buyers group within the maritime sector. Its mission is to accelerate commercial deployment of zero-emission (ZE) shipping solutions, enable economies of scale for freight buyers and suppliers, and help cargo owners maximize emissions reduction potential beyond what any one freight buyer could accomplish alone. ZEMBA's inaugural tender aggregating demand for the environmental attributes associated with zero-emission shipping services was concluded in April 2024.

Ahead of the launch of the inaugural tender, ZEMBA elected not to conduct an RFI, instead proceeding directly to market discovery. For ZEMBA's inaugural tender, despite numerous

announcements about e-fuel production projects, e-fuel-capable vessels on order, and setting a 90% emissions reduction target for bids[3], ZEMBA did not receive any e-fuel bids. This process, then, served as a learning opportunity; an ambitious emissions reduction target and announcements for e-fuel development projects and e-fuel capable vessels do not necessarily correlate to ship operators offering e-fuel-powered shipping services to willing customers.

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Having now demonstrated that ZEMBA is an effective model for aggregating demand among climate-leading cargo owners to invest in decarbonized shipping solutions, ZEMBA seeks to focus its next tender specifically on accelerating e-fuel deployment in the maritime sector. To procure the environmental attributes associated with e-fuel-powered shipping services in the next tender, one of ZEMBA's principal tasks is to understand how its forward procurement process can stimulate e-fuel production and facilitate e-fuel offtake by the maritime sector—helping unlock and catalyze the deployment of e-fuel-powered shipping services.

Toward this ambition, ZEMBA and LR MDH launched an RFI to assess the market readiness of commercial deployment of e-fuels in shipping to inform ZEMBA's second tender design. The RFI focused on understanding the landscape around e-fuel development and e-fuel-capable vessel deployment in the maritime sector from 2027–2030. While e-fuel production and e-fuel-capable vessel availability are two crucial factors that influence the likelihood of ZEMBA receiving e-fuel-focused bids during its next tender, there are additional factors and layers of complexity shaping the maritime sector's decarbonization and, relatedly, the sector's willingness to offer ZEMBA e-fuel-powered bids. The RFI did not ask about potential costs or prices associated with e-fuel-powered shipping services, which will have implications for both the timescale for deployment and the overall uptake of e-fuel in the maritime sector.

For this information-gathering exercise, the ZEMBA and LR MDH teams defined e-fuels as fuels manufactured from hydrogen produced through electrolysis and with production pathways that ensure a very low overall emissions profile. Many in the maritime sector consider e-fuels to be highly scalable fuel solutions capable of meeting a large proportion of the maritime fuel mix by 2050.[4] ZEMBA is in the process of revising its sustainability framework, including its Zero Emission Fuels Definition and Lifecycle Analysis (LCA) guidelines. These were developed to support its inaugural tender, to both aid the submission of e-fuel proposals and clearly define acceptable production pathways.

The RFI was comprised of two surveys, one for fuel producers and a second for ship operators and was supplemented by a series of interviews with a subset of survey respondents. In total, 32 fuel providers and 15 ship operators responded to the written surveys, and the team conducted 18 follow up interviews (12 fuel providers and 6 ship operators). The surveys and interviews aimed

3 Compared to a low sulfur fuel oil baseline. See ZEMBA's tender 1 lifecycle analysis (LCA) guidelines for additional information, https://www.cozev.org/img/3.-Attachment-B-ZEMBA-LCA-Guidelines-and-Proposal-Requirements.pdf.

4 C. Raucci, C. McKinlay and A. Karan, "The future of maritime fuels. What you need to know.," Lloyd's Register Maritime Decarbonisation Hub, 2023.

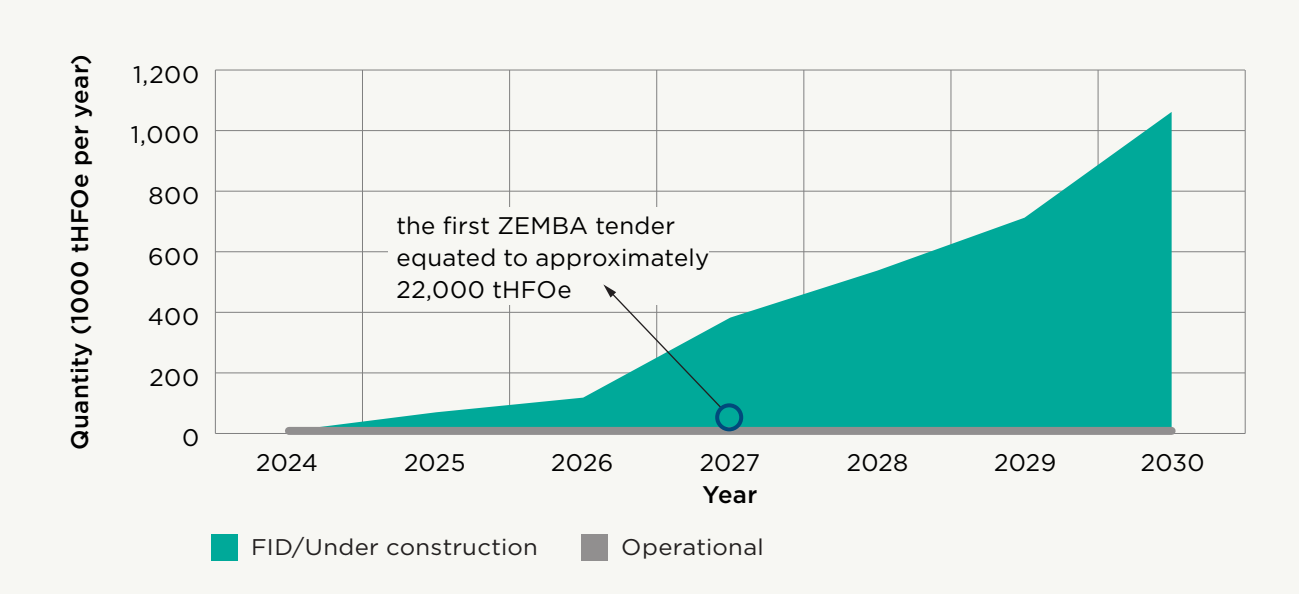
to gather a mix of quantitative and qualitative data to provide a representative overview of the market (readiness of e-fuel supply and the number of e-fuel-capable vessels) from 2027 to 2030, aligning with the projected timeline of ZEMBA's next tender. This report summarizes results from the RFI, focusing on the implications for ZEMBA's next tender. It also comments on how these findings related to overarching trends in the commercial deployment of e-fuels in the maritime sector. The data shown in this report has been anonymized and aggregated to display key trends and protect commercially sensitive information.

Overall, the majority of respondents suggested that commercial e-fuels deployment in the maritime sector would be feasible between 2027 and 2028, with limited deployment potentially as early as late 2026. The RFI results also suggest that e-fuel capable vessels could be operating and on the water on a similar timeframe, with variations based on the type of e-fuel.

To better understand the evolving e-fuels and e-fuel-capable vessel markets and their near-term availability ahead of ZEMBA's next tender, the RFI asked respondents to distinguish between pre- and post-final investment decision (FID)[5] e-fuel projects and e-fuel-capable vessels production status (operational, on order, or under consideration).

The aggregated RFI results for post-FID e-fuel projects[6] (Figure 1) suggest a total e-fuel production availability of at least 391,000 tonnes heavy fuel oil equivalent (tHFOe) in 2027 and 1.07 million tHFOe in 2030.[7] 78% of this projected availability is from suppliers who ranked maritime as their number one target market.

Figure 1: Aggregated total potential fuel production (tHFOe) across nine post-FID e-fuel projects.



5 Final Investment Decision (FID) is a common term used in reference to a company and/or companies approving a project's future development. Typically, FID is a signal that the company feels it has enough certainty in the financial benefits of the project and is the last step of determining whether to move forward with a project, and is a signal that—in the case of e-fuel production—construction of a project would soon commence. Source: https://markets.businessinsider.com/news/stocks/the-complete-guide-to-fids-1028929515.

6 85% of the e-fuel projects reported in the RFI, representing 1.175 million tHFOe in 2027, were pre-FID projects. This suggests that there is a significant bottleneck of e-fuel projects waiting for financing, which could have major implications for the decarbonization of the maritime sector.

7 For context, the first ZEMBA tender equated to approximately 22,000 tHFOe. This expected availability of e-fuels in 2027 equates to over 17 times the fuel consumption required to deliver ZEMBA's round 1 volume, noting that volumes are expected to be higher for ZEMBA's round 2 tender. Since e-fuels all have different amounts of energy, tHFOe is a standardized unit to compare the energy potential between different e-fuel types. One tonne of heavy fuel oil equivalent is equal to the amount of energy that can be extracted from one tonne of heavy fuel oil.

Including operational, on order, and under consideration vessels, the RFI found that 263 e-fuel-capable vessels could be in commercial operation by 2027[8] and 424 e-fuel capable[9] vessels by 2030. For 2027, approximately 38% of those vessels (99 vessels) were found to be containerships, equating to a total of up to 985,000 TEU. For 2030, approximately 28% of those vessels (119 distinct vessels) were found to be containerships, equating to a total of up to 1.15 million TEU.

Comparing results from the ship operator and e-fuel supplier interviews and surveys highlighted a temporal mismatch in supply of some e-fuels and availability of e-fuel capable vessels on a fuel-by-fuel basis in the containership segment, which is summarized in Table 1 on the following page.

Table 1: Aggregated projected e-fuel supply and e-fuel-capable containership vessel availability for e-methane, e-methanol and e-ammonia in 2027 and 2030.

	E-fuel Supply [e-fuels availability—only post FID]		**E-fuel-capable Vessel Availability** [total e-fuel-capable containership capacity—e.g., dual fuel containership capable of using both e-fuels and fossil fuels]	
	2027	**2030**	**2027**	**2030**
E-methane	No projects post-FID	No projects post-FID	27 containership, representing 288,400 TEU	27 containership, representing 288,400 TEU
E-methanol	220,000 tHFOe annually	257,000 tHFOe annually	68 containership[10], representing 653,300 TEU	77 containership[11] representing 785,300 TEU
E-ammonia	172,000 tHFOe annually	814,000 tHFO3 annually	4 containership[12] representing 44,000 TEU	15 containership[13] representing 73,500 TEU

Overall, the RFI's results suggest there could be both sufficient availability of e-methanol-capable containerships (split across different operators) and e-methanol (considering only post-FID projects) to meet ZEMBA's anticipated volume requirements for its next tender starting in 2027. These results support both ZEMBA's focus in its next tender on procuring the environmental attributes associated with e-fuel-powered shipping services and ZEMBA continuing to focus on aggregating demand within the containership segment.[14,15]

While e-methane-capable container vessels are projected to be readily available, no e-methane fuel projects were submitted to the RFI that are post-FID, suggesting e-methane-capable vessels could face difficulties in operating vessels on e-methane in the near term (2027–2030). Conversely, while the RFI suggests there could be sufficient e-ammonia fuel supply, the first potential e-ammonia-capable containerships are not projected to be on the water until earliest 2027, but at this time are only "under consideration" and not yet ordered.[16]

8 This includes 9 vessels that require some degree of retrofitting, also known as "e-fuel ready".
9 This includes 15 vessels that require some degree of retrofitting, also known as "e-fuel ready".
10 Includes 5 e-methanol-ready vessels.
11 Includes 11 e-methanol-ready vessels.
12 Includes 4 e-ammonia-ready vessels.
13 Includes 4 e-ammonia-ready vessels.
14 Scalability concerns remain a factor with e-methanol if biogenic carbon inputs are used to create the fuel; the RFI found that the majority of producers intend to use biogenic sources of CO_2 from exclusively waste based streams in the next 3–5 years, with direct air capture not being viewed as commercially viable for 5–10 years.
15 ZEMBA may expand to other segments for subsequent tender processes, opening membership and/or bidding to stakeholders from other shipping segments (e.g., bulk, RoRo, tankers, etc).
16 A tender focused on e-ammonia would rely on e-ammonia-capable containerships to be ordered as soon as possible factoring shipyard availability and construction lead times.

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When comparing the results of the RFI with the existing literature and orderbooks of e-fuel and e-fuel-capable vessel projections, some differences were uncovered. Existing literature reports higher e-fuels availability than the RFI results when considering projects at all stages of development. However, it appears that a significant proportion of post-FID projects reported in the literature have been captured in the RFI; in fact, a higher number of post-FID projects were found through the RFI than has been reported in the existing literature.[17]

Both the RFI and existing literature found a low number of post-FID e-fuel projects. In the RFI, only 15% of submitted e-fuel projected were in the post-FID stage. In the existing literature, the share is between 4–5%. This reinforcement suggests that the RFI accurately captured a concerning trend in e-fuel project development that many projects are facing challenges reaching the FID stage.

On e-fuel-capable vessels, results between the global vessel orderbook and the RFI varied. The RFI results suggest more e-ammonia capable containerships could be on the water by 2027 than is reported in the orderbooks. For e-methanol-capable vessels and e-methane-capable vessels, the RFI captured 60% and 12% of the fleet register count respectively (see Figure 18).[18] This indicates that there may be e-fuel-capable containership vessel capacity accessible to ZEMBA for the next tender in excess of what was found through the RFI.

17 RFI results found a volume of post-FID e-fuel production projects in 2030 2.2 times higher than the International Energy Agency (IEA), "Hydrogen production projects interactive map," 17 November 2023.

18 The orderbook does not capture vessels that are under consideration. This data can be useful to forecast the next 2 to 3 years of e-fuel vessels, but further along the timeline the numbers are less likely to represent the total future fleet. Furthermore, only newbuild vessels are represented in the orderbooks; additional e-fuel capable vessels could become available by retrofitting existing vessels.

The estimates provided in this report seem to have captured a representative view of the developing e-fuel and e-fuel-capable vessel markets. However, these results represent a snapshot in time of a rapidly evolving and changing market, and a subset of the fuel producers and ship operators engaged in the maritime sector. The RFI results summarize e-fuel production projects and e-fuel-capable vessel orders from respondents as of early July 2024; any subsequent announcements about e-fuel production projects or vessel orders are not reflected in this report.

The RFI results broadly suggest that in its next tender, ZEMBA could procure the environmental attributes associated with an e-fuel-powered shipping service starting in 2027. There is sufficient projected supply of e-methanol and availability of e-methanol-capable vessels in the containership segment captured in the RFI results to provide sufficient confidence that an e-fuel focused tender could result in several viable bids.

Despite the robust projections for e-fuel production, many e-fuel development projects are facing financing gaps that hinder their ability to reach FID. Similarly, while ship operators are increasingly ordering e-fuel-capable vessels[19], there remains a disconnect between e-fuel production projects and ship operators securing e-fuel offtake. Challenges related to infrastructure development, global trade trends, and an uncertain global regulatory environment could impact the willingness of the maritime sector to offtake e-fuels and consequently, their willingness to offer e-fuel powered services to willing freight customers.

Overall, the RFI provided a representative sectoral insight into the potential for commercial deployment of e-fuel-powered shipping services to inform design of ZEMBA's next tender. The majority of respondents emphasized that by focusing on e-fuels in its next tender, ZEMBA could have a potentially significant impact on accelerating the commercial adoption and uptake of e-fuels in the maritime sector. Building on the momentum from ZEMBA's inaugural tender, both ship operators and fuel providers respondents saw ZEMBA's next tender as an important opportunity to contribute toward ZEMBA's mission and expressed their increasing interest in bidding for ZEMBA's next tender to support innovative solutions to decarbonize the maritime sector.

19 Clarksons Research, "World Fleet Register," Clarksons Research, 2024.

01 Introduction

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The maritime shipping industry, a vital enabler of global trade, is also a significant contributor to global greenhouse gas (GHG) emissions.[20] The sector is currently responsible for between 2–3% of global GHG emissions, equivalent to the annual emissions of a Group of Seven (G7) country. Emissions from the maritime sector continue to rise, and under business as usual, analysis shows the 1 billion metric tonnes of GHG emitted per year from the sector are on track to increase up to 130% from 2008 levels by 2050.[21] Decarbonizing this sector is necessary to mitigate the escalating impacts of global climate change and to ensure the long-term sustainability of international trade.

To decarbonize, the maritime shipping sector must transition away from the use of fossil fuels. Closing the price gap between fossil fuels and alternative zero-emission (ZE) fuels is essential to accelerating the decarbonization of shipping. Currently, the economic viability of adopting cleaner alternative ZE fuels is hindered by their significantly higher projected costs. A combination of

20 International Maritime Organization (IMO), "Fourth Greenhouse Gas Study 2020," IMO, London, 2020.
21 Ibid.

first mover action from the private sector and the implementation of policies and incentives to reduce the price disparity and level the playing field are needed.

