The future of maritime fuels

What you need to know

Lloyd's Register Maritime Decarbonisation Hub

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Suggested reference

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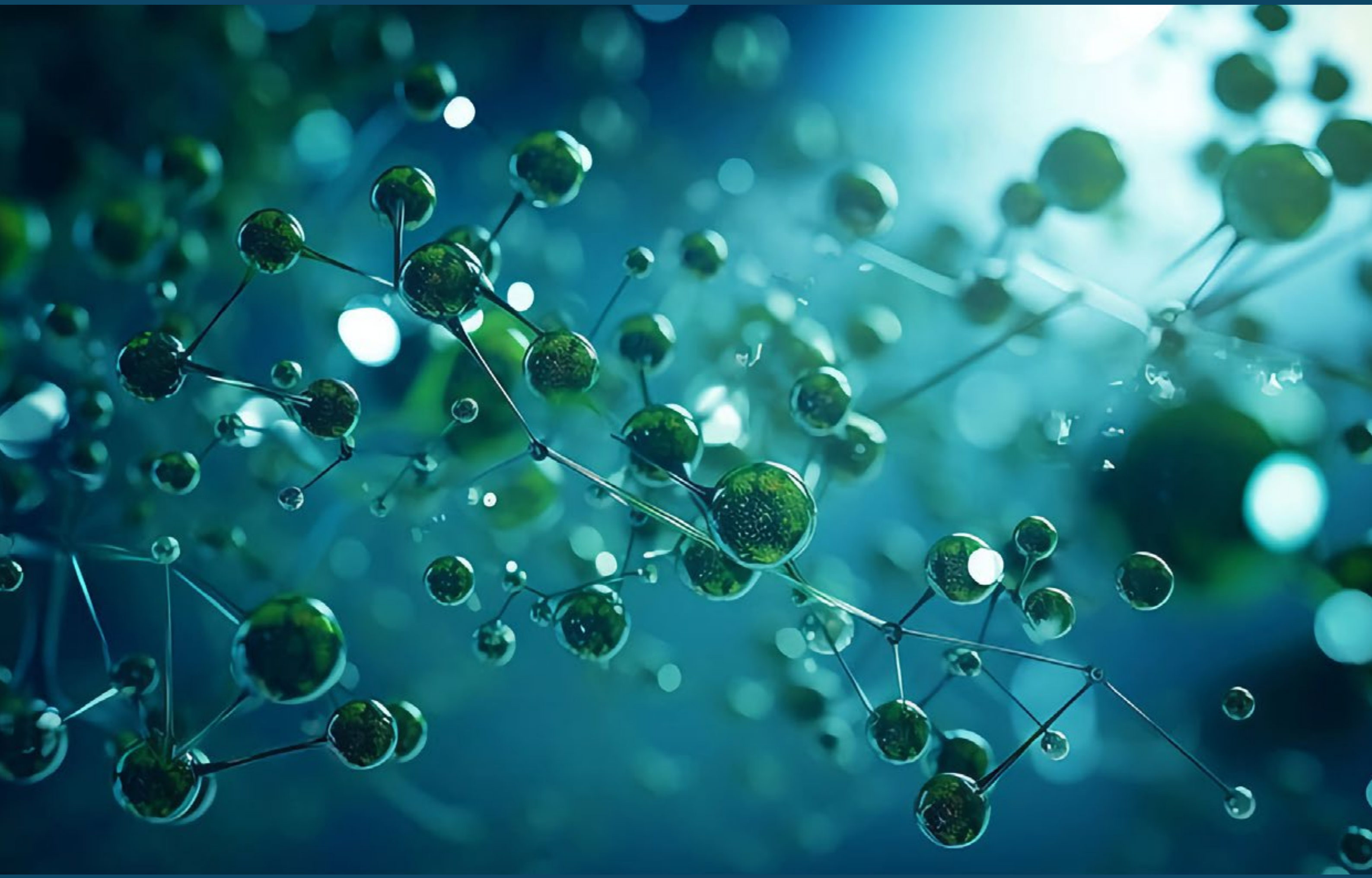
Executive summary

The recent IMO MEPC 80 has set new greenhouse gas (GHG) emissions reduction goals for the shipping industry. This will lead the sector to switch from conventional fuels to zero or near-zero GHG fuels by 2050. There is already a wide range of fuel projections that explore a decarbonised shipping industry based on different sets of assumptions. This report presents a comprehensive analysis of current projections, identifying areas of current consensus and dissensus. It puts fuel uptake projections into a broader perspective, taking into account the expected supply and other sectors' demands. The conclusions provide implications for the industry and areas for further exploration.



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Key findings

Current fuel mix projections fall into two broad categories:

1. **Hydrogen-based fuels scenarios –** in which hydrogen-based fuels have a greater share by 2050.
2. **Biofuels-based fuels scenarios –** in which biofuels have a greater share by 2050.

The review of the existing scenarios reveals the promising potential of both bio-based fuels and hydrogen-based fuels according to the existing literature. However, the most promising fuel faces distinct opportunities and challenges that require careful attention for successful adoption.

This examination of the key projections[1] within these two categories of scenarios uncovers the following:

Among hydrogen-based fuels scenarios:

- Combined blue and e-ammonia capture between 20% and 60% of the market by 2050 with an average share of 46%.
- E-ammonia emerges as the most highly adopted maritime fuel in the long term – on average the market share of e-ammonia is 35% in 2050. However, there is a large variation across the scenarios because of the different assumptions on future prices and the ability to scale fuel infrastructure at the required pace. Most of the scenarios provide a range between 20% and 50% of the market, while the most optimistic outlier scenario projects a market share for e-ammonia of approximately 80% by 2050.
- The average shares translate into considerable energy demands. For example, total consumption of blue and e-ammonia increases on average from 0.79 EJ in 2030 to 6.06 EJ in 2050, making the shipping industry the largest user of ammonia relative to other sectors (such as fertiliser and power generation). Current global ammonia production is 3.4 EJ, although this is primarily for the fertiliser market and derived from fossil fuels.
- As an order of magnitude, the hydrogen required to supply ammonia for the shipping industry could represent 3.7%-7 % of the expected total global hydrogen demand in 2030 and reach up to 8.3%-17.5 % in 2050. While there is little concern about the technical potential to produce hydrogen given the abundance of renewable energy sources (technical potential for hydrogen supply estimated to be 10,000 EJ), one of the key supply challenges is the ability to scale production at the required pace. Demand for clean hydrogen is still low across all sectors and if expected demands materialise at the same time, there could be potential competition among sectors.
- If the shipping industry becomes the largest user of clean ammonia, it will need to drive most of the development for the supply infrastructure and show leadership in securing the adequate scaling of the supply.

1 Projection is defined here as a what-if scenario analysis focused on a desired outcome, in contrast to a forecast which is based on what is expected to happen in the future.

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Among bio-based fuels scenarios:

- Bio and renewable diesel, as well as liquefied biomethane, emerge as the most highly adopted maritime fuels in the long term.

- Liquefied biomethane is projected to capture on average 34% market share by 2050. However, there is a large variation across the scenarios because of the different assumptions on future prices and the supply limit. Most of the scenarios provide a range between 27% and 46% of the market, while the most optimistic outlier scenario projects a market share for liquefied biomethane of approximately 50% by 2050. This indicates consensus that it will be insufficient to supply the total shipping demand given the limit of the energy sources to produce biomethane.

- The average shares of liquefied biomethane translate into considerable energy demands. For example, it increases from 0.5 EJ in 2030 to 4.58 EJ in 2050. However, the expected supply of biomethane for shipping (varying between 0.3 and 2 EJ) will fall short. This means that either the estimated demand is too high or that shipping will have an even bigger share of the global biomethane market than is currently expected. The latter case implies that other sectors will consume less than expected and/or that more supply needs to be ensured to meet shipping's increasing demand.

- The role of the shipping industry in driving the global biomethane market dynamics could become crucial, although it is unlikely that biomethane can become a dominant maritime fuel.

Across both categories:

- Methanol is projected to have a much lower market share than ammonia and biomethane, which is at odds with the current increasing ordering of dual-fuel methanol vessels.

- Combined bio and e-methanol capture on average a market share of 13.4% of total shipping fuel by 2050.

- Biomethanol is projected to have a higher uptake (8.6% share by 2050) than e-methanol (4.8% share by 2050) on average, However, the most optimistic outlier scenario projects a market share for biomethanol of 43% by 2050.

- The average shares translate into lower energy demands compared to ammonia and liquefied biomethane. For example, bio and e-methanol combined are projected to increase up to 1.8 EJ in 2050, compared to 6.06 EJ of ammonia and 4.58 EJ for liquefied biomethane.

- The expected supply of both bio and e-methanol should be able to meet the expected demand. However, this is because the demand estimates from these scenarios are relatively low.

- If the current trend towards ordering methanol vessels continues, methanol uptake could be up to 43% of total shipping fuel consumption, as projected in some outlier scenarios. This corresponds to more than 6 EJ by 2050. The expected global supply of methanol, about 7.7 EJ, would then need to scale significantly further to meet total demand across all sectors. If the shipping industry becomes a major user of methanol, the industry will need to drive and show leadership in the development of economically viable biomethanol and e-methanol options.

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Actions for stakeholders

This analysis has identified various actions for stakeholders.

Policymakers

- The role of policy in achieving shipping's decarbonisation goals is increasingly important. The analysis of the different projections has highlighted the order of magnitude of shipping's potential demand for zero and near-zero GHG fuels. However, they remain projections. The real-world future uptake of these fuels will still depend on the development of key policies. Therefore, policymakers need to establish a policy framework that enables the achievement of the IMO GHG strategy. In addition, these fuels are likely to be in demand in other sectors. Therefore there is a need to increase consistency across different sectors (for example, alignment of fuel definitions and sustainability criteria).