Maritime freight buyers (cargo owners and freight forwarders) wield significant influence in driving the transition to ZE fuels in shipping. As customers of the maritime sector, freight buyers can create a robust demand signal for zero-emission shipping services, stimulating investments up and down the value chain in ZE technologies and infrastructure. However, in this large, global, diverse market, no single cargo owner represents a big enough share of global trade to create a sufficiently large enough demand signal on their own. The Zero Emission Maritime Buyers Alliance (ZEMBA) is a first-of-its-kind buyers group within the maritime sector designed to address this challenge. ZEMBA's mission is to accelerate commercial deployment of ZE shipping by enabling climate-leading cargo owners to achieve economies of scale and maximize emissions reductions beyond what any one freight buyer could accomplish alone. By working together, ZEMBA members are offering committed demand to build confidence among investors, carriers, ship owners, and producers of ZE fuels and renewable energy to invest in these solutions.

In September 2023, ZEMBA launched a collective tender seeking to purchase the environmental attributes (emissions abatement) associated with ZE shipping services for a three-year period on a deep-sea route for deployment starting in 2025. In April 2024, ZEMBA announced that it successfully completed this first tender, with the winning bidder securing independently certified and exclusively waste-based biomethane service to meet ZEMBA's required 90% well-to-wake emission reduction compared to low-sulfur fuel oil (LSFO). The completion of the inaugural tender demonstrated the willingness from cargo owners to invest in the decarbonization of this sector and spur a new market for ZE shipping solutions above and beyond what current regulations require.

What do we mean by e-fuels?

Throughout literature, the definition of e-fuel can vary, however, for the purpose of this RFI the term has been defined as: any fuel that has been derived from e-hydrogen.

E-hydrogen has been defined as hydrogen produced from water electrolysis (the separation of hydrogen and oxygen from water using electricity). Typically, it is expected that the electricity used for this process has very low or zero emissions, for example from wind, solar, or a local grid with very low carbon intensity.

The most common e-fuels under discussion for maritime applications include: e-hydrogen, e-ammonia, e-methanol, and e-methane. Both e-methanol (CH_3OH) and e-methane (CH_4) require a carbon source for production, usually in the form of CO_2. The source of this CO_2 is important for evaluating the lifecycle emissions (LCA) of a utilized e-fuel and ensuring other sustainability concerns—particularly around land use change associated with the carbon source—have been addressed. One potential production pathway is CO_2 from Direct Air Capture (DAC) powered by renewable energy. However, the DAC market is nascent and other sources of CO_2 may need to be utilized in the short-medium term. Sustainable, waste-based biogenic sources of carbon present an alternate pathway for the production of e-methanol or e-methane. E-ammonia has the advantage of being entirely carbon free, although concerns about potential N_2O release and safety must be addressed before its wide-spread usage on vessels.

Though the inaugural tender enabled ZEMBA members to achieve very high near-term emissions reductions, and experts believe biomethane will likely play a role in the 2050 fuel mix decarbonizing the maritime industry, ZEMBA views biomethane, even exclusively waste-based biomethane, as having scalability challenges in the long run.[22] Given this reality, ZEMBA's inaugural tender was

22 C. Raucci, C. McKinlay and A. Karan, "The future of maritime fuels. What you need to know.," Lloyd's Register Maritime Decarbonisation Hub, 2023.

adjusted from three years to two years—2025–2026—to allow members the opportunity through ZEMBA's second tender to focus on supporting e-fuels and other vastly scalable ZE technologies in 2027. Looking ahead, ZEMBA's ambition is for future tenders to not only address cargo owners' scope 3 emissions reduction goals, but also invest in solutions that are scalable, sustainable, and capable of decarbonizing large proportions of the global fleet.

When announcing the successful completion of its first tender, ZEMBA expressed its ambition to focus on procuring the environmental attributes associated with e-fuel-powered shipping services in its next tender. E-fuels are widely considered by many to be scalable and capable of meeting a large proportion, if not all, of the maritime fuel mix by 2050.[23] ZEMBA's next tender is expected to launch in early 2025, with the aim of seeking services that can deploy in 2027. To better understand the developing e-fuel market toward informing ZEMBA's next tender, the Lloyd's Register Maritime Decarbonisation Hub and ZEMBA collaborated to design and execute an RFI to assess the market readiness of commercial deployment of e-fuels in shipping in the near term (2027–2030).

23 Ibid.

More specifically, the RFI sought to meet the following objectives:

- Evaluate the potential availability of e-fuels by 2027 and gain insights about how much could be available to the maritime sector specifically.
- Understand the projected availability of e-fuel-capable vessels by 2027.
- Map the projected available supply of specific e-fuels with the availability of e-fuel-capable vessels on a fuel-by-fuel basis from 2027 to 2030.
- Gather insights to inform design of ZEMBA's second and future tenders to support ZEMBA's mission to kickstart the zero-emission shipping market.

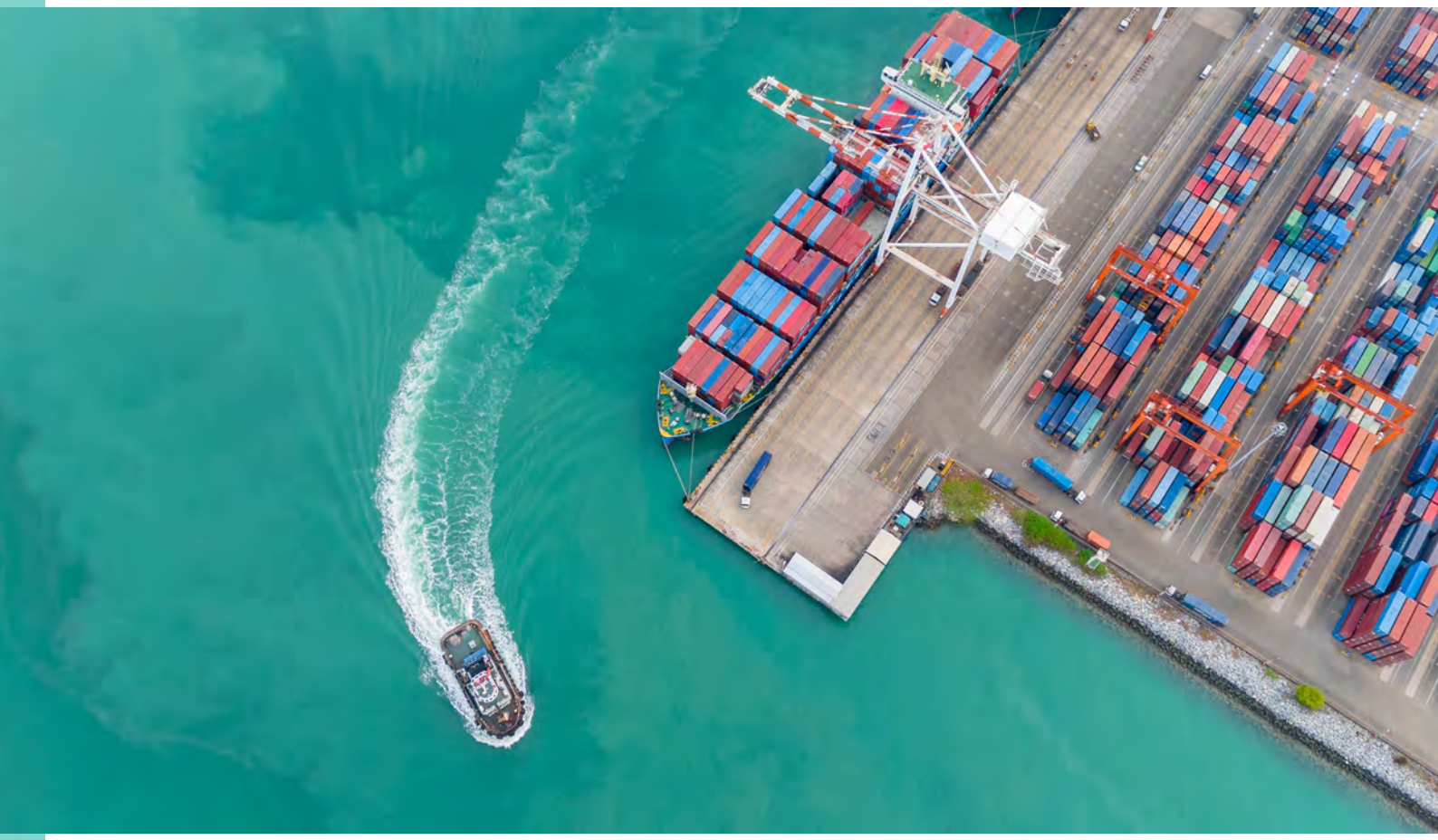
Based on these objectives, two surveys were designed, one for fuel producers and a second for ship operators. These surveys aimed to gather a mix of quantitative and qualitative data, with an aim to provide a representative overview of the development of the e-fuel market in maritime and its trajectory in the next 3 to 5 years. The survey was distributed in May 2024 using a semi-targeted approach. Stakeholders who expressed past interest in ZEMBA or maritime decarbonization were invited to participate directly. The survey was also made publicly available and widely disseminated such that any fuel supplier or ship operator could participate.

To supplement the survey, a series of interviews with a subset of survey respondents were conducted. All interviewees had completed the survey as a pre-requisite. The objective of the interviews was to develop a deeper understanding of current projects, investments, and attitudes toward e-fuel readiness beyond questionnaire responses. The RFI surveys were open for a two-week period, and interviews were conducted during the subsequent several weeks. The RFI process concluded in early July 2024.

The RFI was completed with 47 survey responses (32 fuel providers and 15 ship operators) and 18 interviews (12 fuel providers and 6 ship operators). Responses to the surveys are considered commercially sensitive, so for this report's purpose, data has been anonymized and aggregated to display overarching key findings below. The RFI did not ask about potential costs or prices associated with either e-fuel production, e-fuel-capable vessels, or any eventual e-fuel-powered shipping services. The eventual price of e-fuel-powered shipping services will have major implications on customers' willingness to pay and the uptake of e-fuel in the maritime sector more broadly.

02

Findings from the RFI on E-fuels Availability



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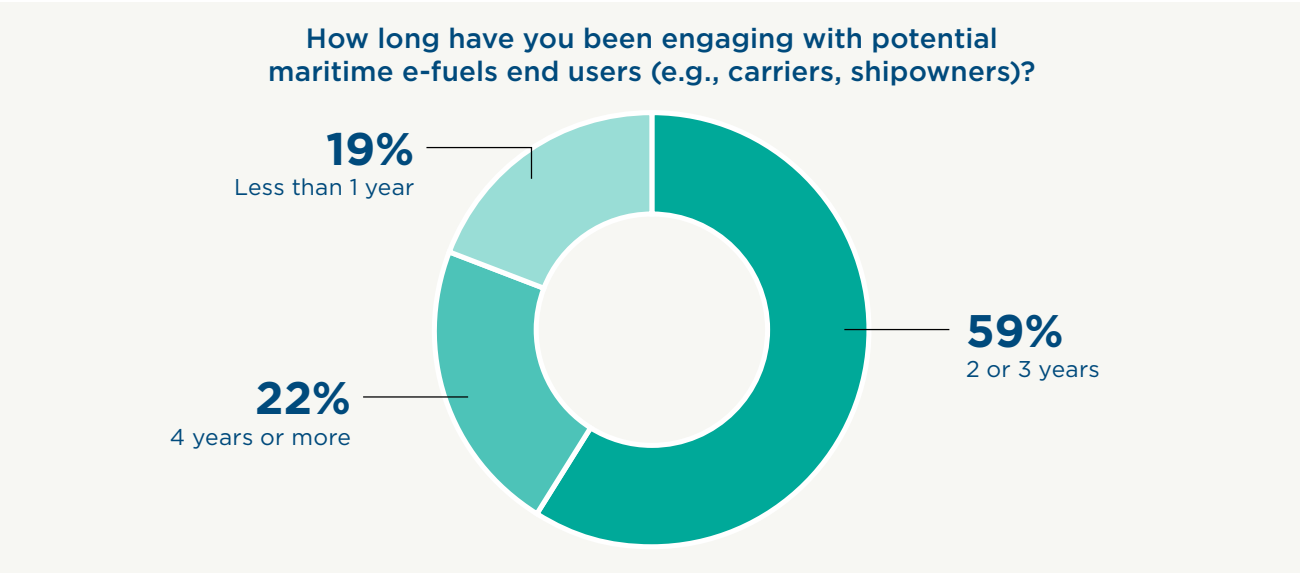
2.1 The Fuel Provider Respondents

In total, the fuel provider survey received 32 responses, representing a diverse range of company sizes and locations. 47% of respondents were small and medium sized companies with fewer than 200 employees and 53% were large and very large sized with more than 200 employees, with headquarters spanning Europe, North America, Africa, Asia, and Oceania.

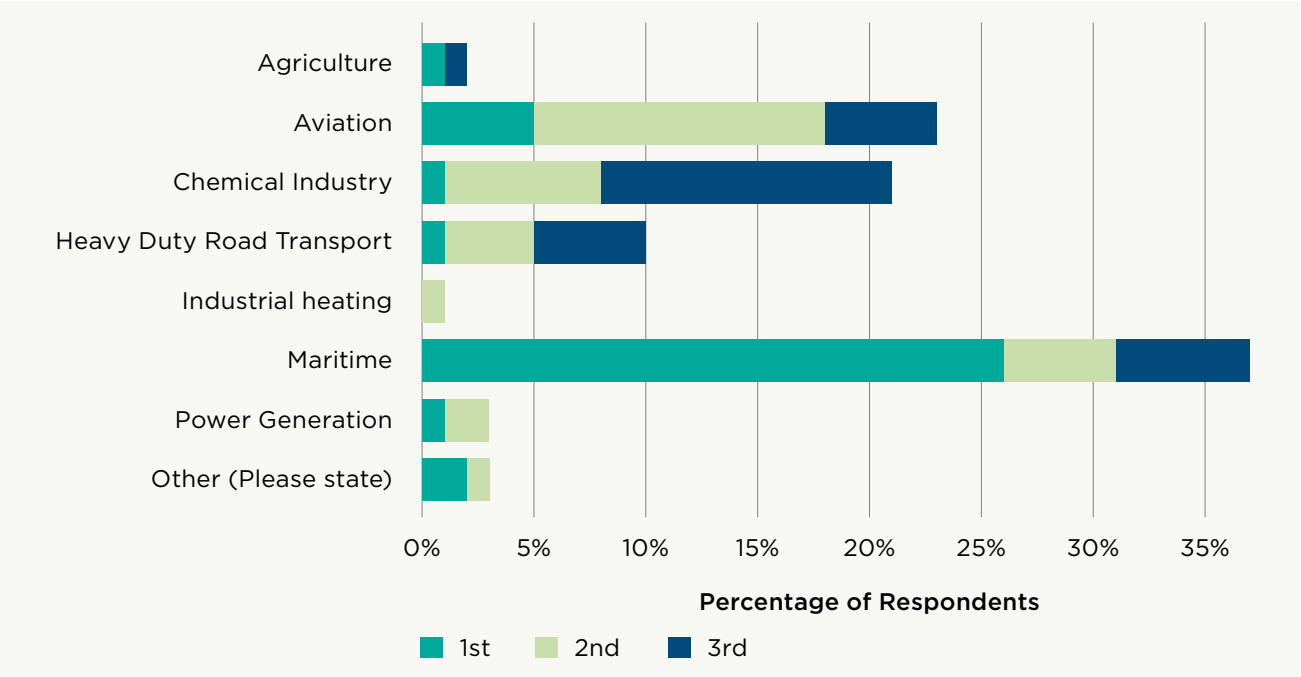
The fuel provider respondents showed great interest in the maritime industry (e.g., carriers or shipowners) as end users of e-fuels. The survey found that the 32 respondents had collectively presented 269 proposals to the maritime industry for e-fuel production for maritime offtake and 81% of these respondents had had some engagement with potential maritime users for more than 2 years (19% for less than one year, 59% for 2 to 3 years, and 22% for 4 years or more), as shown in Figure 2.

Figure 2: Length of fuel provider engagement with potential maritime end users of e-fuels (e.g., carriers, shipowners).



Additionally, 69% of the respondents ranked the maritime sector as their number one focus for the deployment of e-fuels, with full cross-sectoral results shown in Figure 3. These results demonstrate enthusiasm among fuel producers to facilitate maritime offtake for e-fuels but reveals a potential mismatch between available supply of e-fuels and willingness of the maritime sector to offtake e-fuels (discussed further in Section 4).[24]

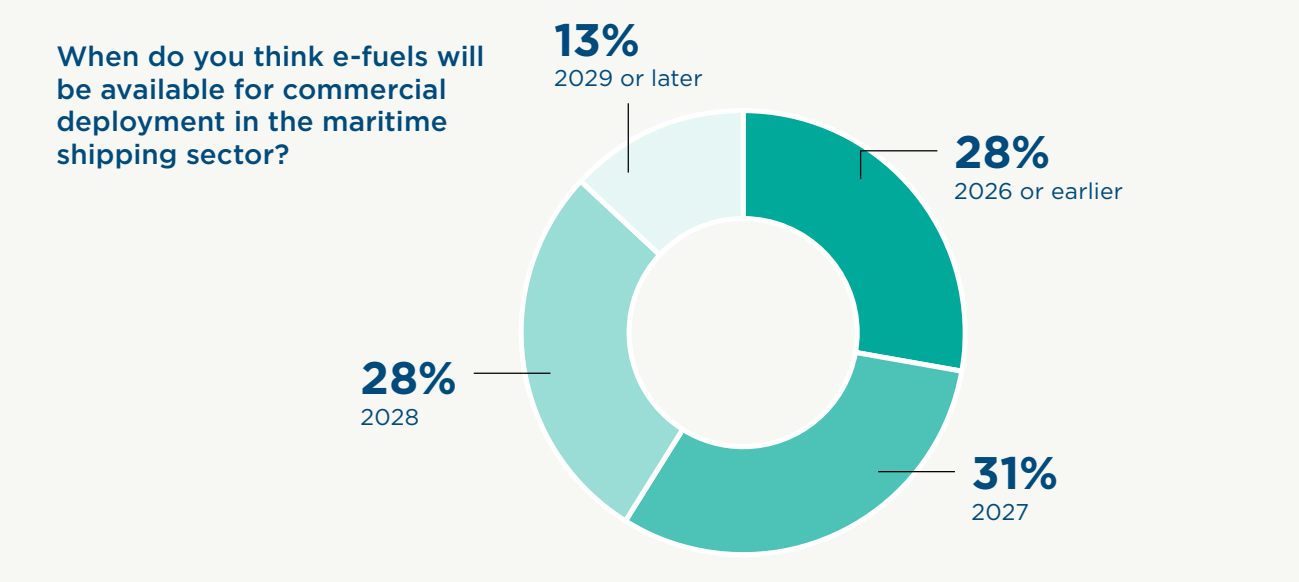
Figure 3: Sectoral ranking of top 3 industries of interest for e-fuel deployment 2027–2030. Results indicate the total % of respondents that ranked each sector either 1st, 2nd or 3rd.



24 Notably, ZEMBA did not receive any bids for e-fuel deployment in its first round RFP. There are numerous potential reasons for why the e-fuel projects described in the RFI were not included as part of bids for ZEMBA's first round RfP, including (1) these fuel projects were pre-FID at the time of ZEMBA's inaugural tender. (2) fuel projects were not operationalizable by 2025 and therefore unable to meet the fast turnaround between contracting and deployment for ZEMBA's inaugural round, or (3) carriers received offers for e-fuels, but did not propose e-fuel bids to ZEMBA. Carriers instead offered advanced biofuel options in Round 1 which were compliant with ZEMBA's Sustainability Framework.

Beyond their individual proposals and projects, when asked to estimate the anticipated wider commercial availability of e-fuels for deployment in the maritime sector, respondents were relatively evenly split between 2026, 2027, and 2028 (see Figure 4). However, a combined 59% of fuel producer respondents believe e-fuels could be commercially deployed in the maritime sector (across all segments) by 2027 or earlier.

Figure 4: Estimated year at which respondents believe e-fuels could be available for commercial deployment in the maritime shipping sector (all segments).

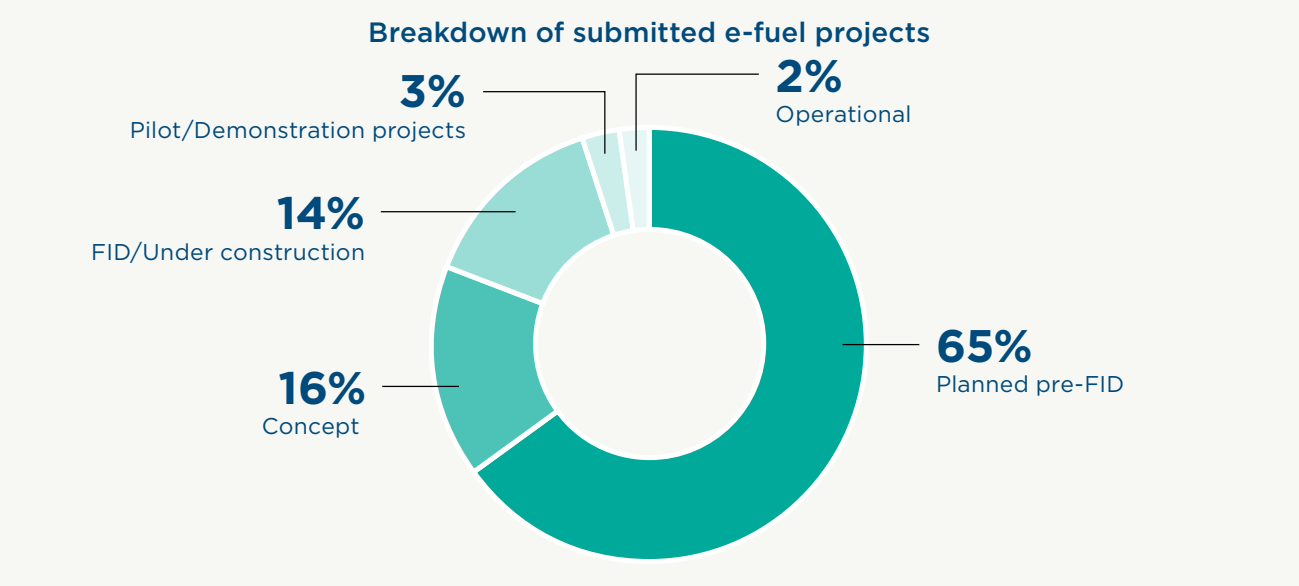


2.2 Aggregated E-fuel Production Projects

In the RFI, the 32 respondents submitted a total of 76 fuel production projects. Of these, 62 met the criteria set out in the RFI of being an e-fuel production project (see Section 3.3 for e-fuel type breakdown).

It is significant that of these projects, approximately 85% were reported to still be in the pre-FID stage, the remaining 15% were post-FID, either under construction or operational (Figure 5). The high percentage of pre-FID projects suggests that moving from feasibility studies to achieving FID and starting project construction and operation remains a major bottleneck for many projects.

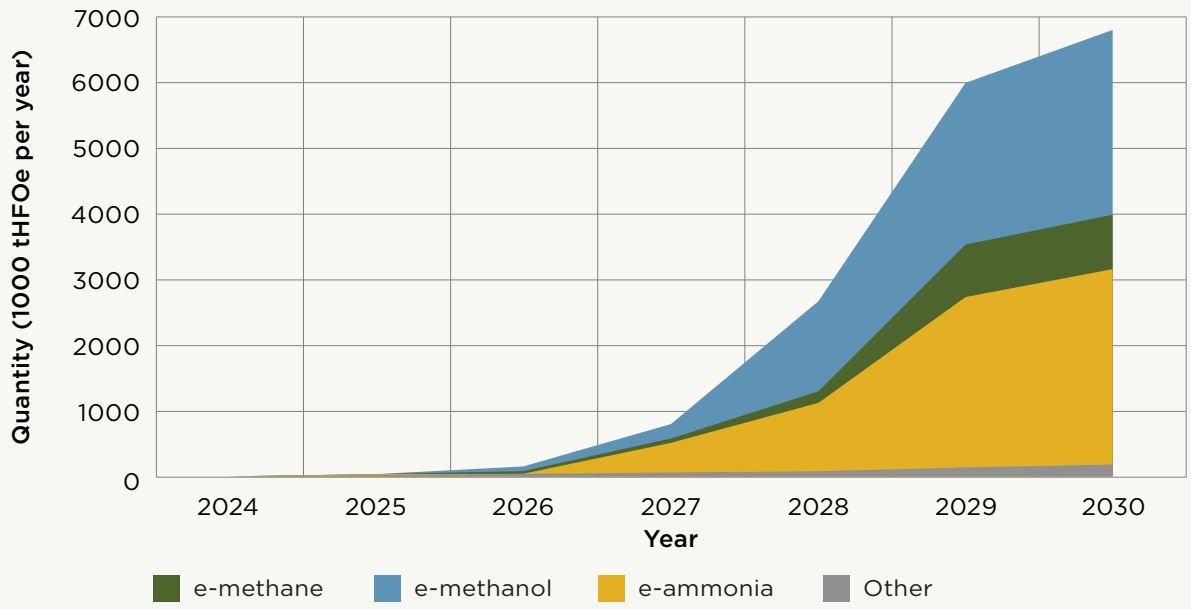
Figure 5: Breakdown of submitted projects meeting e-fuels criteria by stage of project development.



By fuel type, 47% of all projects (pre- and post-FID) identified were e-methanol, 27% e-ammonia, 21% e-methane, and 5% other fuels.[25] RFI survey results did not reveal any projects for e-hydrogen (i.e., projects that produce hydrogen but do not convert to ammonia or methanol).[26]

The RFI requested data from respondents related to the expected production quantities of e-fuels by year between 2024 and 2030. The aggregate projected production results are shown in Figure 7. These quantities have been converted into tHFOe to compare across fuel types. Additionally, these results include fuel from projects at all stages of development (pre- and post-FID), hence representing a best-case scenario of projected e-fuel availability.

Figure 6: Aggregated total potential fuel production (pre- and post-FID) in tHFOe across all 62 reported e-fuel projects by year.



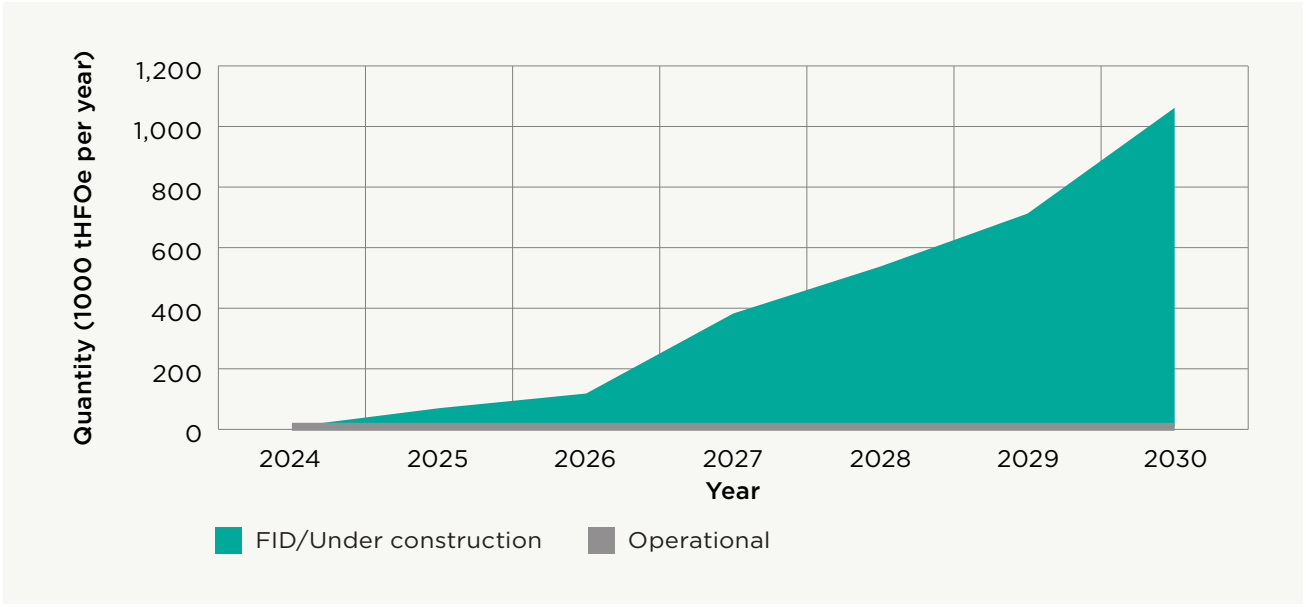
Results in Figure 6 forecast total projected e-fuel production of 795,000 tHFOe by 2027 and 6.86 million tHFOe by 2030.[27] For just post-FID projects, the aggregated results in Figure 7 shows a total projected e-fuel production capacity of 391,000 tHFOe in 2027 and 1.07 million tHFOe in 2030.

25 The projects classed as 'other' appear to be mainly designed for the aviation sector, such as e-SAF (sustainable aviation fuel).

26 Fuel provider respondents' were primarily interested deployment of e-fuel for deep-sea shipping. This may explain the absence of e-hydrogen projects, as hydrogen direct use on board vessels is perceived as more operationally challenging than other hydrogen-derived fuels listed.

27 When considering the near term (e.g., 2027), we assumed a higher level of confidence in the potential operationalization, deployment, and potential uptake of e-fuel from post-FID projects. As a result, ZEMBA and Lloyd's Register Maritime Decarbonisation Hub focused more so on the projected tHFOe of post-FID e-fuels projects (represented in Figure 8) when considering the scope and goals of the next tender, projected for a 2027 deployment.

Figure 7: Aggregated total potential fuel production (tHFOe) across all 9 reported e-fuel projects at post-FID by year.



Of the annual 391,000 tHFOe production of e-fuels forecasted (post-FID only) for 2027, 304,000 tHFOe (78%) is from suppliers who ranked maritime as their top target market. For context, the first ZEMBA tender equated to approximately 22,000 tHFOe. Whilst volumes are expected to increase for future ZEMBA tenders, the demand of the first ZEMBA tender represents only 5% of the projected availability of e-fuels (post-FID projects) in 2027. Therefore, it appears reasonable to assume that the projected volume of e-fuels available for shipping should be sufficient to meet ZEMBA's demand for 2027 and beyond. However, as noted above, these figures represent a snapshot in time, and do not account for changes in project status since the RFI was conducted, the share of the projected e-fuels volume from post-FID projects already committed via other offtake agreements, and the willingness of ship operators to offer ZEMBA e-fuel-powered shipping services.

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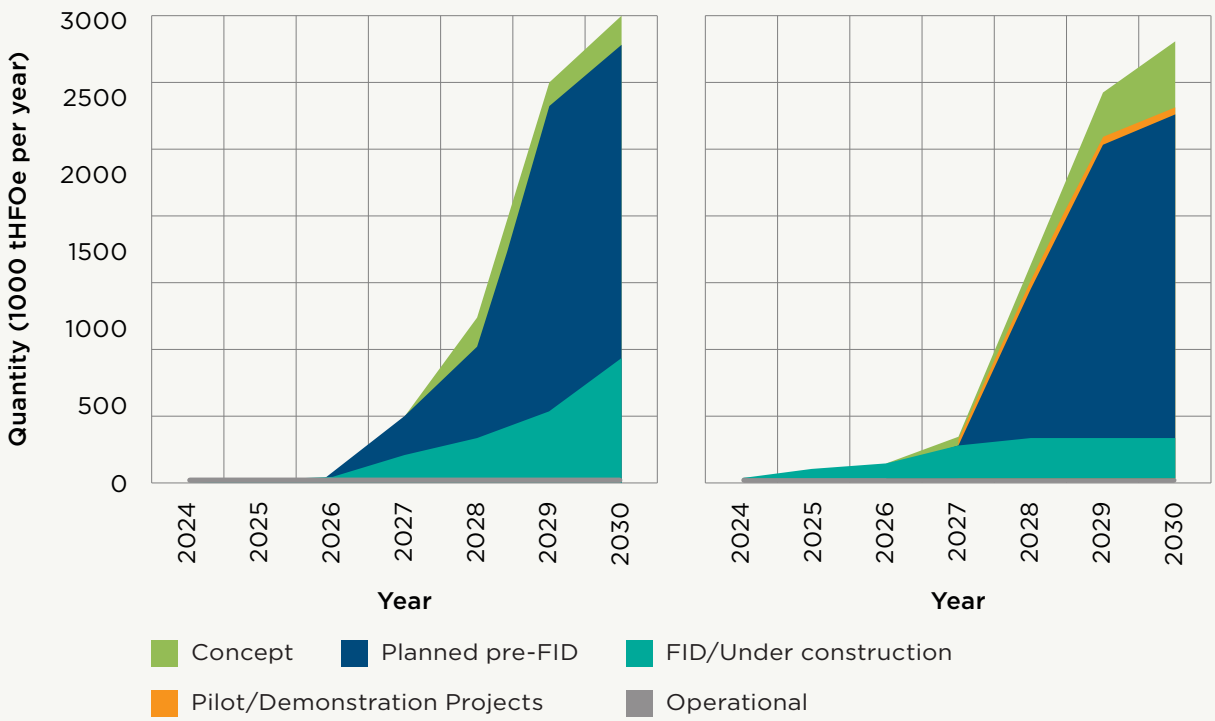
2.3 E-fuels Availability by Fuel Type

The projected availability of e-fuels was also analyzed on a fuel-by-fuel basis. Results for e-ammonia and e-methanol are shown in Figure 8 and Figure 9 respectively.[28]

Figure 8: Stacked plot for the aggregated fuel production forecast for e-ammonia by year.