Investors

- The role of investors in shipping decarbonisation is crucial to unlock concrete actions. The projected demand for zero and near-zero GHG fuels from the shipping industry is not negligible. The role of shipping in leading the global demand for these new fuels needs further examination. However, investors need to consider the role of shipping's demand for clean energy sources offering economies of scale and a means of unlocking broader investment cases at the company, national and regional levels. Moreover, fuel procurement practices and strategies must fundamentally change. In the short term, both buyers and sellers need to explore further strategies involving risk sharing and the involvement of key interested stakeholders (such as governments and institutions interested in investing in clean energy) and potentially increase strategic partnerships.

First movers

- This report suggests that it is still uncertain if one category of fuel will dominate the maritime fuel mix in the short and long term. However, a multi-fuels future will likely play out. In the short term, first movers are challenged to select a fuel or fuels and start implementation. To minimise risks, first movers' initiatives, such as green shipping corridors, should carefully assess the regional multi-sectors fuel supply dynamics that would directly impact their initiatives. This could lead to potential synergies in aggregating demand and lower the risks.

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Further areas of exploration

This analysis has identified various actions for stakeholders.

- This report highlights the potential implications of supplying a certain amount of zero or near-zero GHG fuels to shipping. Regardless of the fuel of choice, it is evident that shipping will not be the only user because these fuels or the associated clean energy sources will also be required in other sectors. Therefore, further work should go into the assessment of the fuel supply dynamic and integration with existing shipping fleet-based models. To enrich insights, efforts should go into exploring in greater detail the potential future interaction of the shipping industry with the energy system.

- This assessment of a diverse set of projections has led to the identification of several key factors that should be taken into account when fuel supply is represented in models. In particular:

  - Ammonia supply must account for credible time and costs to deploy systems to overcome safety challenges across the entire supply chain and onboard ships. The impact on time and cost of gaining public acceptance, and personnel cultural shift should also be considered.
  - Methanol supply must account for the techno-economic assessment of sustainably sourced carbon supply to produce e-methanol at scale. Assessment of biomethanol's role in the short and long term under different scenarios from bio to e-methanol pathways should also be considered.
  - Biomethane supply must account for supply allocation across different sectors. In doing so, the assessment of the cost-effective deployment of biomethane across different sectors in remote regions should also be considered. In addition, biomethane production pathways need to ensure that the fuel reaches zero or near-zero GHG fuel specification.

- Other areas that deserve further exploration are:

  - Better understanding of carbon intensity levels versus costs over time for all potential fuel options.
  - Understanding the potential impact of new policies that try to establish a certain demand for zero or near-zero GHG fuels in line with the new IMO GHG strategy goals.
  - Assess the sustainability of supply for all types of fuel while considering suitability under a multi-sectors perspective.
  - Assess aggregated demands across sectors at the global and regional level to better understand the order of magnitude and the diverse short-term and long-term willingness to pay.
  - Understand the potential synergies and role of the shipping industry as a transporter and user of zero and near-zero GHG fuels.
  - Analyse the suitability of different fuels and energy systems based on ship types, trades and geographies.

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Introduction

The 80th meeting of the Marine Environment Protection Committee (MEPC) [1] has put more pressure on the shipping industry to renew its fleet with zero and near-zero greenhouse gas (GHG) emissions fuels. The IMO's GHG strategy's level of ambitions is now aiming to reach net-zero GHG emissions close to 2050. Moreover, new levels of ambitions have been introduced such as at least 5% striving for 10% of the energy used to be zero or near-zero GHG emissions, checkpoints to reduce GHG emissions by 2030 and 2040, as well as the lifecycle assessment (LCA) draft guidelines, including a Well-to-Wake (WtW) methodology and sustainability criteria. At the regional level, other regulations are also increasing the pressure to renew the maritime fleet with alternative fuels. For example, the FuelEU Maritime regulation is a European Union regulation that will lead to an increase in the demand for renewable and low-carbon fuels.

Overall, this will drive a rapid energy transition in shipping that has been already examined in previous studies. However, there is still uncertainty about the future fuel mix for maritime shipping, given the several and often contrasting views provided. The uncertainty is due to mainly different assumptions around future prices, WtW emissions factors, and availability which are not always transparent or accessible. In addition, other factors such as the interconnection with other sector demands is unclear and needs more examination. All of this leads stakeholders to hesitate to accelerate fuels take-up and policymakers to design effective policies.

Further analysis will be required to understand how the demand and supply of zero or near-zero GHG emissions fuels could look to meet the new IMO GHG strategy's level of ambitions and support the wide range of stakeholders. However, new insights can be derived by having a closer look at the existing scenarios.

The report takes a top-down approach, placing trends from these scenarios into context by considering a wide range of approaches, assumptions and findings from existing studies. It aims to:

- Enable stakeholders to develop their decarbonisation plans by outlining significant trends.
- Provide a broader perspective on the supply of these fuels that will help identify key implications and aspects that require further exploration.
- Reduce uncertainty and provide adequate decision-making support.

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Mapping fuel mix projections

Maritime fuel mix projections are based on scenario analysis, which is a strategic planning method that helps organisations make long-term plans while considering alternative possible outcomes. There is no single correct prediction of what will happen. However, exploring and analysing a range of possible futures can help to prepare for whatever may come. Therefore, this review focuses on the potential implications of these possible futures rather than what is likely to happen.

By examining the potential implications, new insights are provided to support stakeholders in decarbonising the shipping maritime industry.

We have mapped maritime fuel mix projections into two major categories, Figure 1.[2]

- The first category is Hydrogen-based fuels scenarios (hydrogen-fuels scenarios throughout the rest of the report). These scenarios have a higher share of hydrogen-based fuels (synthetic fuels manufactured from a hydrogen feedstock) by 2050.

- The second category is Biomass-based fuels scenarios (biofuels scenarios throughout the rest of the report). These scenarios have a higher share of biofuels (synthetic fuels manufactured from a biomass feedstock) by 2050.

Some studies offer a variety of scenarios, some of which differ significantly from one another. In contrast, other studies offer a single scenario or a range of scenarios with less significant differences.

The scenario that will play out is determined by the availability, cost and access to clean energy sources, as well as the assurance that the fuels used will be able to reach zero or near-zero GHG emissions.

2 Hydrogen-based fuels are all fuels that are derived from hydrogen such as blue and e-ammonia, e-methanol, e-methane, as well as the direct use of hydrogen

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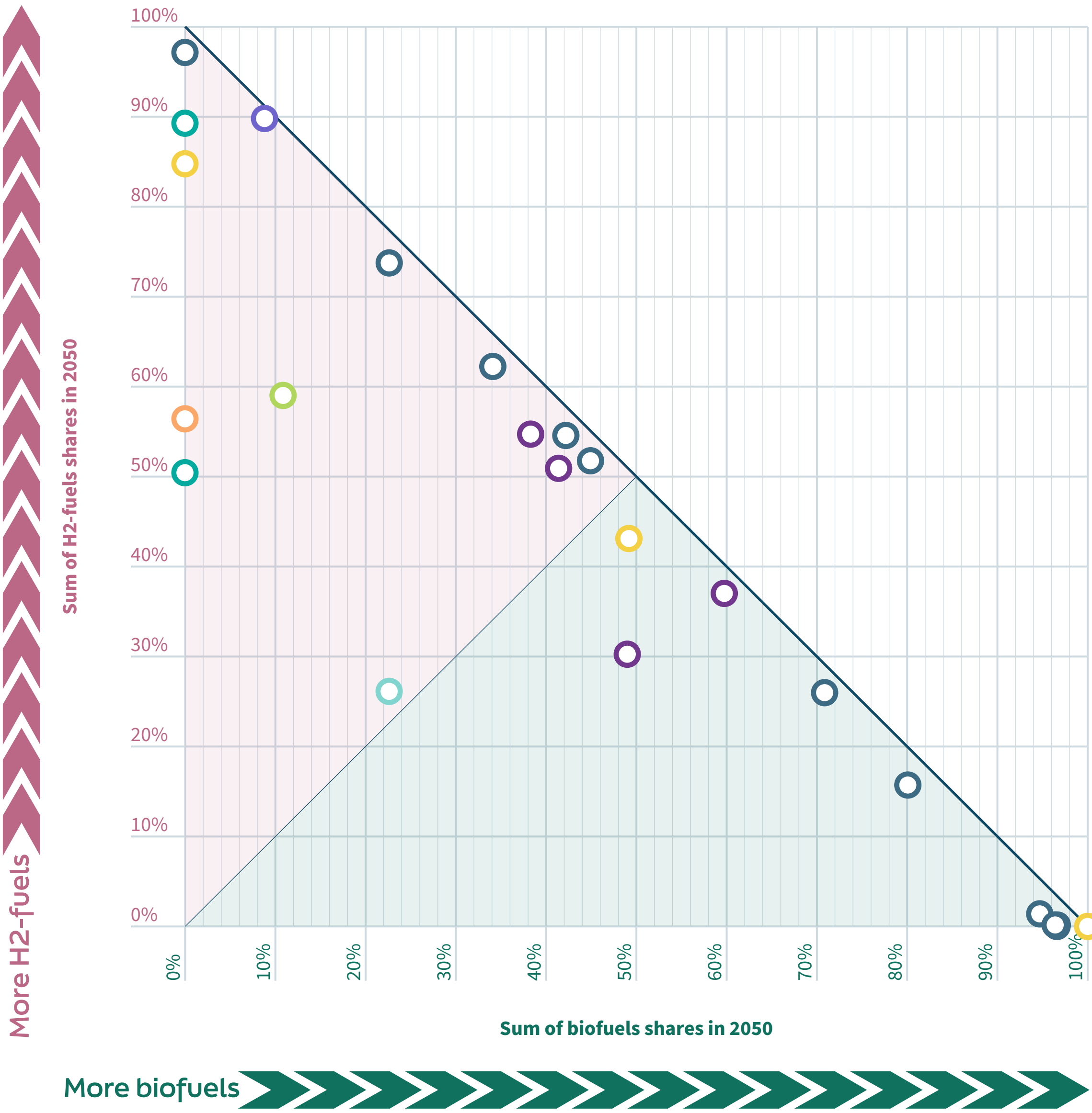
Figure 1: Mapping most recent fuel mix scenarios: Hydrogen (H2)-fuels scenarios versus Biofuels scenarios.