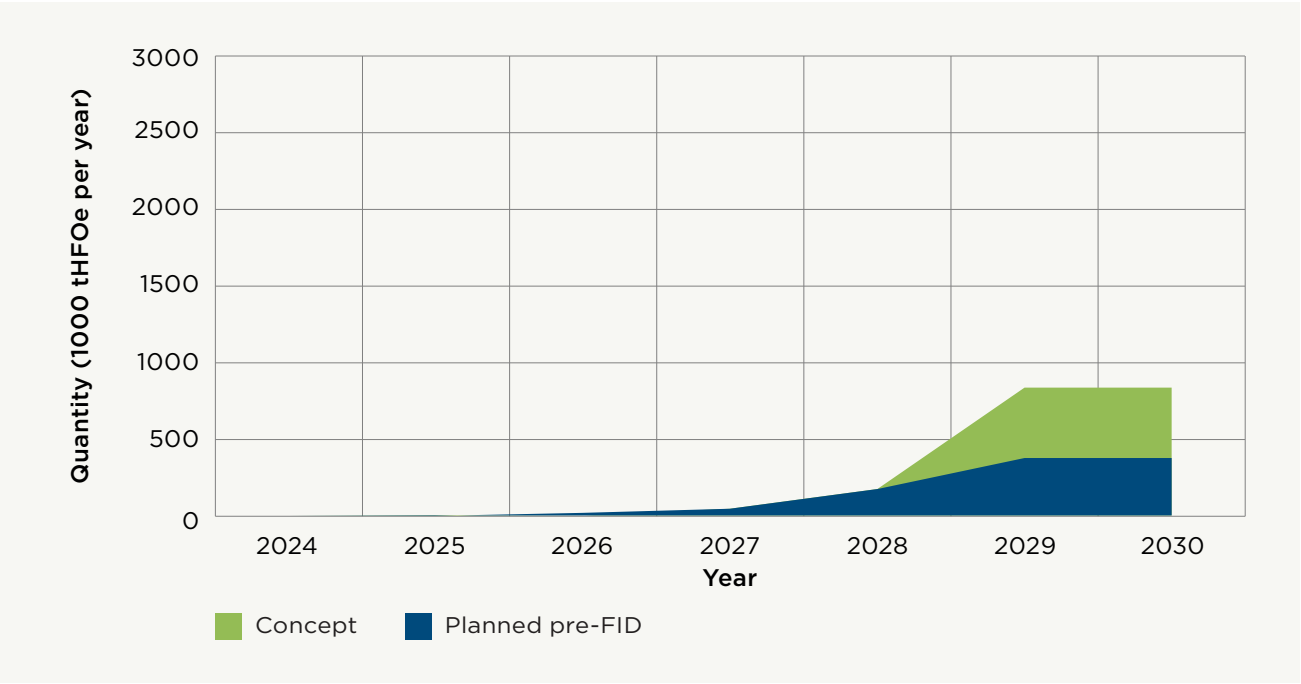
Figure 9: Stacked plot for the aggregated fuel production forecast for e-methanol by year.



As shown in Figure 8 and Figure 9, the RFI found that both e-ammonia and e-methanol are projected to have similar exponential trajectories from 2024 until at least 2029. Including only post-FID projections, the expected production of these fuels in 2027 is 172,000 tHFOe for e-ammonia and 220,000 tHFOe for e-methanol. These projected totals are 8x and 10x the volume of fuel used to fulfil ZEMBA's first tender, respectively. As such, there can be a reasonable degree of confidence that, for either of these fuels, there would be sufficient supply available to meet the expected ZEMBA demand for the second tender.

28 The quantities shown in these figures represent the expected years of e-fuel production coming online and the colors represent the current project stage. The lower elements of these stacked graphs (representing operational and under construction e-fuel production) could be seen as having a higher likelihood of potential uptake by the maritime sector than the upper stacks (planned pre-FID and concept), especially on the 2027 timeframe for ZEMBA's next tender.

Figure 10: Stacked plot for the aggregated fuel production forecast for e-methane by year.



As part of the RFI survey, 13 e-methane production projects were submitted. The aggregated projected production for these projects is plotted in Figure 11.

Figure 10 shows that the production forecasted for e-methane projects is significantly lower than either e-ammonia or e-methanol from 2027 to 2030. Of the projects submitted to the RFI, none have reached FID stage, and 2027 projections are particularly low. Based on this information, the RFI suggests there may be an insufficient projected quantity of e-methane available for ZEMBA's expected demand by 2027 and would require relying on projects submitted under the RFI to reach FID stage and quickly move to production.

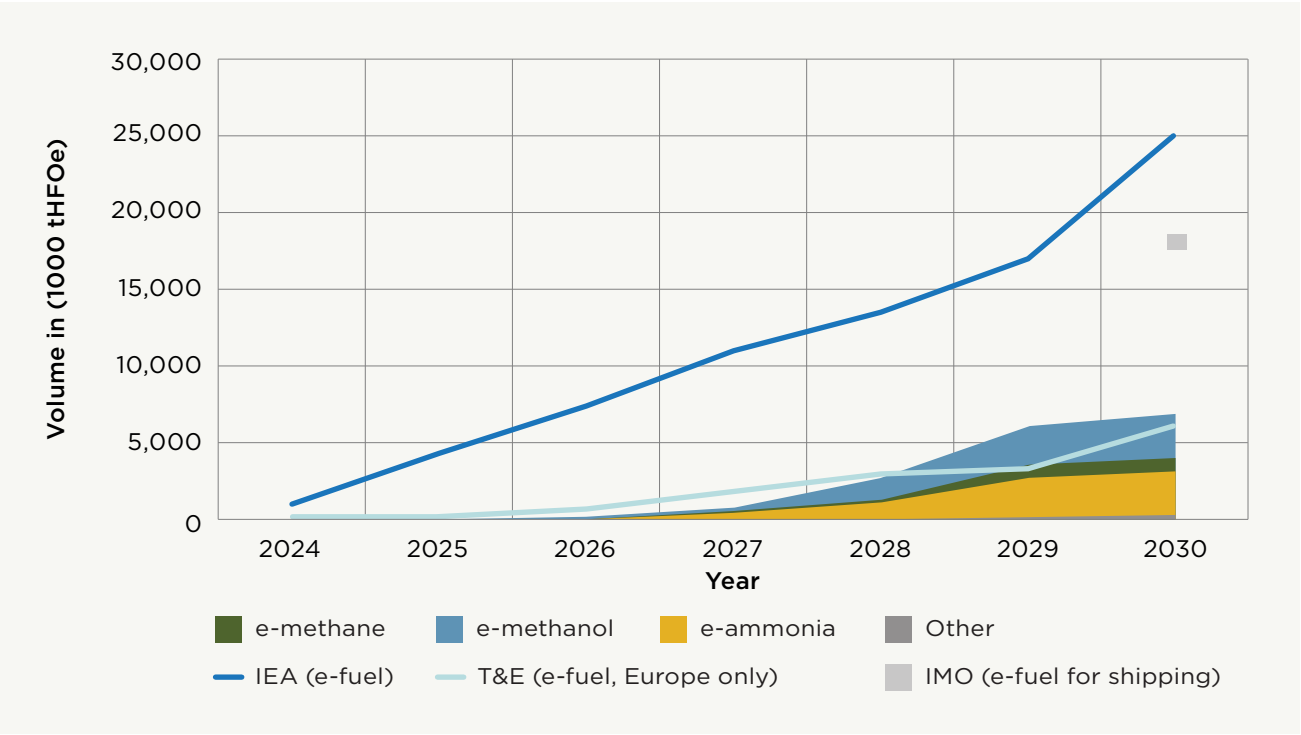
2.4 A Comparison with Existing Literature on E-fuels Availability

Some information on projected e-fuels availability is already available in the public domain. This section compares the results of the RFI e-fuels availability survey with existing literature with the aim of understanding the representativeness of the RFI results.

Several studies have reported estimated e-fuels supply availability.[29] On an aggregated level, there seem to be many projects referenced in the existing literature that the RFI did not capture. The existing literature suggests that there could be higher e-fuels availability in the coming years if considering pre- and post-FID projects for all sectors, including those beyond maritime, and if these projects actual enter and remain in operation (see Figure 11).

29 Note: each of the subsequent reports cited has a slightly different definition for e-fuels. Please refer to each report for further details.

Figure 11: Comparison of aggregated projections of e-fuels availability by year from various sources and the RFI results.



Citations: T&E, "E-fuels observatory for shipping"; IEA, "Hydrogen production projects interactive map," Ricardo Energy & Environment DNV, "Study on the readiness and availability of low- and zero-carbon ship technology and marine fuels."

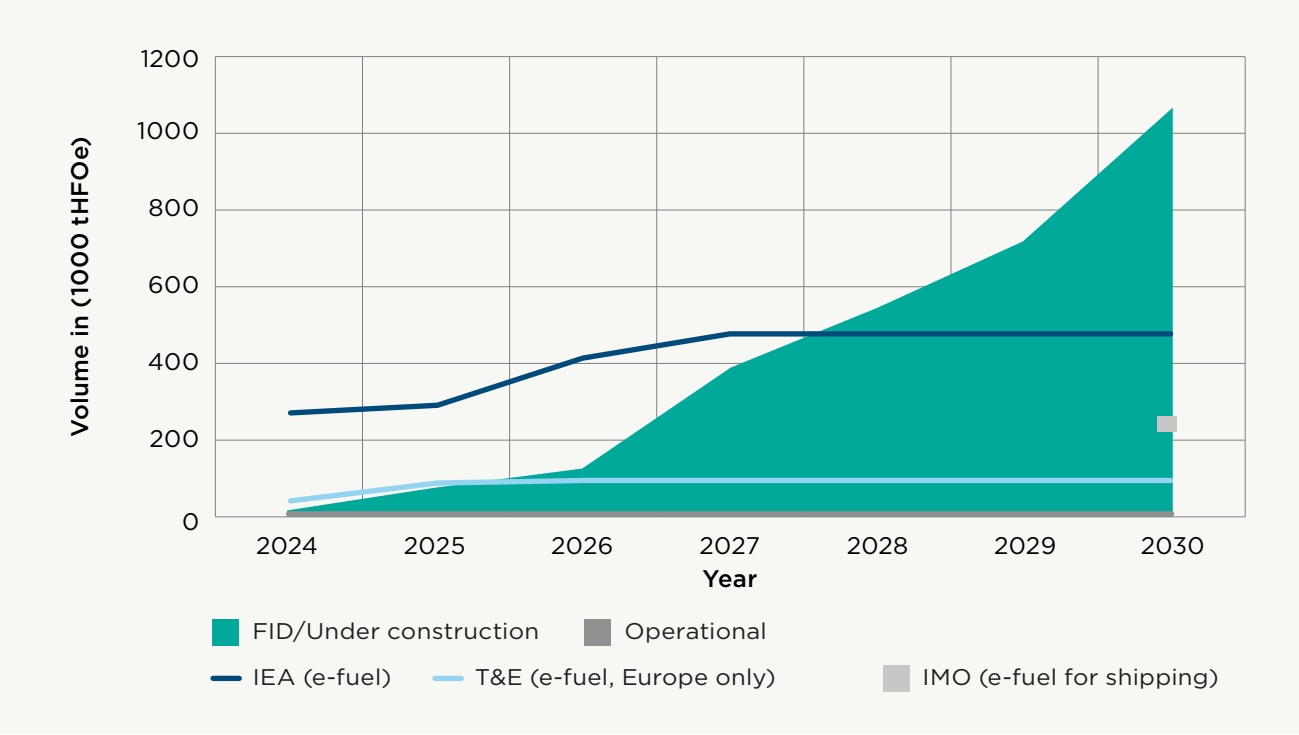
Similar to what was found through the ZEMBA RFI, in the literature, the proportion of projects at post-FID stage is significantly smaller than the total number for all projects. The share of post-FID projects in the existing literature is confirmed to be low, 4% (IEA[30]), 5% (T&E[31]); this is lower than 15% found through the RFI. These results from the literature underline the findings from the RFI; many e-fuel projects appear to have difficulties reaching FID stage. However, these results also suggest that ZEMBA tenders could potentially be seen as a means to unlock some pre-FID e-fuel projects, particularly if coupled with additional first mover action across the value chain and robust policy support.

When comparing the post-FID e-fuel availability estimates, the results of the RFI are broadly in line with IEA, in 2027 the aggregated e-fuel production covers 82% of the estimated value from IEA, as shown in Figure 12. For 2030, the results of the RFI show the projected production of e-fuels for post-FID projects 2.2 times higher than IEA's projection. This shows that a significant proportion of projected post-FID e-fuel projects have been captured in the RFI.

30 IEA, "Hydrogen production projects interactive map," 17 November 2023. [Online]. Available: https://www.iea.org/data-and-statistics/data-tools/hydrogen-production-projects-interactive-map.

31 T&E, "E-fuels observatory for shipping," Transport & Environment, 2024.

Figure 12: Comparison of FID only projections of e-fuel availability by year from various sources and the RFI results.



Citations: T&E, "E-fuels observatory for shipping"; IEA, "Hydrogen production projects interactive map," Ricardo Energy & Environment DNV. "Study on the readiness and availability of low- and zero-carbon ship technology and marine fuels."

A comparison with existing literature can also be made on a fuel-by-fuel basis. In a paper by DNV, all 'committed' ammonia projects dedicated to shipping fuel use were listed as e-ammonia projects.[32] 48% of 2030 target volumes came from one project in Australia at 4.3 million tHFOe of ammonia production by 2028. 48% of 2030 target volumes came from one project in Australia at 4.3 million tHFOe of ammonia production by 2028. While listed as 'committed'[33], it's described as a 'feasibility study' under the IEA dataset.[34] T&E data estimates the global e-methanol supply reaches 48,500 tHFOe by 2027, only accounting for production facilities in Europe.[35] RMI and GMF state that the pipeline of announced green methanol projects suggests there could be supply of around 3.5 million tonnes (1.9 million tHFOe) of bio- and e-methanol per year available for shipping by 2030, once projects targeting markets other than shipping are excluded.[36] This is lower than the total projected project capacities submitted by the RFI respondents.[37] A comparison of these projections versus RFI results is shown in Figure 13 and Figure 14 for e-ammonia and e-methanol projects respectively.

32 DNV, "Availability of Green and Blue Ammonia in 2030 to 2050," DNV, 2024.

33 Ibid.

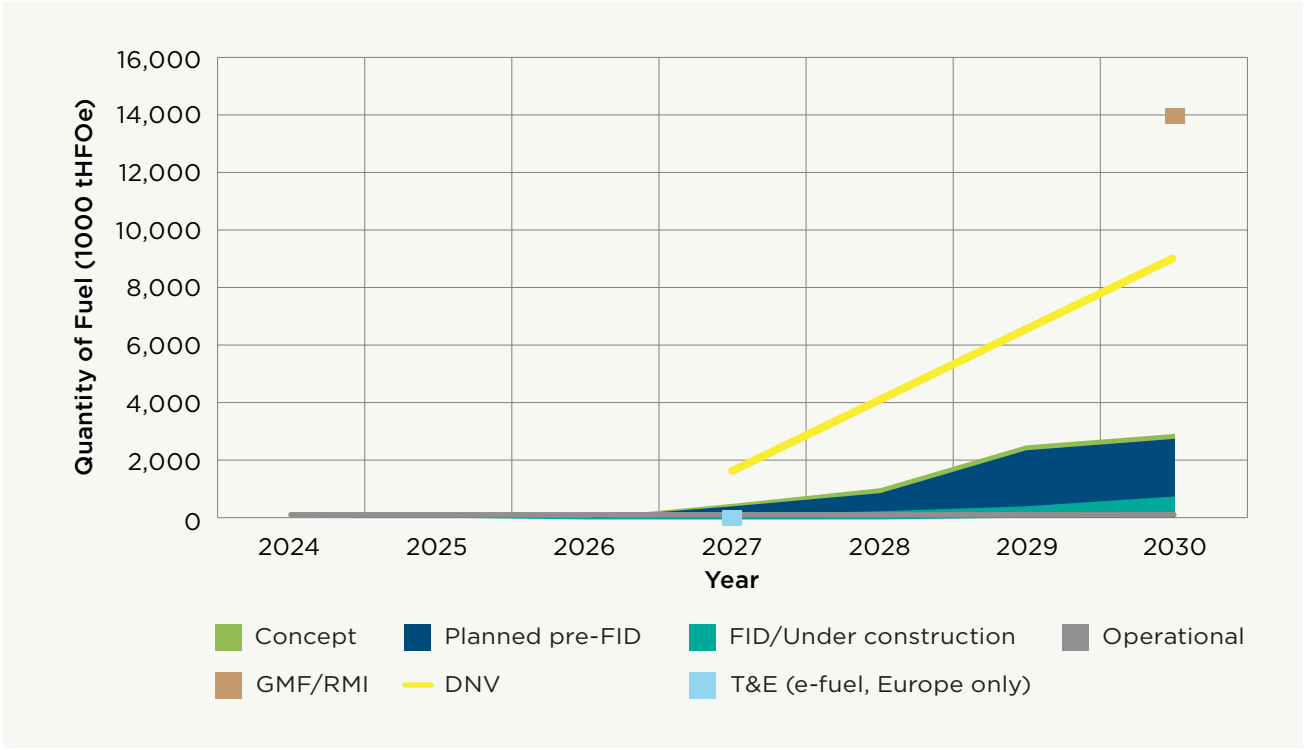
34 IEA, "Hydrogen production projects interactive map," 17 November 2023. [Online]. Available: https://www.iea.org/data-and-statistics/data-tools/hydrogen-production-projects-interactive-map.

35 T&E, "E-fuels observatory for shipping," Transport & Environment, 2024.

36 RMI and Global Maritime Forum, "Oceans of Opportunity," Zero-Emission Shipping Mission, 2024.

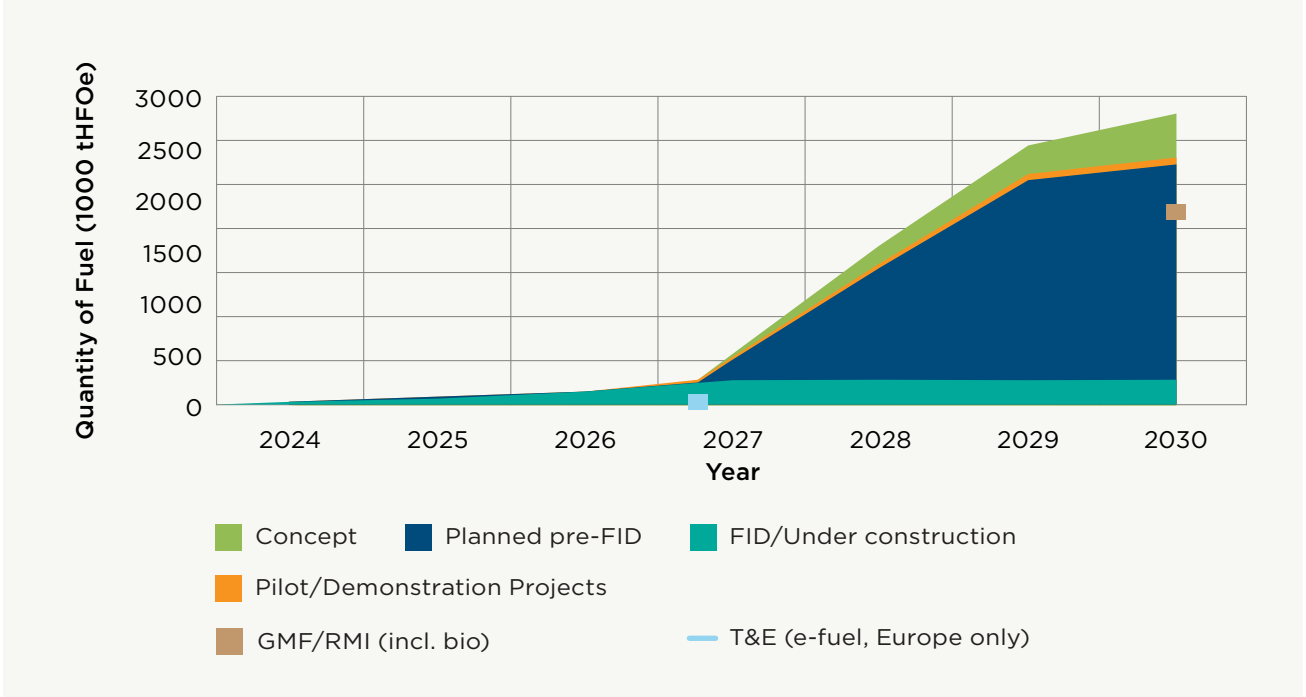
37 Noting that the RMI and GMF estimates include bio- and e-methanol, versus the RFI which only includes projections for e-methanol, thus the comparison isn't perfectly analogous.

Figure 13: Stacked plot for e-ammonia projects submitted for the RFI by year, compared with projections from various sources.



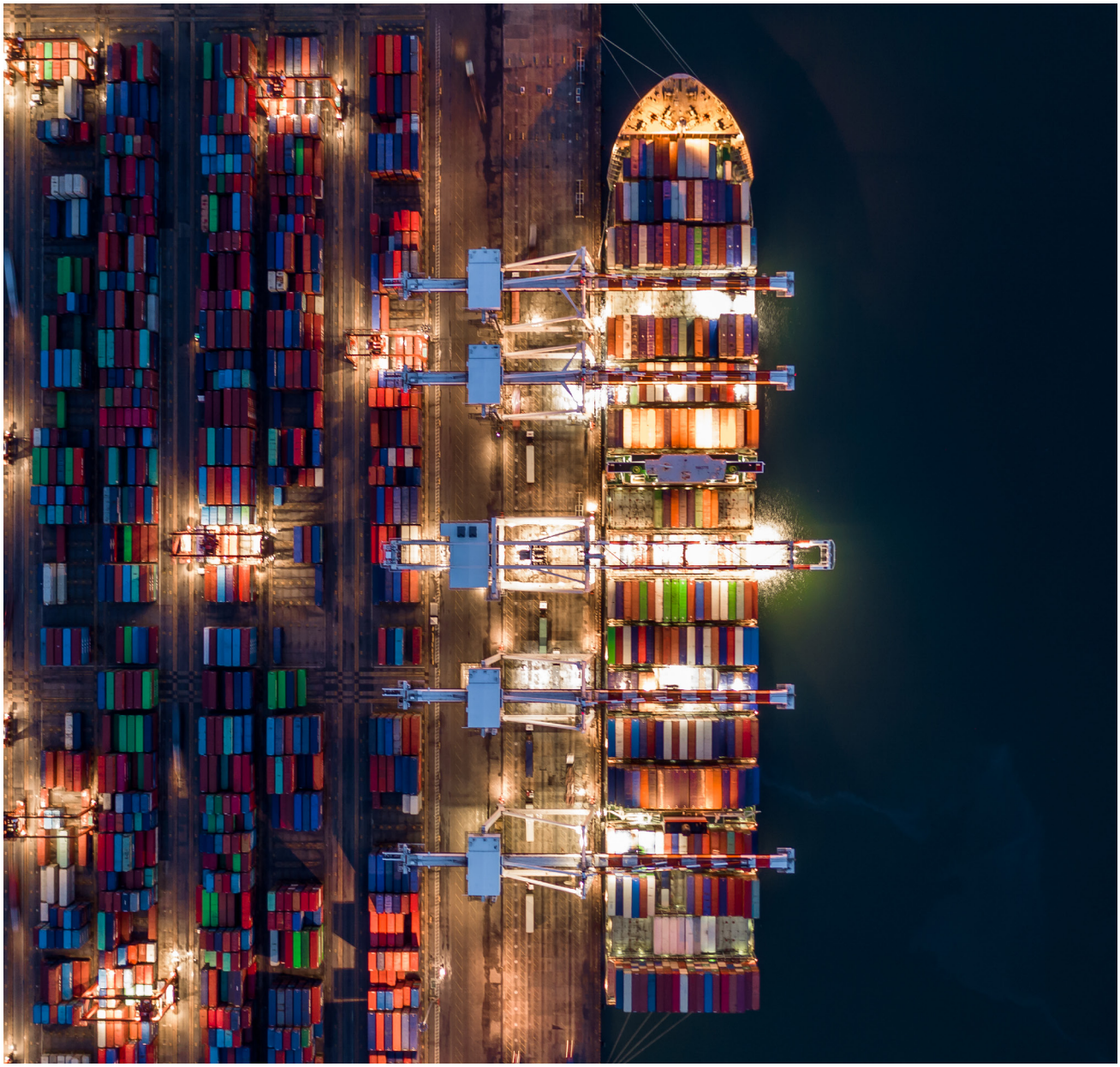
Citations: DNV, "Availability of Green and Blue Ammonia in 2030 to 2050; T&E, "E-fuels observatory for shipping,"; RMI and Global Maritime Forum, "Oceans of Opportunity."

Figure 14: Stacked plot for e-methanol projects submitted for the RFI by year, compared with projections from various sources.



Citations: T&E, "E-fuels observatory for shipping,"; RMI and Global Maritime Forum, "Oceans of Opportunity."

Overall, the existing literature shows that projections of post-FID e-fuel projects are in line with the results found through the RFI. The estimated availability of e-fuels described in the literature could meet ZEMBA's demand in a next tender; there's even a potentially higher availability of e-fuels when also considering pre-FID projects from the literature that were not captured through the RFI.[38] As ZEMBA moves toward its next tender, a key consideration is how ZEMBA's forward procurement process can help drive uptake of these projected volumes of e-fuel into the maritime sector to facilitate the offering of e-fuel-powered shipping services.



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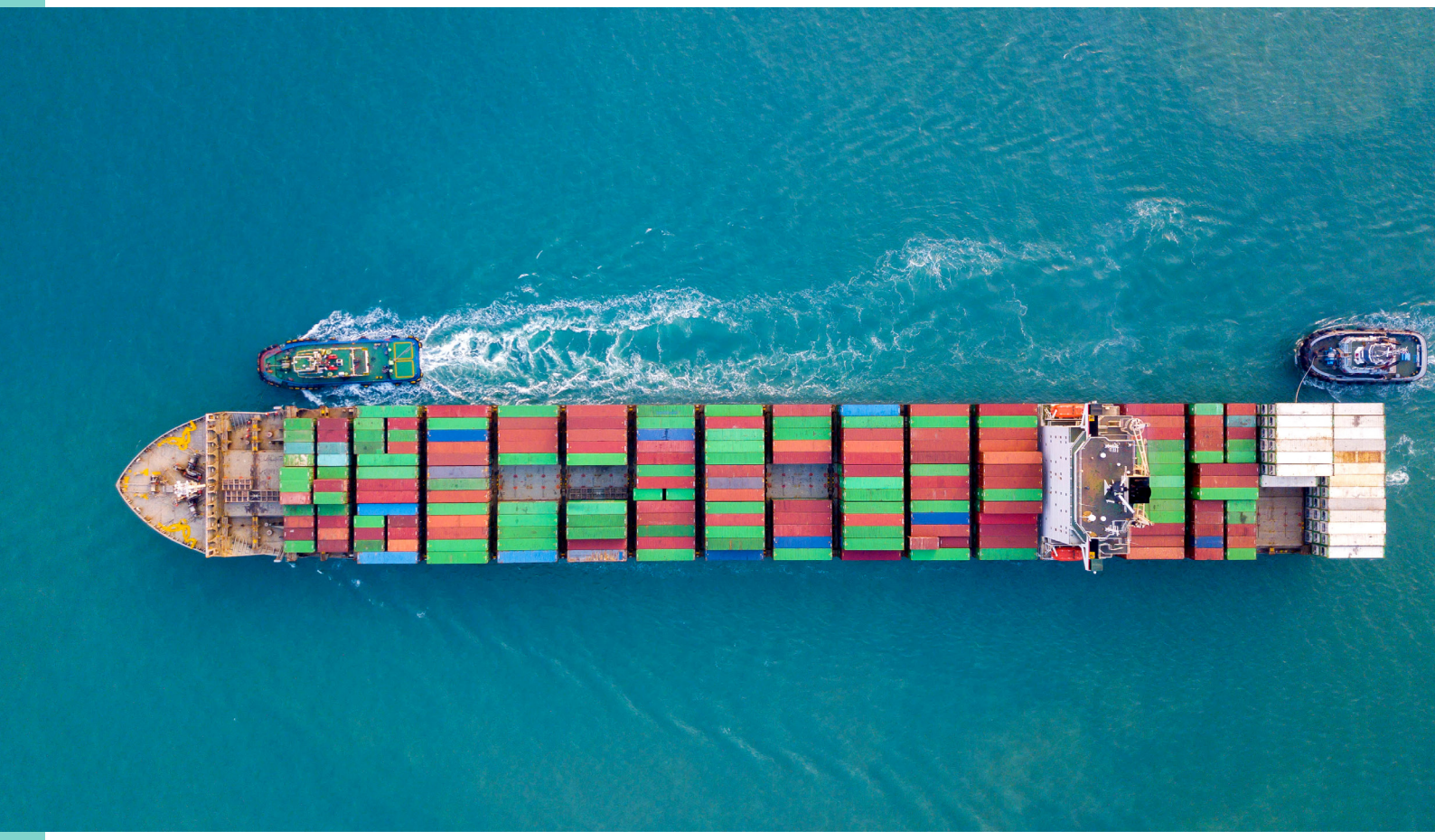
38 The projected e-fuel tonnage potential found both through the RFI and in the existing literature still lags behind what is required to meet the International Maritime Organization's (IMO) goal of 5%–10% adoption of zero and near-zero carbon fuels by 2030, which are estimated to be a minimum of 1.5 million tHFOe. Uncertainty around the availability of e-fuels for the shipping sector compared to other sectors, and the continued uncertainty regarding the impact of regulation makes it difficult to evaluate if the expected supply of zero and near-zero carbon fuels will be sufficient to meet the IMO targets.

03 Findings from the RFI on E-fuel-capable Vessels



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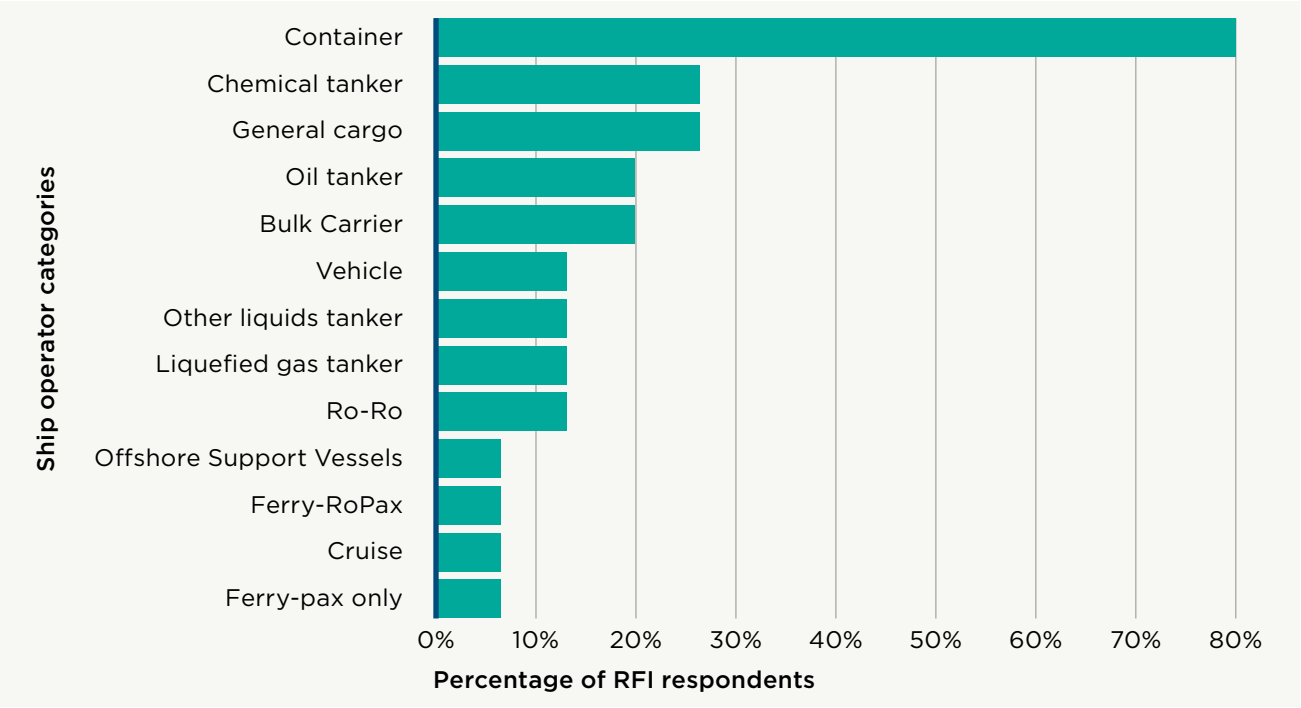
3.1 The Ship Operator Respondents

Another key factor when considering the timeline for the commercial readiness of e-fuel-powered shipping services is the availability of e-fuel-capable vessels in various segments of the maritime sector. ZEMBA's inaugural tender was focused on aggregating demand for the containership segment. With ZEMBA's aim to pivot to specifically supporting e-fuel-powered shipping services through its next tender, the RFI was seeking to not only understand e-fuel-capable vessel deployment across the maritime sector, but if these vessels were projected to be available specifically in the containership segment on ZEMBA's timeline.

Fifteen different ship operators responded to the ship operator-focused survey of the RFI. Six ship operators were invited to a follow up interview. While respondent companies' sizes varied, responses were predominantly from large or very large companies (20% small- and medium-size with less than 200 employees and 80% large and very large size with more than 200 employees). The majority of respondents were both owners & operators of vessels. Respondents operated in different segments, however, the respondents were predominantly operating containerships (Figure 15).