Key

- DNV (2022)
- UMAS &E4tech (2022)
- Clarksons Research (2022)
- Ricardo Energy & Environment (2022)
- ABS (2022)
- Maersk Mc-Kinney Moller Center for Zero Emission Shipping (2021)
- IRENA (2021)
- IEA (2020)

Similarities and differences

The initial step to analyse these scenarios is to search for similarities and discrepancies regarding the main themes., Table 1.

Table 1: Similarities and differences derived from the existing studies

Theme	Most of the studies agree on:	There are contrasting views on:
The role of biofuels	Biofuels are cheaper to produce than hydrogen fuels in the short term. In addition, their deployment could be easier and faster because of the similarity in onboard engines and bunkering infrastructure of current fuels. However, availability and sustainability must be addressed, particularly their ability to reach zero or near-zero GHG status and still be able to be defined as sustainable and available at scale. Moreover, they rely on carbon credits being transferred to allow tank-to-wake emissions to be offsets.	The prices of biofuels in the future are not certain. Some hydrogen-fuels scenarios suggest that biofuels may only have a secondary role due to supply limitations, causing their prices to rise higher than hydrogen fuels. However, in biofuels scenarios, these fuels are considered the top choice, overcoming issues on availability, sustainability and competitive feedstock.
The role of e-fuels	E-fuels are scalable and a promising long-term solution. However, they are expensive to produce today and require access to water and a lot of renewable energy both to produce green hydrogen and for other additional processes.	It's unclear how quickly e-fuels can be produced on a large scale and how costly renewable electricity will be. In certain regions where access to cheap renewable electricity is available, e-fuel prices may greatly decrease in the future. The hydrogen-fuels scenarios predict that the world will rapidly increase its renewable energy capacity to achieve complete decarbonisation by 2050. However, biofuels scenarios suggest that hydrogen fuels will only play a supporting role in the short and long term, while renewable electricity will primarily be used elsewhere.
Opportunities and challenges for e-ammonia	One of the main concerns with using ammonia as a maritime fuel is ensuring its safe handling, operation and maintenance. However, compared to other e-fuels, ammonia is expected to be the most cost-effective fuel in the long run in terms of the Total Cost of Ownership (TCO).	It is unclear what percentage of the future fuel market will be filled by e-ammonia. Most models prioritise finding the most cost-effective option, which often leads to e-ammonia being the preferred choice. However, scenarios that rely heavily on ammonia assume that it will be readily available without any limitations on supply and with zero or close to zero carbon intensity. On the other hand, scenarios with a lower share of ammonia take into account potential barriers to deployment that could slow down its adoption, such as: safety challenges, other emissions from engines, public acceptance of the solution, whether it is produced from 100% renewable electricity or the grid.
The role of blue ammonia	Blue ammonia can be cheaper to produce than e-ammonia in the short term. It is a lower-carbon fuel than traditional grey ammonia, but it is still not a zero-GHG fuel.	It is unclear what the future holds for the use of blue ammonia. While some anticipate that it may become more popular than e-ammonia in the near future due to its cheaper production costs and near-zero GHG fuel status, others believe that it may not be considered an eligible near- zero GHG fuel, leading to stranded infrastructure assets and a lower uptake in the long-term.

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Theme	Most of the studies agree on:	There are contrasting views on:
The role of methanol	Biomethanol could serve as a useful transitional fuel while moving to e-methanol. However, according to most of the studies, e-methanol is not expected to become the dominant fuel in any scenario due to its higher long-term production costs. Nonetheless, many studies suggest that if the prices of Direct Air Capture (DAC) and Bioenergy with Carbon Capture and Storage (BECCS) technologies decrease significantly within the next decade, e-methanol could potentially replace ammonia as the preferred fuel.	The future use of methanol as fuel depends on the assumptions made for other fuel options. In scenarios where e-ammonia has low or no usage, the use of e-methanol is projected to be higher and vice-versa.
The role of liquefied biomethane	Liquefied biomethane can play a crucial role as it could tap into a growing gas-fuelled fleet. There is a need for better monitoring and fixing of methane leaks across the entire supply chain as recent evidence suggests that this is underestimated [10]. Fossil LNG can be a transition fossil fuel for liquefied bio-methane, which must be adopted within the decade, as continued use of fossil LNG in the long term is not in line with decarbonisation by 2050.	The future share of liquefied biomethane is uncertain. Hydrogen-fuels scenarios see liquefied biomethane playing only a complementary role because of logistic supply challenges and a more cost-effective use in other sectors. In contrast, biofuels scenarios see liquefied biomethane as one of the leading candidates together with biodiesel overcoming logistic supply challenges, reaching zero or near-zero GHG status, and still being more competitive compared to other options.
The use of direct hydrogen	Hydrogen is a promising fuel for small, medium-size and short-range ships. However, it is expensive to transport and store, taking up significant space on board, which makes its use challenging in large vessels.	
The use of direct electrification with batteries	Batteries are feasible for short-haul shipping (e.g. domestic shipping). However, sourcing raw materials and recycling batteries can be a challenge.	

The main factors driving the differences in these scenarios are assumptions about fuel prices and availability, as well as overall constraints on emissions over time.

By examining the different findings, we can also see a consistent message – both biofuels and e-fuels have great potential, but each fuel also faces specific challenges:

- Biofuels need to demonstrate their ability to reduce GHG emissions while remaining competitive in the long-term.
- E-ammonia faces safety challenges, and e-methanol requires a sustainable source of carbon.
- Direct hydrogen and batteries are promising for small and medium-size vessels in short-haul shipping.

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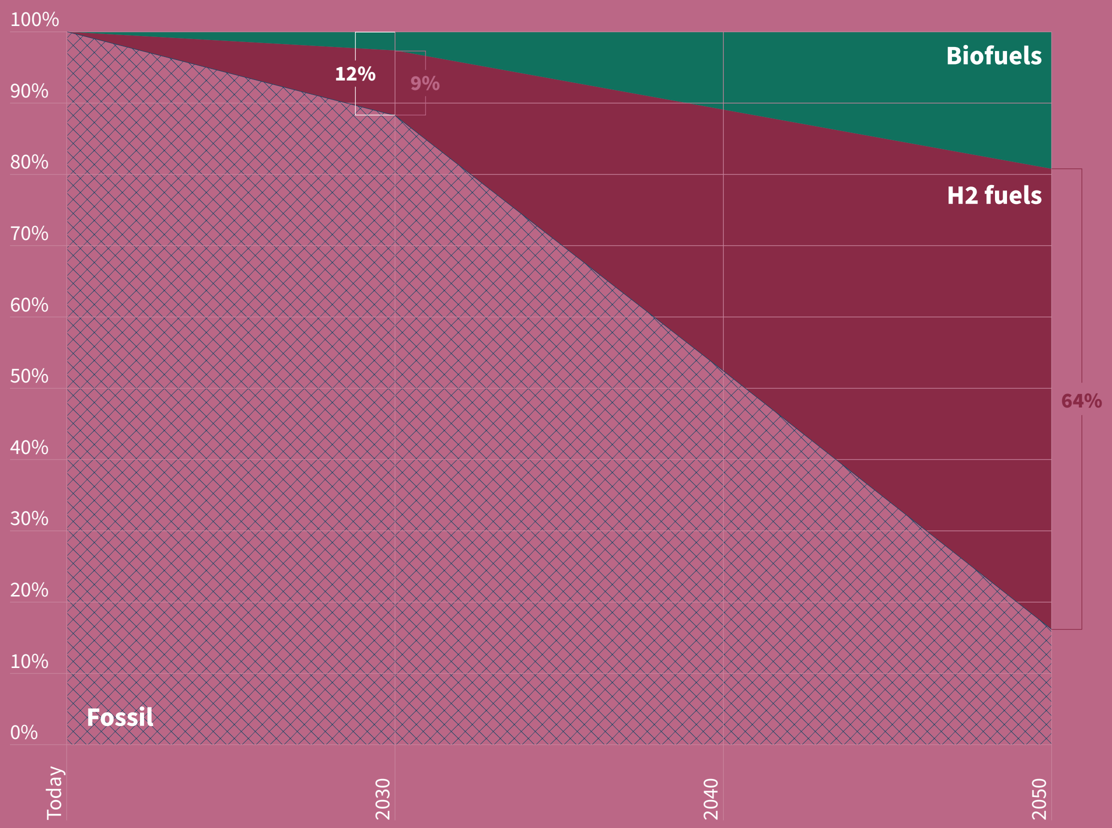
Hydrogen-based fuels scenarios

This report examines the various scenarios and provides an overview of the average trends for each category (hydrogen-based fuels scenarios and biofuels scenarios). Instead of analysing each scenario, it calculates the average trend of each category by using the mean of the shares for each fuel. Although the approach may oversimplify the detailed modelling in each scenario, analysing the fuel mix breakdown and distribution of shares for 2030 and 2050 can reveal crucial trends that warrant discussion.

Hydrogen-based fuels are seen as the leading candidates for decarbonising shipping. On average, they can make up 14% of the total fuel mix by 2030 and reach 66% by 2050.

By 2030, the percentage of zero or near-zero GHG fuels, which includes biofuels and hydrogen fuels, is estimated to be around 12%, Figure 2.

Figure 2 Average trends for the H2-fuels scenarios



In 2030, 88% of the share is fossil fuels. Blue ammonia is likely to be more popular than e-ammonia (5% compared to 3%, Figure 3), although, there is ambiguity regarding the role of blue ammonia, as it is a lower-carbon fuel compared to traditional grey ammonia, but not a zero-GHG fuel.

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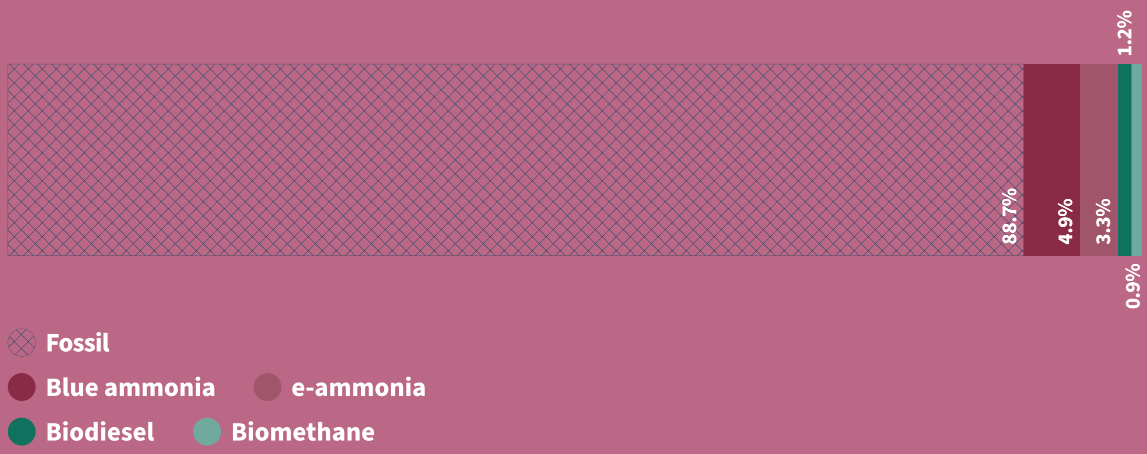
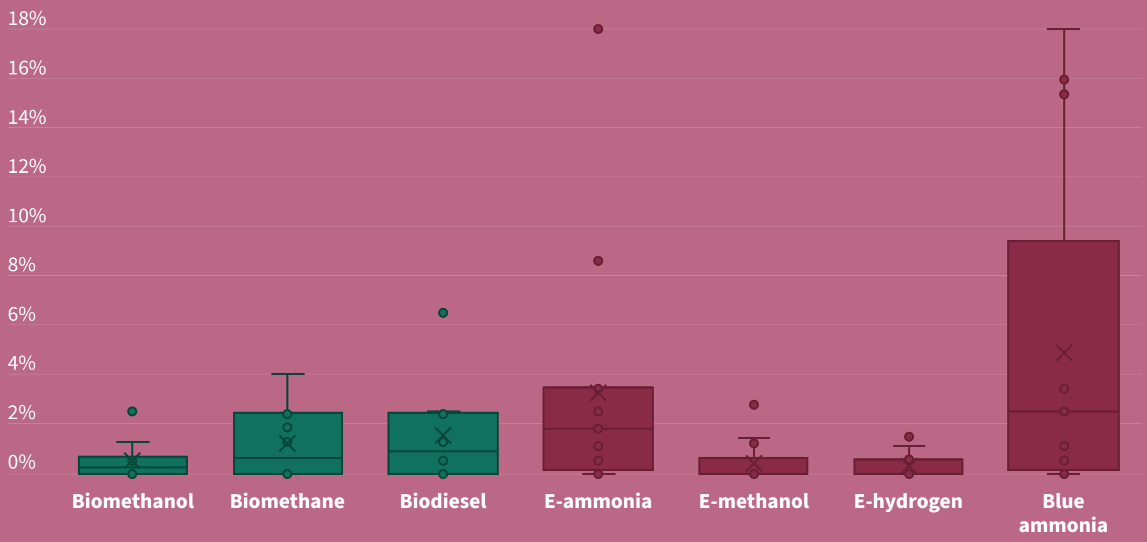
Figure 3 Fuel mix breakdown in 2030 based on the mean values of the hydrogen-fuels scenarios.



There is a considerable amount of uncertainty for both e-ammonia and blue ammonia, with each ranging from 0% and 18% of the fuel mix by 2030 (see Figure 4). However, the overall trend is that blue ammonia will have a higher share with three separate scenarios forecasting over 15% in 2030.

Biomethane and biodiesel are viewed as more promising biofuels. In contrast, bio- and e-methanol, and e-methane are projected to have a lower share by 2030.

Figure 4 Distribution of fuel shares in 2030 for the hydrogen-fuels scenarios.



E-ammonia is expected to be the most popular maritime fuel in the long term – on average the share of e-ammonia is 35% in 2050, Figure 5. A large share is still fossil, 17%. However, this may not be in line with the new IMO targets, meaning that all shares of zero and near-zero GHG fuels are expected to be higher than these averages to be in line with the new IMO strategy. The category of other e-fuels includes e-methanol, e-hydrogen and e-marine gasoil. For these fuels, a few outliers have disproportionately inflated the average as shown in Figure 6. Therefore, the share of 18% for other e-fuels is indicatively the portion that these fuels could cover collectively.

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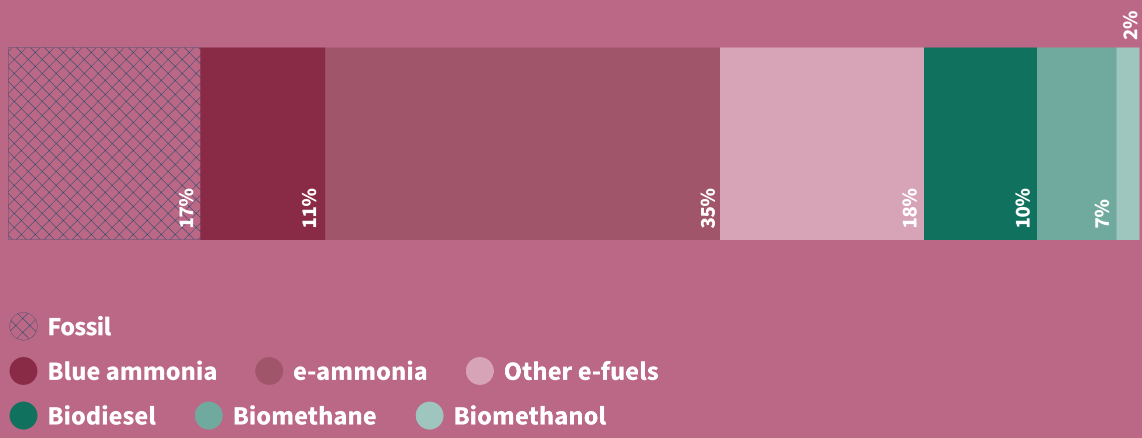
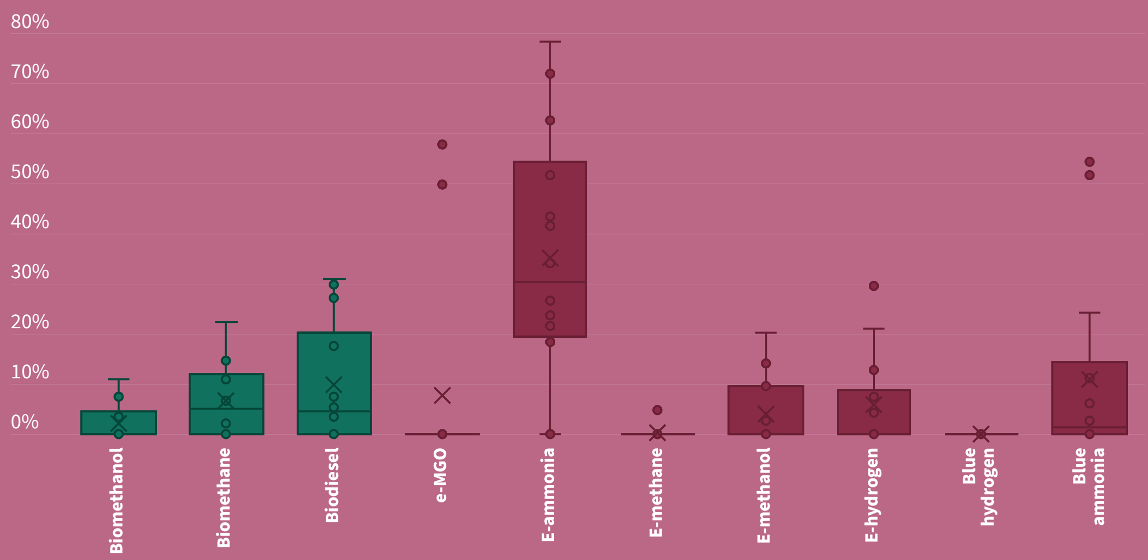
Figure 5 Fuel mix breakdown in 2050 based on the mean values of the hydrogen-fuels scenarios.



Most studies think that e-ammonia will make up between 20% and 50% of the marine fuel market in 2050. However, some outliers think that it could be as high as 79% or as low as 0%, Figure 6.

The scenarios that project low or 0% for e-ammonia see higher shares for other e-fuels, such as e-methanol and e-hydrogen, and a higher contribution from all biofuels.

Figure 6 Distribution of the shares in 2050 for the hydrogen-fuels scenarios.



E-ammonia is expected to be the most popular maritime fuel in the long term – on average the share of e-ammonia is 35% in 2050. However, there is a large variation across the scenarios because of the different assumptions on future prices and the ability to scale at the required pace given safety challenges.