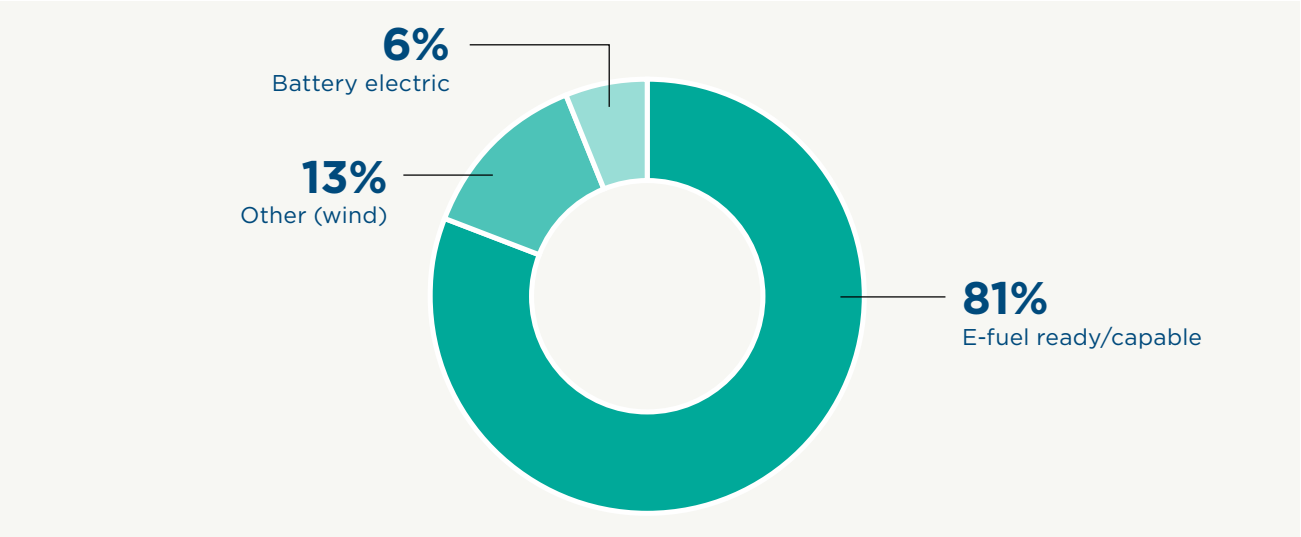
Figure 15: Percentage of RFI ship operator respondents operating in different segments of the maritime shipping sector. Categories based on IMO standard categorization.



3.2 Aggregated E-fuel-capable Fleet

Survey respondents were asked to provide details of their plans to deploy e-fuel-capable vessels. In total, 47 vessel designs were submitted, which equated to a total of 447 distinct actual vessels. Of these vessel designs, 81% were for e-fuel-capable vessels (424 distinct vessels)[39] (Figure 16).

Figure 16: Submitted vessel designs broken down by propulsion technology.



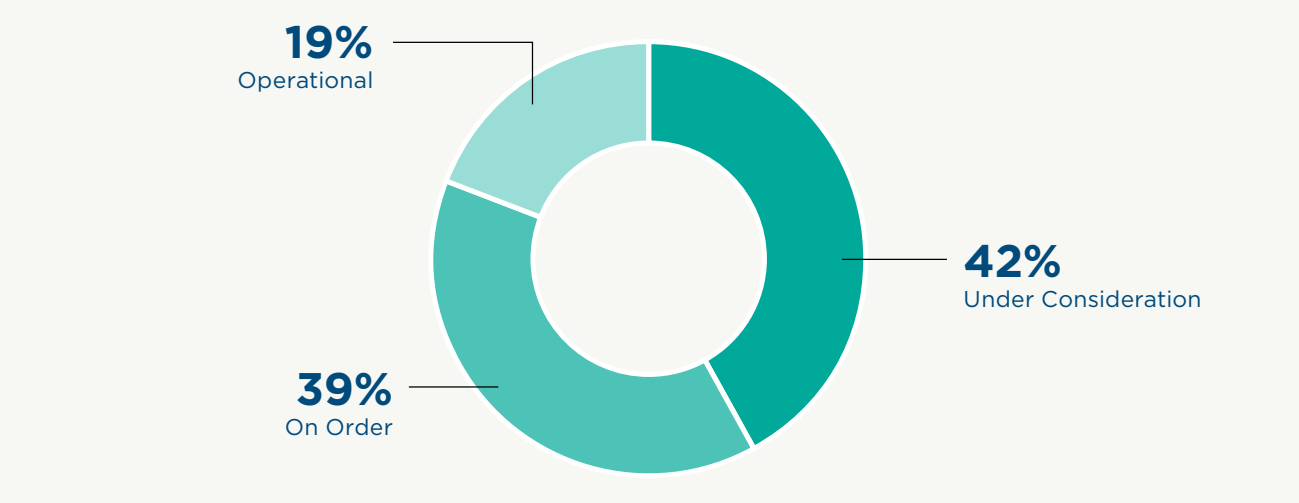
Of the 424 distinct e-fuel-capable vessels[40], 81% were reported to be on order or under construction; 42% under consideration, 39% on order, only 19% were reported to be operational

39 Other vessel types submitted included those that could run on wind as a primary propulsion or batteries. While ZEMBA is interested in how it can support these ZE technologies through future tenders, the focus of this report is on e-fuel-capable vessels.

40 This includes 15 vessels that require some degree of retrofitting, also known as "e-fuel ready". The remaining 409 vessels can run on a specific e-fuel without any further modifications. Citation: UMAS and UN Climate Change High Level Champions, "Climate action in shipping. Progress towards shipping's 2030 breakthrough," 2023.

(Figure 17). By 2027, there are forecasted to be 166 e-methane-capable vessels, 80 e-methanol-capable vessels, and 22 e-ammonia-capable vessels on the water across all segments of shipping. Within just the containership segment, by 2027, the RFI found that there are projected to be 27 e-methane-capable vessels, 68 e-methanol-capable vessels, and 4 e-ammonia-capable for a total of 99 vessels.

Figure 17: Breakdown of e-fuel-capable vessels submitted by operational status.



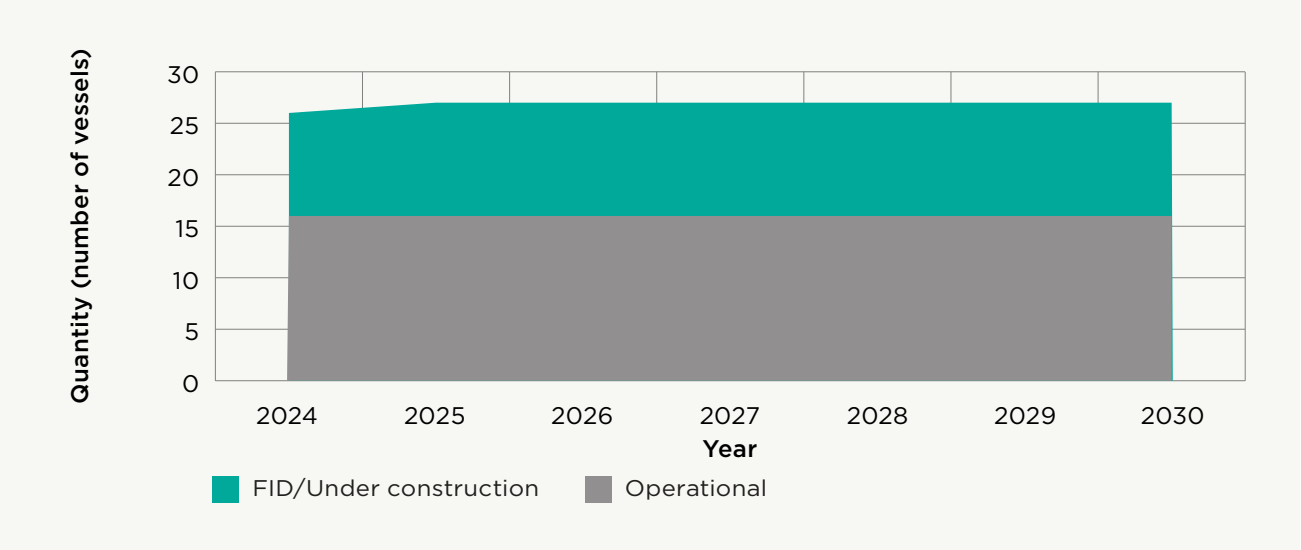
3.3 E-fuel-capable Fleet by Fuel Type

3.3.1 E-methane-capable Vessels

The RFI results captured 16 e-methane-capable containerships currently operational, with a further 11 on order and due to come online by the end of 2025 (Figure 18). These 27 e-methane-capable containerships equate to a total combined capacity of 288,400 TEU. For context, the volume for the first round of ZEMBA will be delivered from one 24,000 TEU vessel. Therefore, this suggests there might be a sufficient e-methane-containership fleet to cover the demand aggregated through the next ZEMBA tender.

Interestingly, the RFI did not capture any additional e-methane-capable container vessels due to launch after 2025, either on order or under consideration. This could imply that there may be an approaching plateau for the building of e-methane-capable container vessels, or this highlights an area where the RFI failed to capture a representative view of the market. When accounting for all segments, however, the results showed orders for and consideration of additional e-methane-capable vessels (see Appendix A).

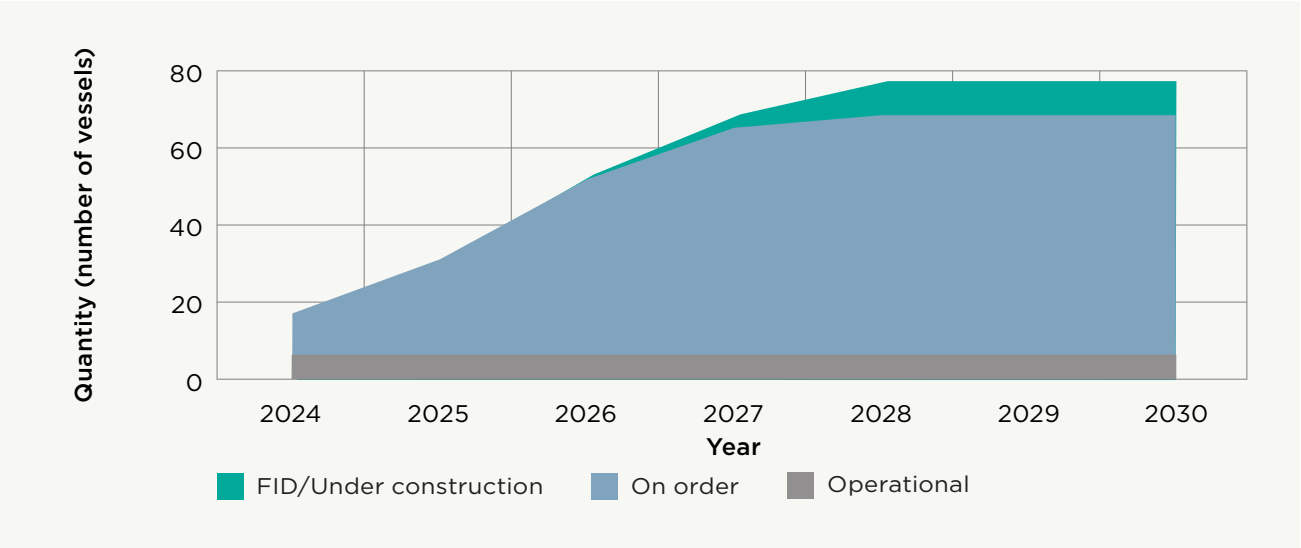
Figure 18: Total cumulative number of e-methane-capable container vessels submitted for the RFI by year.



3.3.2 E-methanol-capable Vessels

The results of the RFI captured 6 currently operational e-methanol-capable vessels in the container segment. By the end of 2026, there are projected to be 52 e-methanol-capable container vessels operational and 65 by the end of 2027[41] (Figure 19). This equated to a total combined capacity of 433,700 TEU by end of 2026 and 653,300 TEU by end of 2027. Additionally, 100% of this projected capacity for 2026 is reported to be either currently operational or on order and 99.3% for 2027. These operational statuses suggested there can be a higher degree of confidence that this forecasted capacity can be delivered on time. Overall, the results from the RFI suggest that there should be sufficient e-methanol-capable containership capacity for the next ZEMBA tender, starting as early as 2026.

Figure 19: Total cumulative number of e-methanol-capable and e-methanol-ready vessels submitted for the RFI by year. Quantities indicate the number of vessels; the colors show the current state of readiness.



41 Includes 5 e-methanol-ready container vessels, meaning they would require some degree of retrofitting.

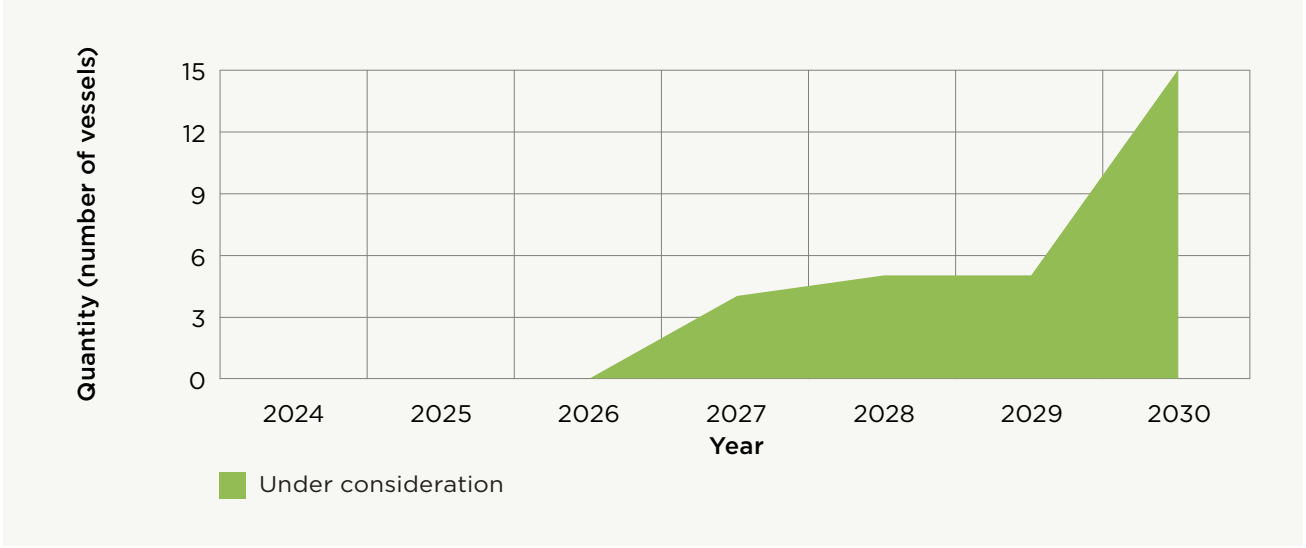
Most e-methanol-capable vessels reported in the RFI were containerships, equating to 94% of all operational or on-order methanol vessels reported to the RFI by 2027. This suggests that the container segment fleet alone should have sufficient capacity to meet ZEMBA demand. Forecasts for e-methanol-capable powered vessels for all segments are shown in Appendix A.

3.3.3 E-ammonia-capable Vessels

The RFI found no e-ammonia-capable vessels currently operating, with the first projected to enter operation in 2026. When considering all segments (e.g., bulk carriers and liquefied gas tankers), the RFI results suggested that the global fleet could have 8 e-ammonia-capable powered vessels in 2026 (6 are on order) and 22 by 2027 (14 on order), see Appendix A.

No e-ammonia-capable container vessels are projected to be available in 2026, but the RFI found there are 4 vessels under consideration and forecasted for deployment in 2027 (Figure 20) with a combined capacity capable of delivering the full ZEMBA inaugural tender volume.[42]

Figure 20: Total cumulative number of e-methanol-capable and e-methanol-ready vessels submitted for the RFI by year. Quantities indicate the number of vessels; the colors show the current state of readiness.