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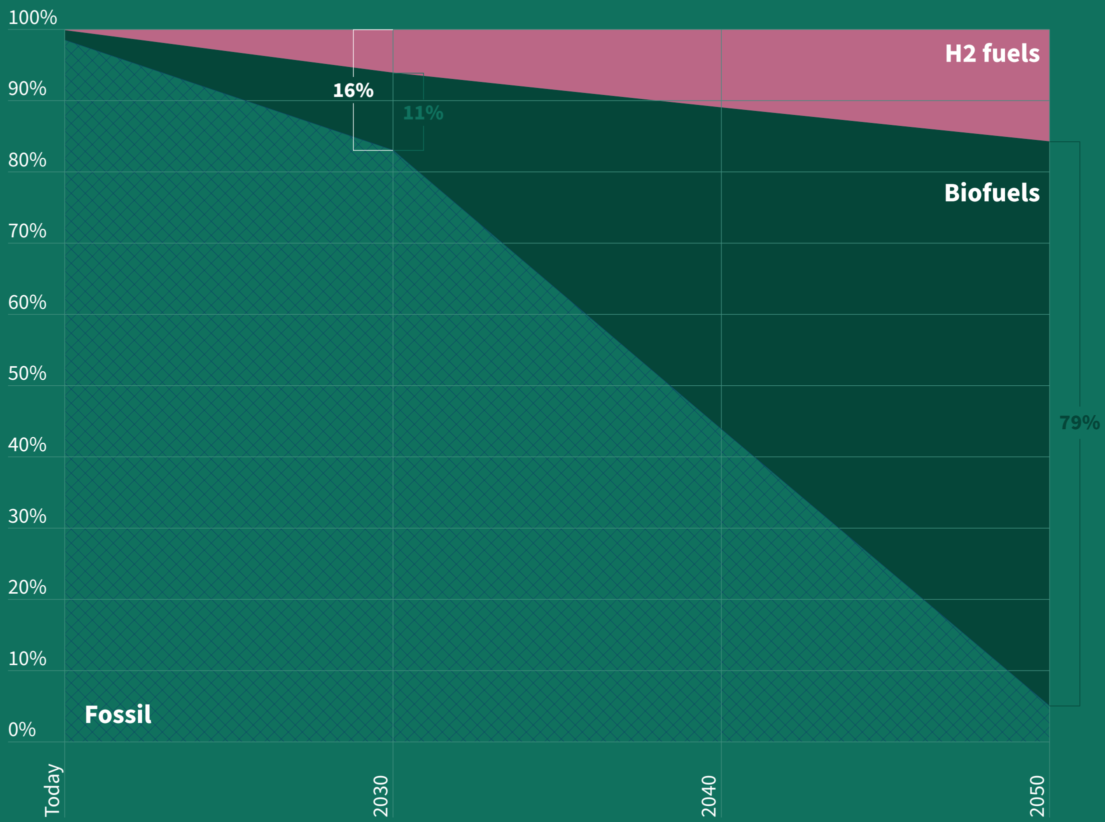
Biofuels scenarios

According to this category of scenarios, biofuels share sees a significant increase over time, reaching 11% by 2030 and 79% by 2050. One of the key assumptions is that these biofuels can eventually reach a level of carbon intensity considered zero or near-zero GHG fuel.

Figure 7 Average trends for the biofuels scenarios



In 2030, 84% of the share is fossil fuels. Among the biofuels, liquid biomethane and biodiesel (FAME, HVO, and bio-oils) cover on average the larger shares, approx. 11% combined, Figure 8.

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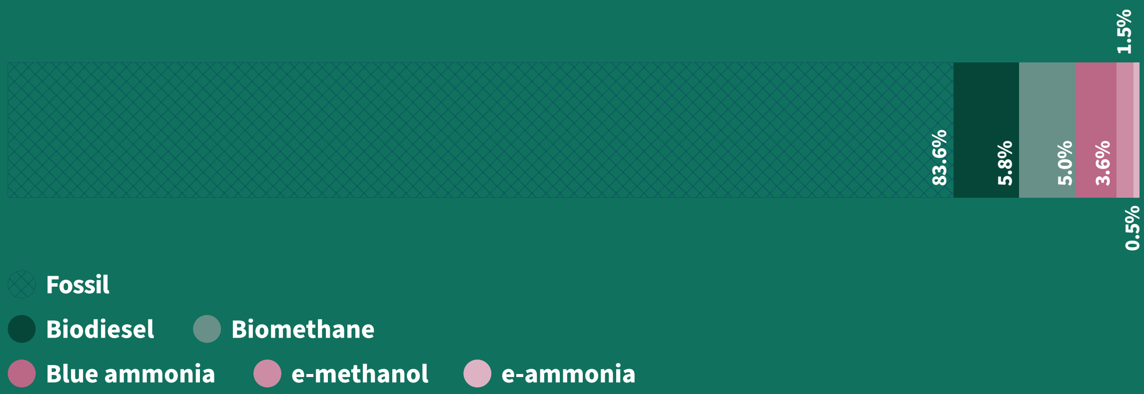
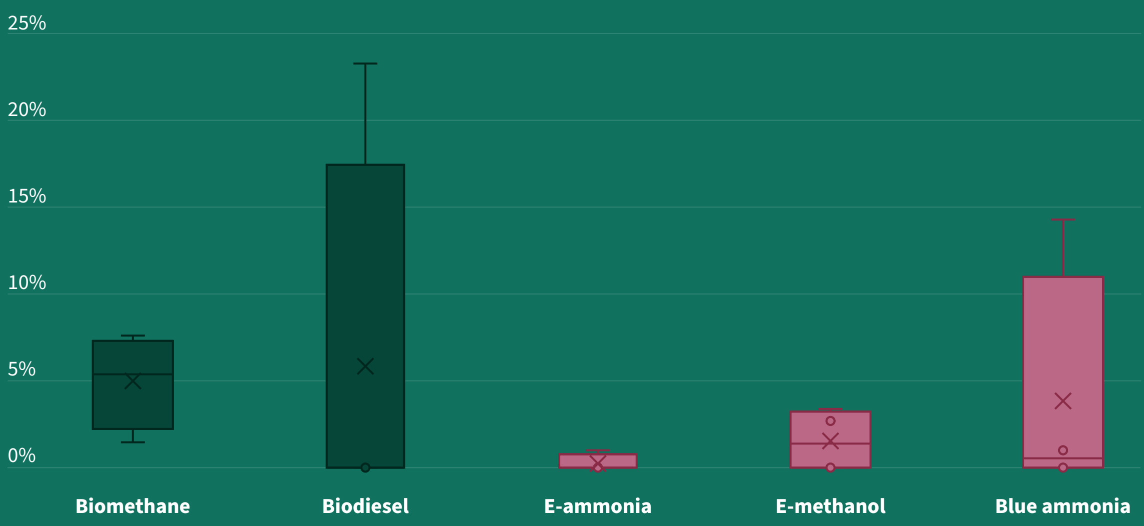
Figure 8 Fuel mix breakdown in 2030 based on the mean values of the biofuels scenarios.



Some projections for biodiesel in 2030 are as high as 23% and as low as 0%, meaning that there is significant uncertainty around the uptake of this subgroup of fuels. Figure 9. In contrast, the share of biomethane is expected to be between 3%-6%, supported by the view that a switch from fossil LNG to liquid biomethane will be competitive.

Biomethanol is not seen as a major contributor to the fuel mix by 2030, which is at odds with the recent increasing ordering of dual-fuel methanol vessels. See section Methanol demand and supply and further details in (ZFCM).[3]

Figure 9 Distribution of the shares in 2030 for the biofuels scenarios.



By 2050, biodiesel and biomethane continue to have the highest shares (respectively 37% and 34%). This is because there is greater confidence in their availability and competitive cost of feedstock in the long term. In addition, there are existing vessels and bunkering facilities that can operate on these fuels without modifications. The share of biomethanol also increases, reaching up to 8.6% in 2050, which combined with e-methanol is projected to reach over 13.4%.

3 https://www.lr.org/en/expertise/maritime-energy-transition/maritime-decarbonisation-hub/zcfm/

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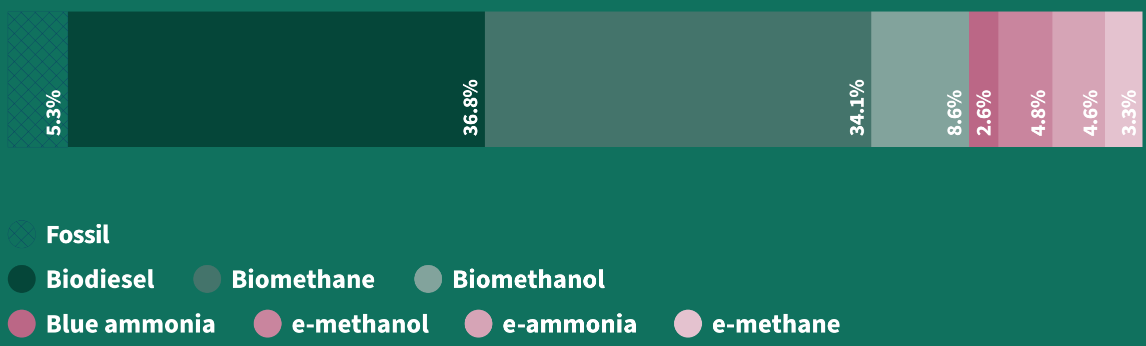
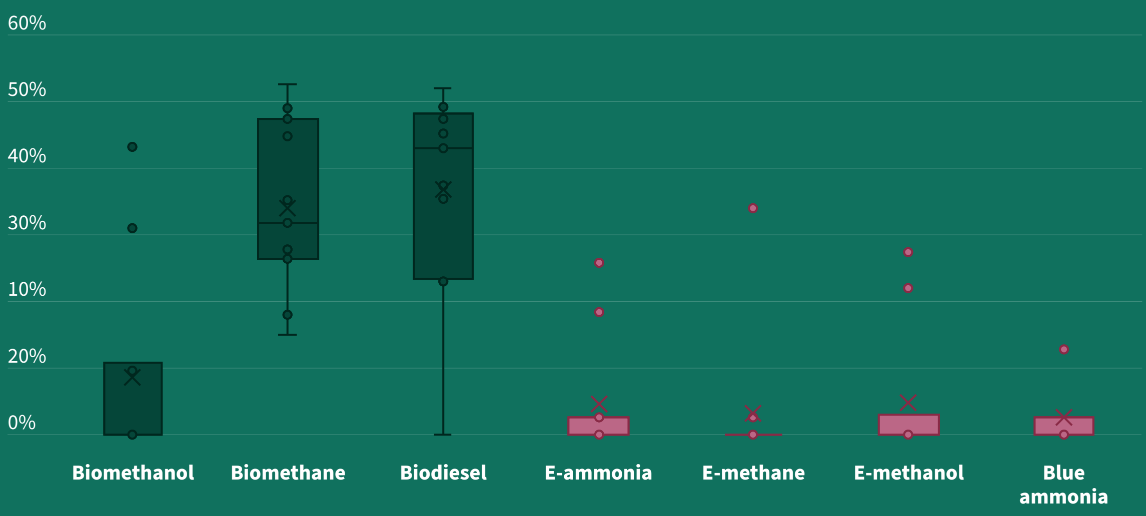
Figure 10 Fuel mix breakdown in 2050 based on the mean values of the biofuels scenarios.



There is, however, uncertainty as shown by the ranges in Figure 11. Most studies think that liquefied biomethane will make up between approximately 27% and 46% of the marine fuel market in 2050, while biodiesel will make up between 29% and 48%. The mean biomethanol share is 8.6%. However, some studies think that the biomethanol share could be as high as 43%.

For these scenarios, hydrogen fuels have a small role, averaging just 15% of the fuel mix. However, some studies see a more balanced mix between biofuels and hydrogen fuels with the latter reaching between 20% and 43%, giving concerns around biomass availability in the long term.

Figure 11 Distribution of the shares in 2050 for the biofuels scenarios.



Biodiesel and liquid biomethane continue to be the most popular. However, some see biomethanol and hydrogen fuels playing a more significant role due to long-term concerns about the competitive cost of bioenergy.

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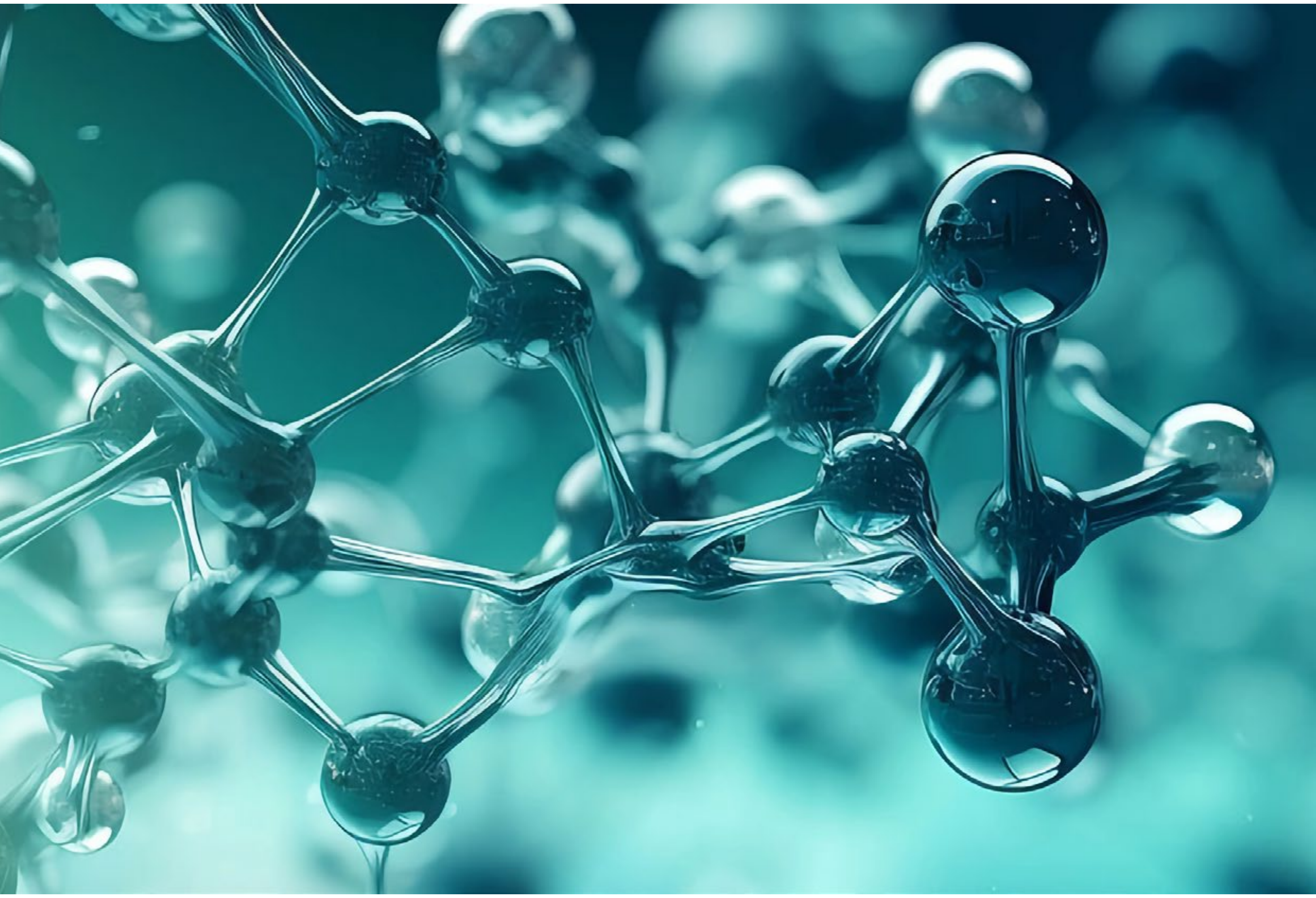

Ammonia demand and supply

Ammonia is seen by many as the dominant long-term solution. Therefore, examining the potential implications of using ammonia as a dominant fuel in the shipping industry in the long term is of utmost importance. To do so, this report estimates the demand for ammonia on an energy basis (EJ). This can be determined by multiplying the shares (excluding outliers) by the upper and lower energy demands for shipping as provided in [11]. This estimate is then compared to the demands from other sectors and the expected supply. Additionally, since hydrogen is the primary feedstock and cost driver for ammonia, this report also estimates the amount of hydrogen required to produce maritime ammonia and compares it to the hydrogen demands of other sectors.

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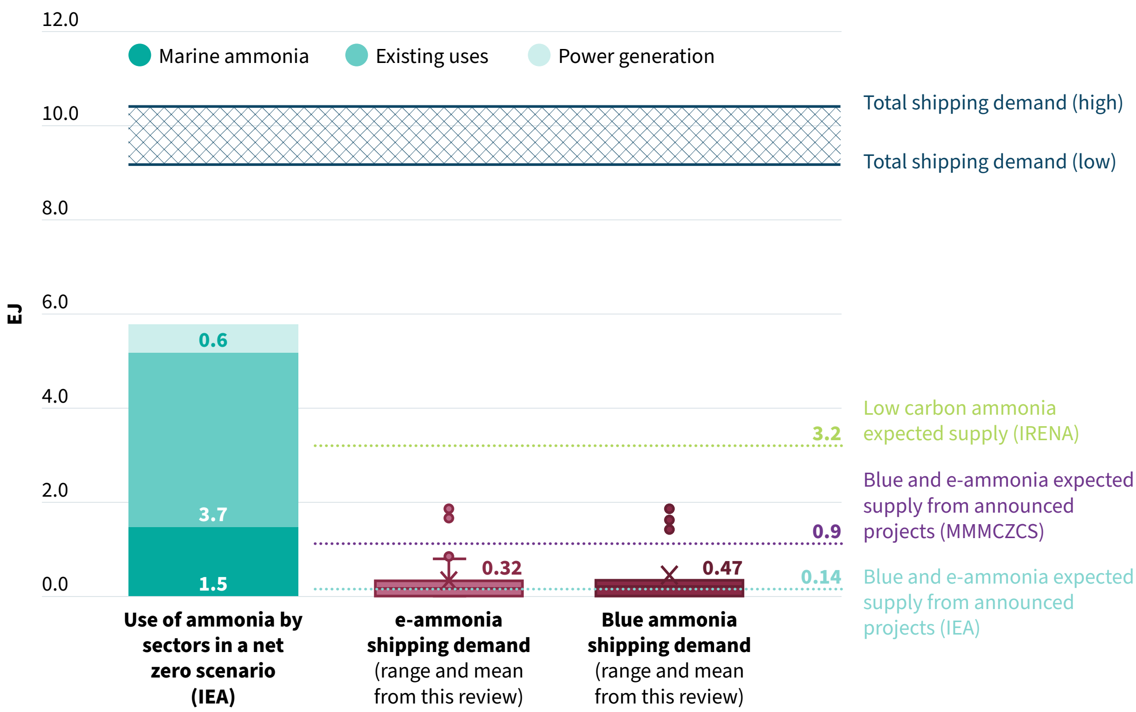
Ammonia supply and demand in 2030

Currently 183 million tonnes of ammonia are produced globally per year [12], equivalent to 3.4 EJ. However, this is primarily produced for the fertiliser industry.

In the future, ammonia is expected to play an important role in power generation and as fuel in the maritime sector. To meet the demand for clean ammonia in a net-zero future, it is necessary to increase its supply. Currently, announced projects are only projected to supply 0.14 – 0.9 EJ of blue and e-ammonia [12], while others estimate a higher value of 3.2 EJ [13]. However, this anticipated supply falls short of the almost 6 EJ required for all sectors Figure 12.

This review suggests that by 2030, the demand for e-ammonia in shipping is on average 0.32 EJ, while blue ammonia demand reaches 0.47 EJ. Although the expected supply may currently meet this demand, as the need for clean ammonia grows, it is crucial for shipping to ensure access to its supply

Figure 12 Ammonia shipping demands compared to other sectors' demands and expected supply in 2030.