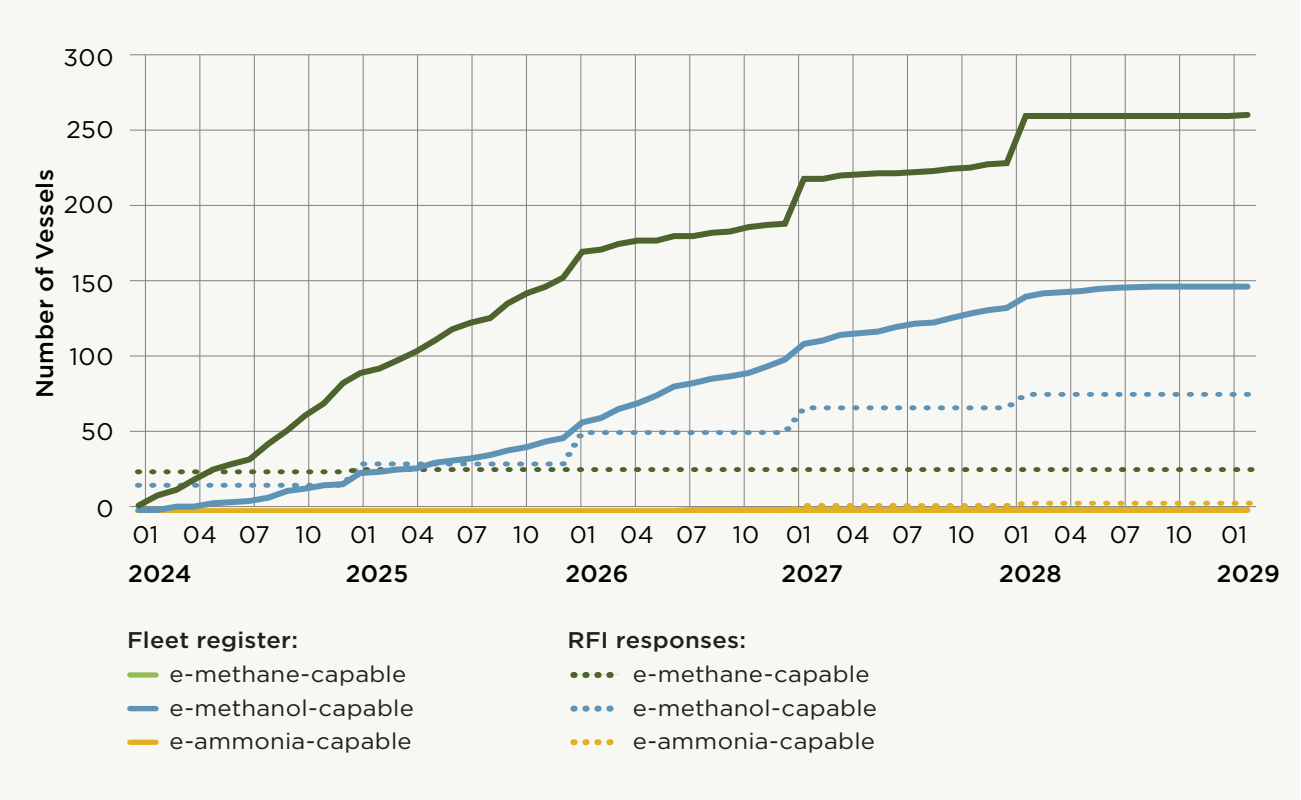
3.4 A Comparison with the Fleet Register on E-fuel-capable Fleet

An analysis of the global vessel orderbook indicated there are projected to be 364 new e-fuel-capable container vessels by the end of 2027, including 229 e-methane-capable container vessels, 134 e-methanol-capable container vessels, and only 1 e-ammonia-capable containership. However, information retrieved through the RFI suggested more e-ammonia capable containerships in the responses, with 4 vessels in consideration by end of 2027, while the e-methanol- and e-methane-capable vessel count captured 60% and 12% of the fleet register count respectively (see Figure 21).[43]

42 The delivery of these e-ammonia-capable container vessels by 2027 relies on a myriad of factors including but not limited to shipyard availability and construction lead times.

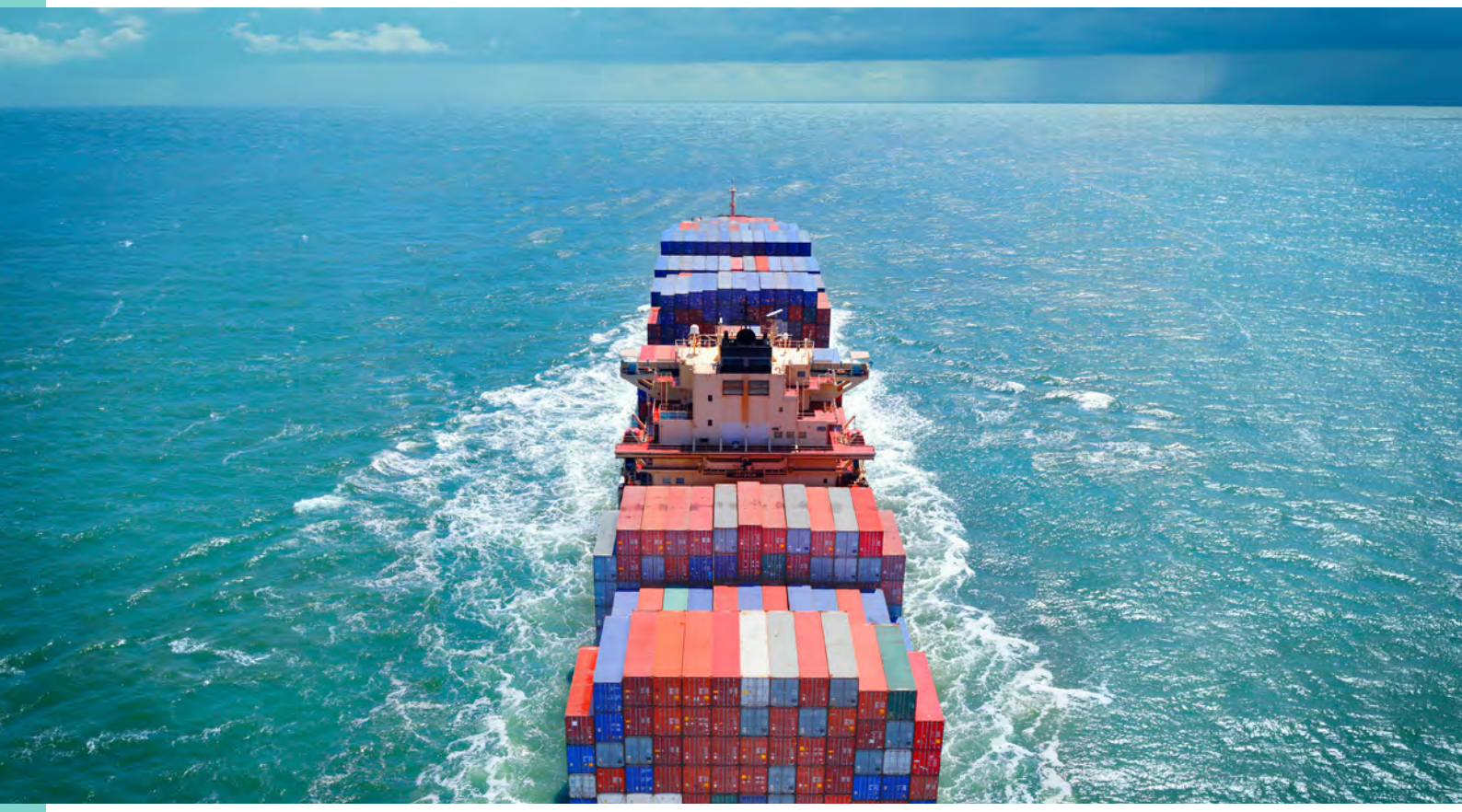
43 The orderbook does not capture vessels that are under consideration, so there is potential growth to these vessel counts. This data can be useful to forecast the next 2 to 3 years of e-fuel-capable vessels but further along the timeline the numbers are less likely to represent the total future fleet. Furthermore, only newbuild vessels are represented here, further e-fuel capable vessels could become available by retrofitting existing vessels.

Figure 21: Comparison between fleet register and RFI responses of all e-fuel capable container vessels by year.



Citation: Clarksons Research, "World Fleet Resigter.

04 Comparing Supply of E-fuels Versus Availability of E-fuel-capable Vessels



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Based on the comparison to the global orderbook and external literature of e-fuel outlook projections, the RFI results can be considered relatively indicative of the maritime market opportunity for deployment of e-fuel-powered shipping services. Despite not capturing the entire market potential, the RFI resulted in valuable estimates, especially within the context of designing ZEMBA's next tender, which was the overarching goal of the RFI.

The RFI found that operational or under construction e-fuel projects are projected to deliver a total of 391,000 tHFOe of e-fuels per year across all e-fuel types starting in 2027, an amount of fuel 17x higher than the fuel needed to satisfy ZEMBA's inaugural tender volume. 78% of this aggregated e-fuel production is reported to be produced by suppliers who ranked maritime as their number one target market (304,000 tHFOe per year). Out of 62 e-fuel production projects reported, only 2 declared that they have binding offtake agreements, implying there are large quantities of e-fuel are still available for uptake by the maritime sector. This suggests that there is a significant potential e-fuel market for maritime that might be made available for ZEMBA to tap into for the next tender.

However, comparing the results from the supply of e-fuels versus the supply of e-fuel-capable vessels over the next 3–5 years demonstrates a fuel-by-fuel nuance. Table 2 shows the estimated supply for e-methane, e-methanol and e-ammonia fuels versus the availability of e-fuel-capable vessels for each of these fuels based on the results of the RFI.

Table 2: Aggregated projected e-fuel supply and e-fuel-capable vessel availability for e-methane, e-methanol and e-ammonia in 2027 and 2030.

	E-fuel Supply [e-fuels availability—only post FID]		E-fuel-capable Vessel Supply [total e-fuel-capable containerships capacity—e.g., dual fuel container vessels capable of using both e-fuels and fossil fuels]	
	2027	2030	2027	2030
E-methane	No projects post-FID	No projects post-FID	27 containership, representing 288,400 TEU	27 containership, representing 288,400 TEU
E-methanol	220,000 tHFOe annually	257,000 tHFOe annually	68 containership, representing[44] 653,300 TEU	77 containership[45] representing 785,300 TEU
E-ammonia	172,000 tHFOe annually	814,000 tHFO3 annually	4 containership[46] representing 44,000 TEU	15 containership representing[47] 73,500 TEU

During the timeframe examined by the RFI, there is a projected mismatch between availability of e-methane-capable vessels and projected e-methane fuel supply. The RFI identified no e-methane projects post-FID, with the forecasted production only reaching 34,000 tHFOe by 2027.[48] While e-methane could be a pathway to help decarbonize the existing methane fleet, there is limited confirmed supply in the next few years. To meet ZEMBA's preferred timeline for its second tender, all projected e-methane fuel projects reported in the RFI would need to quickly reach FID and concept projects would need to be rapidly accelerated. Thus, the results from the RFI suggest that the demand from ZEMBA's next tender is not likely to be met by an e-methane-capable vessel operating with e-methane fuel.

Conversely, the results from the RFI suggest that the demand of ZEMBA's next tender could be satisfied solely by e-methanol-capable vessels operating on e-methanol.[49] The RFI results suggest that there are a sufficient number of vessels capable of using e-methanol split across different operators and that there is projected to be sufficient availability of e-methanol produced (considering only post-FID projects) relative to expected ZEMBA's demand.

44 Includes 5 e-methanol-ready vessels.

45 Includes 11 e-methanol-ready vessels.

46 Includes 4 e-ammonia-ready vessels.

47 Includes 4 e-ammonia-ready vessels.

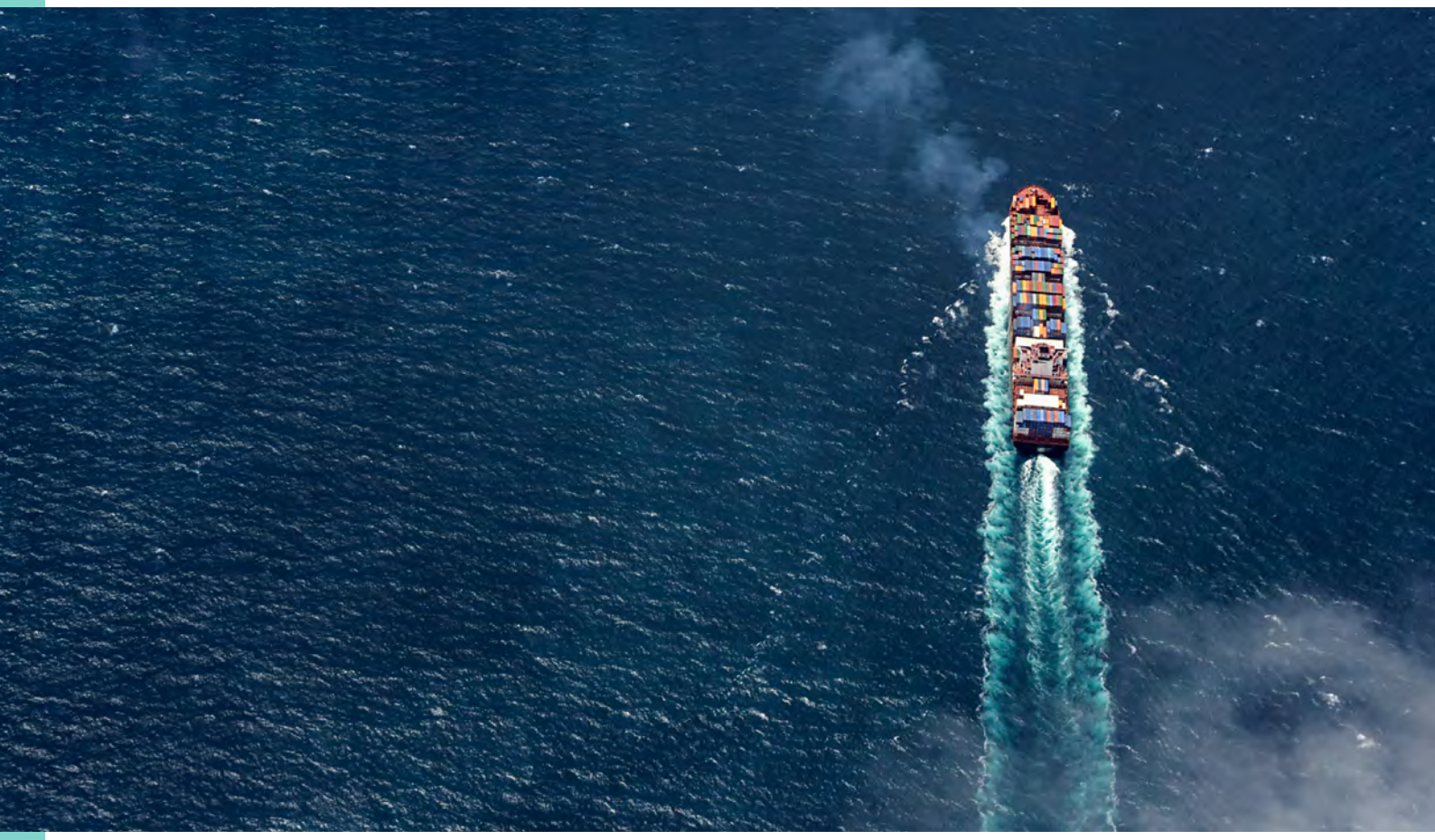
48 This amount is only slightly above the amount of fuel that was needed to satisfy ZEMBA's first round demand.

49 To note: for e-methanol fuel projects, most producers reported that they were planning to use biogenic CO_2 from waste streams, with some production plants even specifically located in close proximity to a source of sustainable CO_2. Other sources included the capture of excess CO_2 from industrial processes, such as ethanol production. Only one submitted e-fuel project was considering using direct air capture (DAC) as a source of CO_2, and this project was reported to only be at pilot/demonstration project stage. During the interviews, all e-methanol and e-methane producers were asked about DAC. The interest in this solution was strong but it is generally seen as a longer-term solution due to current high costs and technological barriers, with the general consensus being that DAC is between 5 and 10 years away from being commercially viable.

The RFI found that the production of e-ammonia is forecasted to exceed the baseline requirement outlined in ZEMBA's first tender, with one production site currently operational and a further four under construction. However, the limiting factor for the uptake of e-ammonia-powered shipping services appears to be the availability of e-ammonia-capable vessels. There were zero reported operational e-ammonia-capable container vessels as part of this RFI, and only 1 vessel on order in the fleet register. While some respondents listed e-ammonia-capable vessels as 'under consideration' for launch in 2027 and 2028, these vessels have not yet been ordered, meaning there is a risk that they would not be available as forecasted. In conclusion, a next ZEMBA tender focused primarily on e-ammonia would require either a rapid ordering and retrofitting of e-ammonia-capable containerships, a delay of the deployment of the aggregated demand of the next ZEMBA tender until 2028, or a broadening of the ZEMBA scope to consider bids from other shipping segments (e.g., bulk carriers and liquefied gas carriers).

Crucially, while these e-fuel production and e-fuel-capable vessel projections are positive and suggest that ZEMBA could procure the environmental attributes associated with e-fuel-powered shipping services starting in 2027, these numbers are not a guarantee of successful e-fuel bids for ZEMBA's next tender. In a constantly evolving marketplace, there are many complex, interrelated factors that could influence ZEMBA's ability to successfully broker contracts for e-fuel-powered shipping services.