The supply of clean ammonia by 2030 may not be sufficient to meet the rising demands in a net-zero scenario. Other industries will also require clean ammonia, leading to a potential strain on the supply. To overcome this challenge, stakeholders in the shipping industry should identify and adopt synergies and strategies (e.g. commercial partnerships) while addressing supply barriers, thus facilitating the scaling up of necessary infrastructure.

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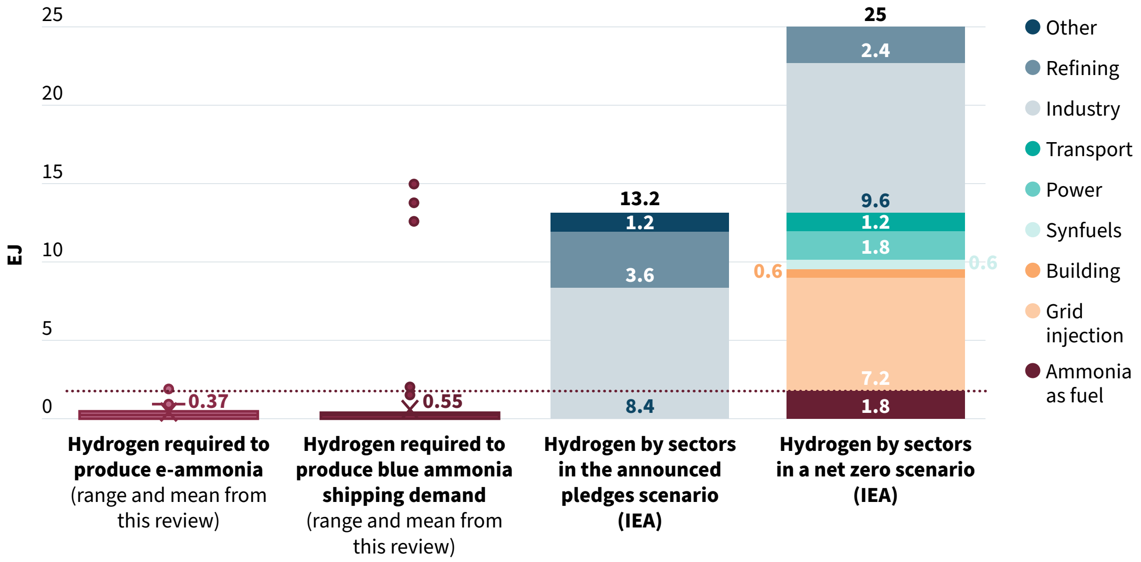
Hydrogen is the main feedstock and key cost driver to produce ammonia. Today, hydrogen is mainly used in industrial processes, however, in the future it is expected to play an important role in various sectors, By 2030, hydrogen is projected to reach approximately 13.2 EJ in accordance with government commitments [14] . This, however, falls short of the necessary levels to achieve net-zero carbon emissions, which are estimated to be around 25 EJ by 2030, Figure 13. In the net-zero emissions scenario about 1.8 EJ of hydrogen will be used to produce ammonia as fuel. This would be sufficient to cover the hydrogen required to produce blue and e-ammonia as estimated in this review. It is estimated that 0.37 EJ of hydrogen will be required for e-ammonia and 0.55 EJ for blue ammonia by 2030 (based on 177.5 kg of hydrogen required per tonne of ammonia [15]). Collectively, the hydrogen necessary for maritime ammonia production (0.92 EJ) could represent approximately 50% of the total hydrogen dedicated to the production of ammonia as fuel. In the short term, the shipping industry is expected to represent a relatively small share, 3.7% of the total hydrogen required in a global energy system that aims for net-zero emissions (25 EJ), or 7% of the total hydrogen demand in the announced pledges scenario.4

Figure 13 Hydrogen required to produce maritime ammonia compared to other sectors' demands for hydrogen in 2030 under the announced pledges scenario and the net-zero scenario. The estimate of hydrogen by sectors is approximate and derived from the graphs provided in [14].



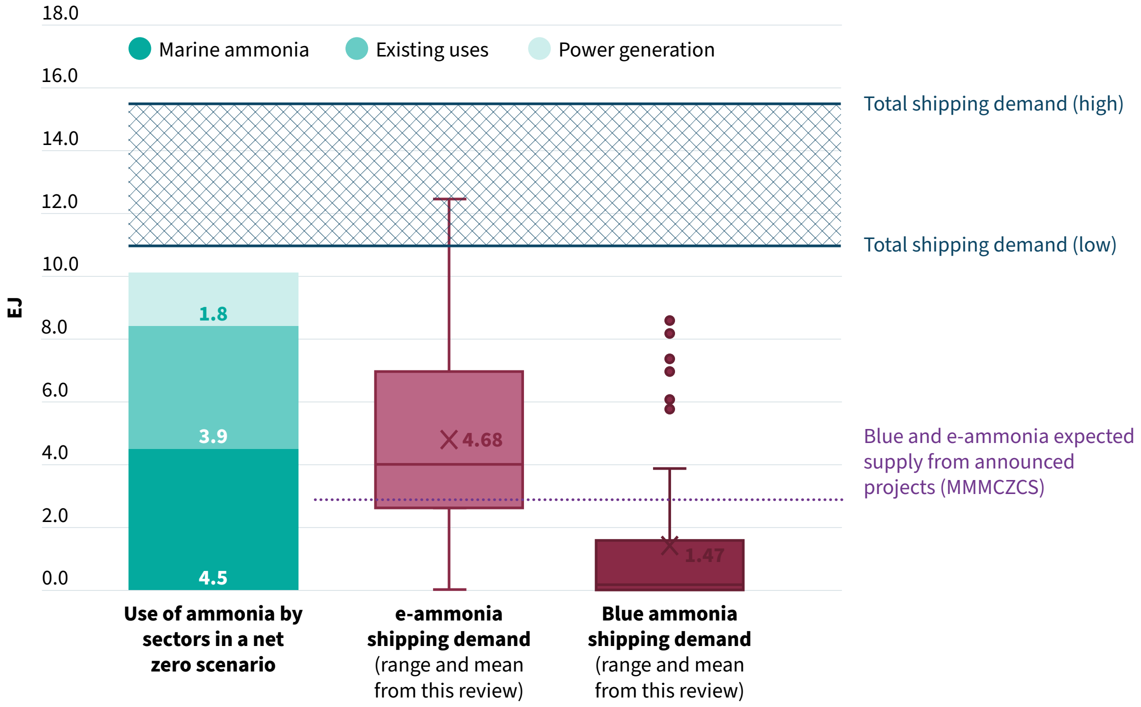
In the short term, the shipping industry could play a significant role in catalysing investment in clean hydrogen infrastructure specifically dedicated to the production of ammonia as fuel. This is because, in a net-zero scenario, the projected demand for hydrogen to produce ammonia for shipping could constitute a considerable portion of the overall hydrogen used to produce ammonia as fuel. In the announced pledges scenario, where only limited hydrogen is allocated to produce ammonia as fuel, the shipping industry would consequently need to secure the supply by collaborating closely with fuel producers to ensure a sufficient and timely scaling of the supply.

Ammonia demand and supply in 2050

Shipping can become the main user of ammonia by 2050. This review suggests that e-ammonia shipping demand could be on average 4.76 EJ, which is in line with the expected use in a net-zero scenario, 4.5 EJ [12], Figure 14

The expected supply of blue and e-ammonia is 2.7 EJ [7] which falls short to meet the expected demand. If the uptake of ammonia would be much higher than the average, the supply will need to scale accordingly to meet that demand. This means that in the long term, the shipping industry will need to drive most of the demand for clean ammonia and show leadership in securing the adequate scaling of the supply.

Figure 14 Ammonia shipping demands compared to other sectors' demands and expected supply in 2050. Marine ammonia demand derived from [12], supply in 2030.



By 2050, shipping may become the largest consumer of ammonia. However, supply will be challenged to respond quickly and scale accordingly to meet the growing demands.

Shipping could play a growing significant role in scaling hydrogen infrastructure in the long term.

By 2050, hydrogen is projected to reach approximately 31 EJ in accordance with government commitments (IEA). This, however, falls short of the necessary levels to achieve net-zero carbon emissions, which are estimated to be around 63 EJ by 2050, Figure 15.

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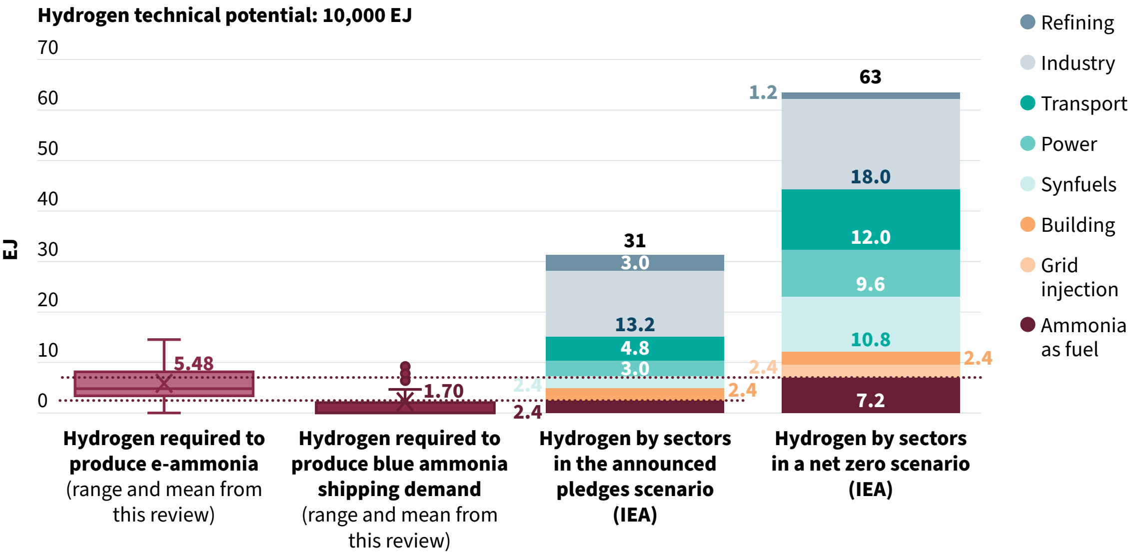
In the net-zero emissions scenario about 7.2 EJ of hydrogen will be used to produce ammonia as fuel. This would be just enough to cover the hydrogen required to produce blue and e-ammonia as estimated in this review. It is estimated that 5.48 EJ of hydrogen will be required for e-ammonia and 1.7 EJ for blue ammonia by 2050. Collectively, the hydrogen necessary for maritime ammonia production (~7 EJ) could represent almost the total hydrogen dedicated to the production of ammonia as fuel. The announced pledge scenario only has 2.4 EJ of hydrogen to produce ammonia as fuel, which means that it will fall short to meet the expected maritime demand.