05 Implications for ZEMBA's Next Tender



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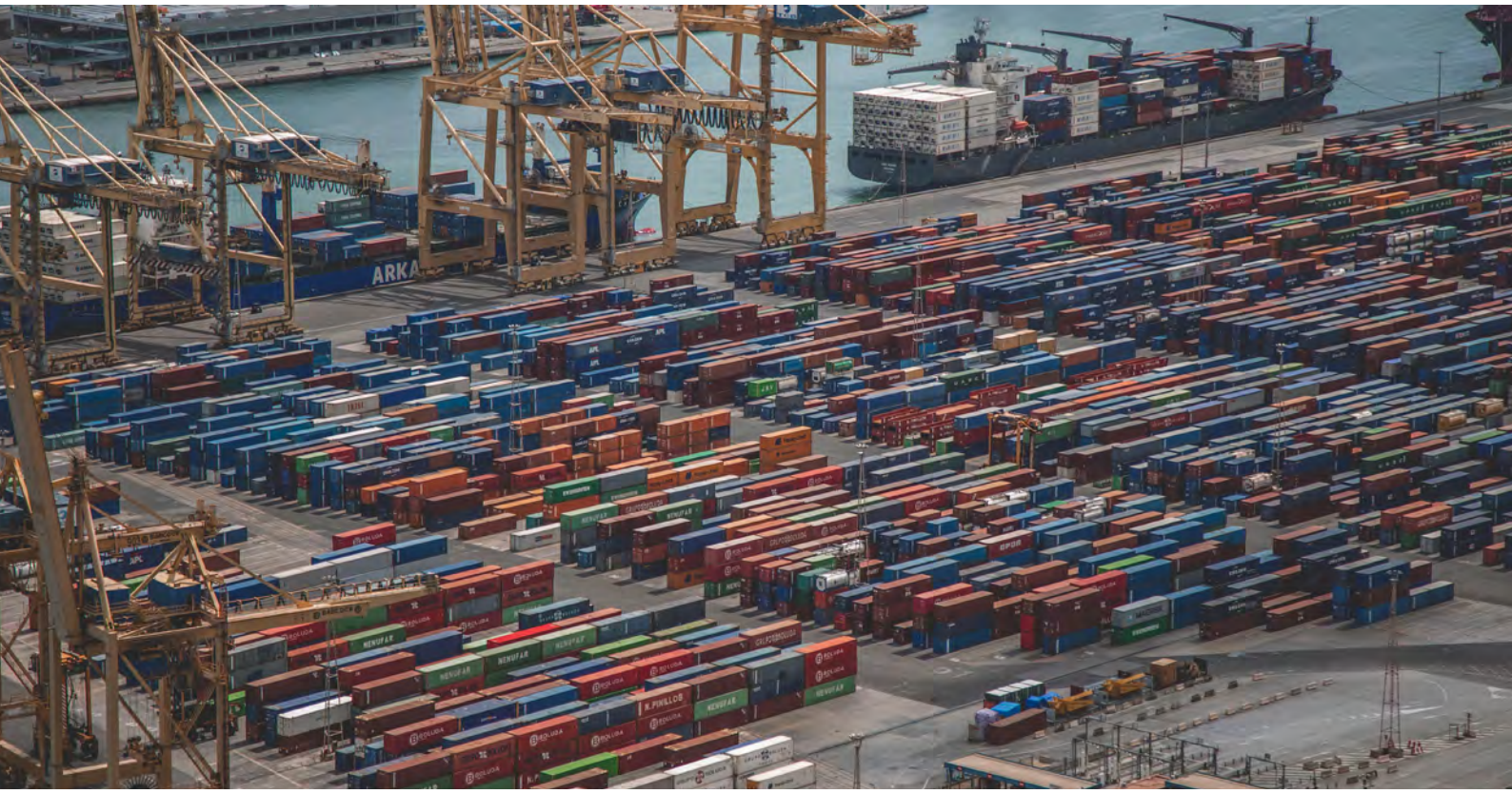
The results from the RFI provided insights into the evolving market and timelines for the commercial deployment of e-fuels and e-fuel-capable vessels in the maritime shipping sector. Results from fuel suppliers and ship operators suggest that ZEMBA can continue targeting the containership segment and plan for a 2027 deployment schedule for a next tender while focusing on procuring the environmental attributes associated with an e-fuel-powered shipping.

Moving toward the next tender, one of ZEMBA's principal tasks is to understand how its forward procurement process can stimulate e-fuel production and facilitate e-fuel offtake by the maritime sector, helping unlock the deployment of e-fuel-powered shipping services. While insights derived from this RFI regarding e-fuel production and e-fuel-capable vessel availability are two crucial factors that influence the likelihood that ZEMBA receives e-fuel-focused bids during its next tender, there are additional factors and layers of complexity shaping the maritime sector's decarbonization and, relatedly, the maritime sectors willingness to offer ZEMBA e-fuel-powered bids. One significant factor that can impact the deployment of e-fuel shipping services in the maritime sector is around cost and price, a topic that the RFI did not cover. Potential costs or prices associated with e-fuel-powered shipping services will have major implications on the timescales for e-fuel-powered



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shipping deployment, customer willingness to pay for e-fuel-powered shipping services, and the overall uptake of e-fuel in the maritime sector. While the ZEMBA model cannot and should not strive to address all the additional factors and barriers facing the maritime sectors' decarbonization, the insights gained from the RFI have identified some common challenges that ZEMBA's next tender will need to keep in mind as part of its design.

Fuel suppliers identified several potential barriers to the commercial deployment of e-fuel services in the maritime sector. Main concerns identified included infrastructure availability, the complexity of varying carbon intensity requirements and fuel certifications, the uncertainty around the evolving regulatory environment, as well as general concerns about the slow rate of adoption of e-fuel in the maritime sector. Ship operators conveyed similar concerns regarding barriers to commercial e-fuel deployment: the high costs associated with conversion and operation, regulatory uncertainty, and the alignment—or perceived lack-thereof—between supply and demand. Fuel suppliers also expressed a strong focus on securing long-term contracts for e-fuel offtake, the broader need to address investment challenges hindering e-fuel projects from reaching FID, and the impact of the broader economic environment on their operations. Ship operators emphasized the importance of customer commitment, the practical challenges of ship conversion, and specific operational challenges related to running vessels on new fuels while aiming to achieve specific emissions reduction targets.

These broader results from the RFI highlight the challenges facing ZEMBA—and all first movers—working to drive rapid decarbonization of the maritime sector. The insight gained from the RFI, however, provide ZEMBA with a clearer idea of the near-term market readiness of e-fuels for commercial deployment in the shipping sector, and additional considerations to keep in mind when shaping its next tender to support its goals of incentivizing the uptake of e-fuel in the maritime sector and kickstarting the market for zero-emission shipping services.

06 Conclusions

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The purpose of this RFI was to assess the market readiness of e-fuels for commercial deployment in the maritime sector, specifically toward informing the design of ZEMBA's next tender. ZEMBA is aiming to aggregate demand for the environmental attributes associated with e-fuel-powered services, that can deploy starting in 2027. Survey responses and interviews from 32 fuel suppliers and 15 ship operators based in Europe, North America, Africa, Asia, and Australia have provided a representative view of this fast-evolving market.

The RFI results project that there could be a significant potential e-fuel market in the maritime industry for ZEMBA's next tender to tap into; estimates for both e-fuel production and e-fuel-capable vessels in 2027 greatly exceed the aggregated demand for ZEMBA's inaugural tender. However, the RFI uncovered a mismatch between e-fuel production and e-fuel-capable vessel deployment. From 2027–2030, the RFI results found that e-methane supply will be limited, suggesting that e-methane-capable vessels will not have access to sufficient e-methane fuel for a next ZEMBA tender focused on e-fuels. E-methanol as a pathway is projected to have both sufficient production of e-methanol and a compatible number of e-methanol-capable vessels on the water by 2027. Lastly, while e-ammonia production capacity is strong, the pathway faces

limitations due to a shortage of e-ammonia-capable vessels on the water in 2027. Examining these e-fuel-capable vessels by segment, the RFI found the containership segment to have sufficient projected capacity of e-fuel-capable vessels in 2027. While e-methanol-powered shipping services were found to be the most likely pathway, ZEMBA remains open to all qualifying e-fuel bids and innovative, scable zero-emission propulsion technologies.

Despite the RFI's results indicating the availability of both e-fuel and e-fuel-powered vessels on ZEMBA's timeframe for 2027 deployment, broader sectoral questions remain that could influence the willingness of the maritime sector to offer ZEMBA viable e-fuel-powered bids. Interrelated factors such as the likelihood of e-fuel production projects to reach FID, the willingness of ship operators to sign longer term offtake agreements, the evolving regulatory landscape, infrastructure development concerns, and the projected premium for e-fuel-powered shipping services are just some of the challenges that could influence ZEMBA's success in kickstarting the market for e-fuel-powered shipping services in its next tender.

Overall, the majority of respondents to the RFI emphasized their support for ZEMBA's mission and the potential significant impact that ZEMBA could have through its next tender to accelerate the adoption of e-fuels in the maritime sector. Although respondents acknowledged the importance of policy to unlock wider adoption of e-fuels in the maritime sector, respondents said that ZEMBA's clear demand signal for e-fuel-powered shipping services through its next tender could help enable existing e-fuel-capable vessels to run on e-fuels versus fossil fuels and help justify financing for future e-fuel-capable vessels and e-fuel production projects.

07

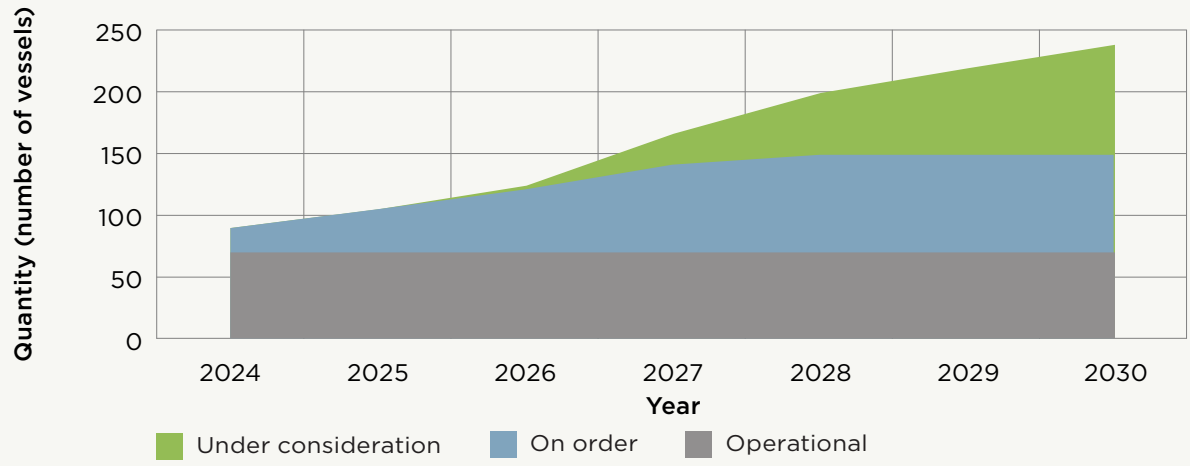
Appendix A: E-fuel-capable Vessels Across All Segments

The RFI study focused mainly on the forecasted uptake of e-fuel-capable containerships. This Appendix details the survey results across all segments.

7.1 E-methane-capable Vessels (All Segments)

When accounting for all segments that responded to the ZEMBA RFI (vessel types), the results showed orders for and consideration of additional e-methane-capable vessels. Figure 23 shows the forecast of all methane powered vessels across segments.

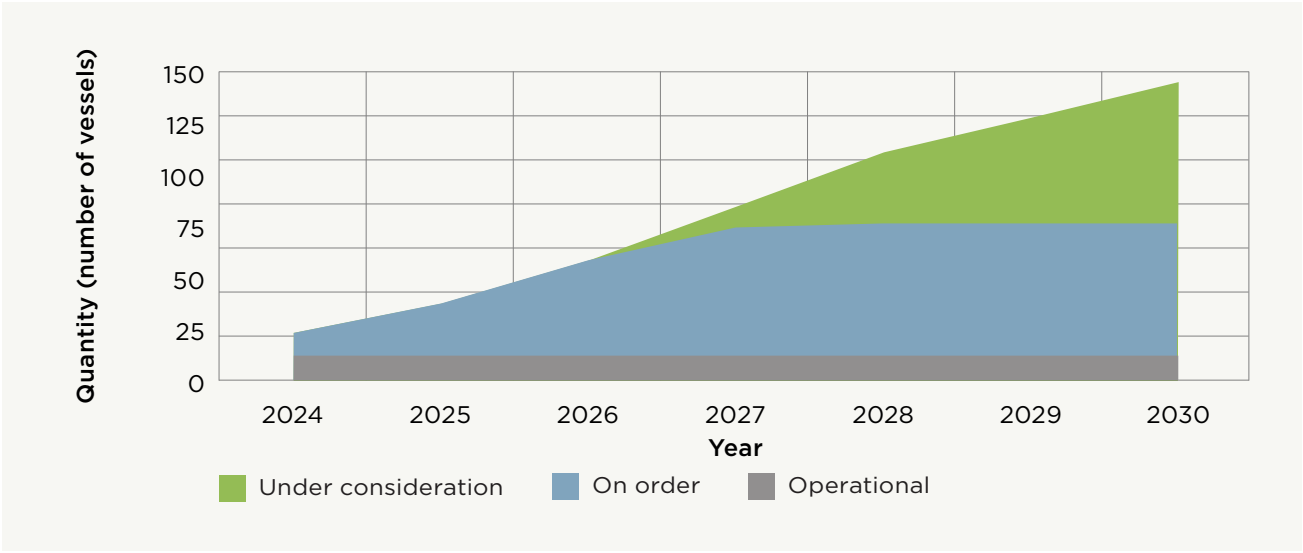
Figure 22: Total cumulative number of e-methane-capable vessels submitted for the RFI (all segments).



7.2 E-methanol-capable Vessels (All Segments)

The vast majority of e-methanol-capable vessels reported in the RFI were containerships, equating to 94% of all operational or on-order methanol vessels by 2027. This suggests that the container segment fleet alone should have sufficient capacity to meet ZEMBA demand. Forecasts for e-methanol-capable powered vessels for all segments are shown in Figure 23.

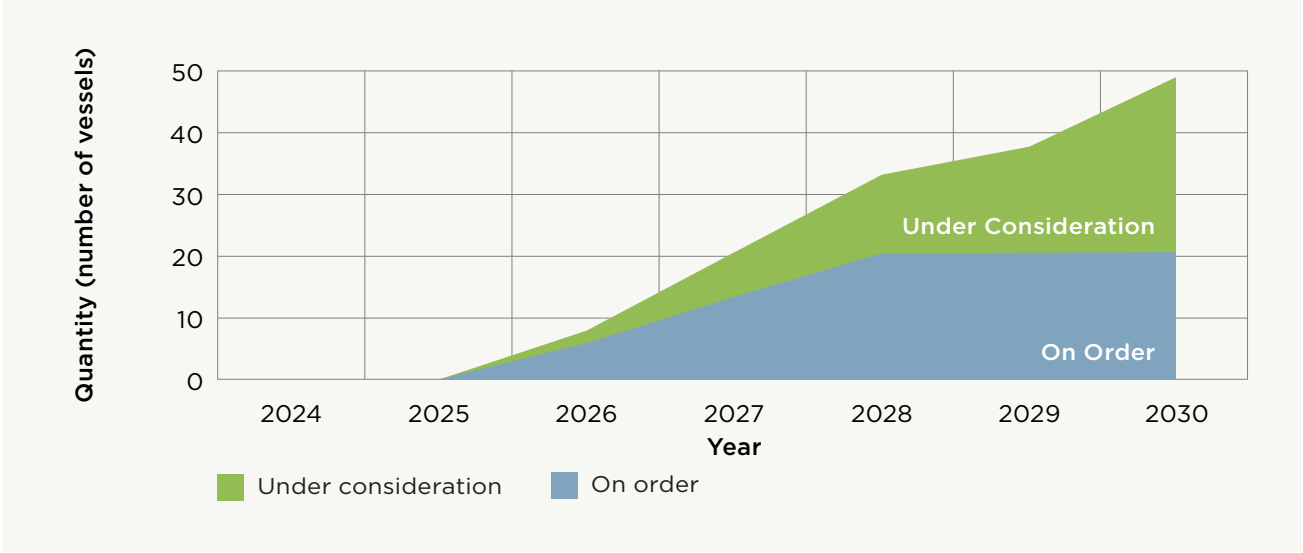
Figure 23: Total cumulative number of e-methanol-capable and ready vessels submitted for the RFI (all segments).



7.3 E-ammonia-capable Vessels (All Segments)

The RFI found no e-ammonia-capable vessels currently operating, with the first expected to be operating in 2026. When considering all segments (e.g., bulk carriers and liquefied gas tankers), the forecast suggests that the global fleet is projected to have 8 e-ammonia-capable powered vessels in 2026 (6 are on order) and 22 by 2027 (14 on order).

Figure 24: Total cumulative number of e-ammonia-capable and ready vessels submitted for the RFI (all segments).



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