In the long term, the shipping industry is expected to represent a bigger share of the hydrogen market, 8.3% of the total hydrogen required in a global energy system that aims for net-zero emissions (63 EJ), or 17.5% of the total hydrogen demand in the announced pledges scenario (31 EJ) [14]. Despite challenges to scaling hydrogen supply to meet the necessary levels to achieve net zero by 2050, there isn't a supply constraint even considering land availability limits. The hydrogen needed to produce maritime e-ammonia is only a fraction of the technical potential[5] for green hydrogen, which is estimated to be approx. 10,000 EJ [16].

Figure 15 Hydrogen required to produce marine ammonia compared to other sectors' demands for hydrogen in 2050.



In the long term, the shipping industry can make a significant contribution to the expansion of hydrogen infrastructure. The projected demand for hydrogen to produce ammonia for shipping could constitute almost the entire hydrogen used for the production of ammonia as fuel. In the announced pledges scenario, the shipping industry would need to secure the supply by collaborating closely with fuel producers as hydrogen for ammonia production may not be sufficient and the potential demand for hydrogen from other industries could also affect the ability to scale at the required pace.

5 The technical potential refers to the maximum amount of energy that can be technically generated from a particular resource, given the available technology and without considering economic, environmental or social constraints.

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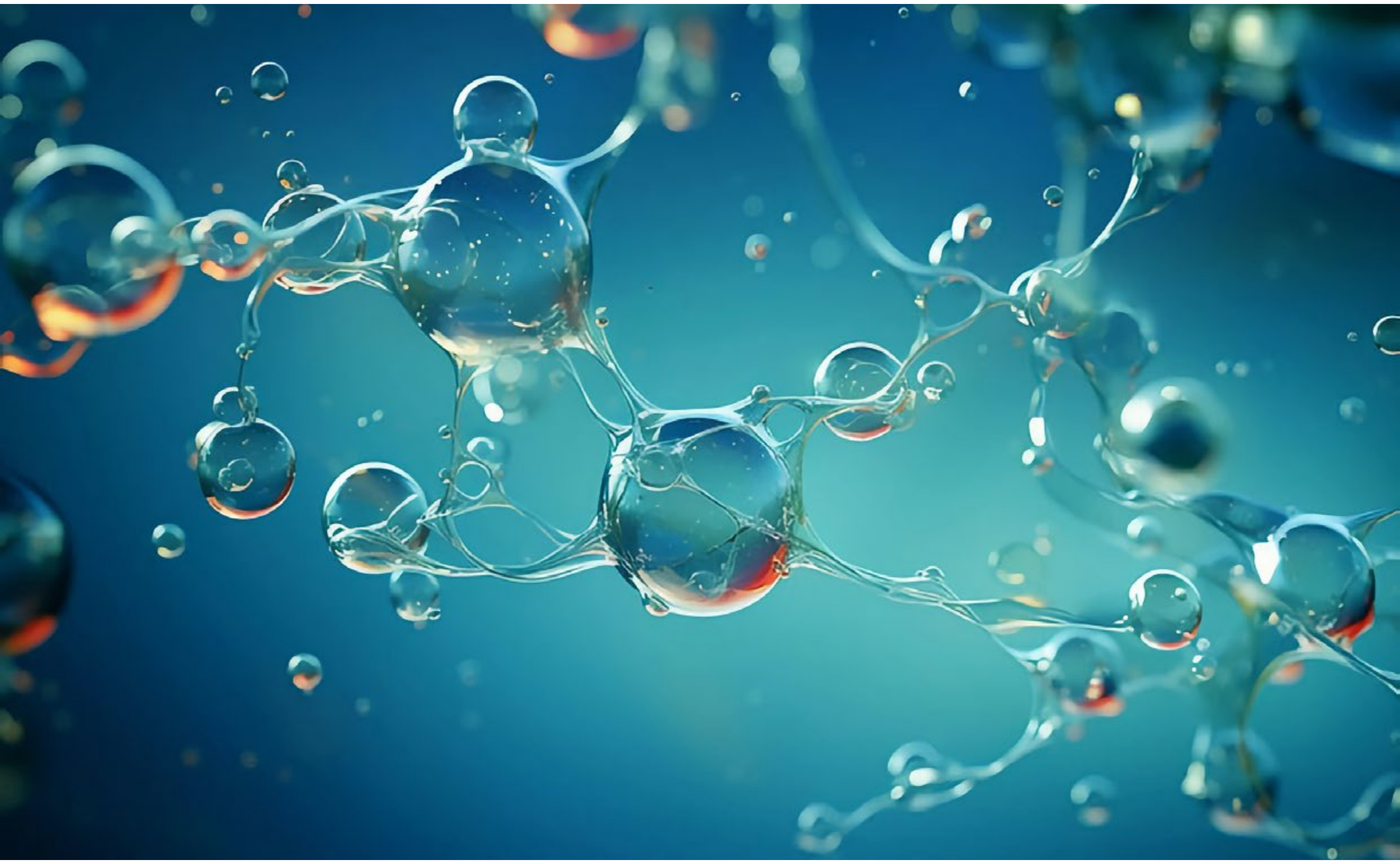

Liquefied biomethane demand and supply

Biofuels scenarios see an important role for liquefied biomethane in shipping. Therefore, it is crucial to thoroughly analyse the effects of using liquefied biomethane in the shipping industry. This report applies a similar approach to the ammonia demand and supply analysis. First, estimates the demand for liquefied biomethane on an energy basis (EJ), then compares it to the demands from other sectors and the current and expected supply.

Biomethane shares similarities with natural gas, so its use is seen to mirror natural gas usage. In the future, biomethane is expected to be used in end-use sectors where there are fewer low-carbon alternatives, such as high-temperature heating, petrochemical feedstocks, heavy-duty transport and maritime shipping. However, it can play an important role in rural development instead of natural gas and complement renewable electricity. In the transportation sector, biomethane can be used in the current CNG and LNG-powered vehicles, and it is expected to be used in long-haul road freight such as buses and heavy-duty trucks, and shipping [17].

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Liquefied biomethane demand and supply in 2030

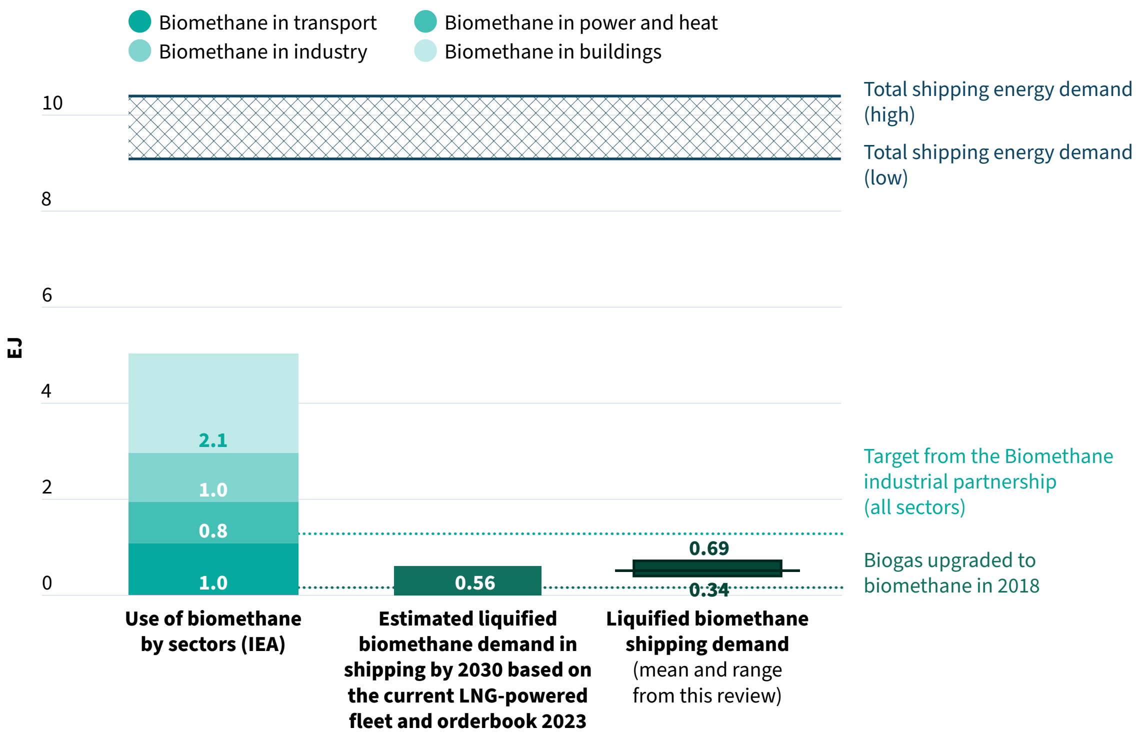
The use of liquefied biomethane can be crucial in shipping. However, meeting the expected demand requires a substantial expansion of production facilities.

In 2018, biogas that was upgraded to biomethane amounted to 0.12 EJ, and the Biomethane Industrial Partnership (BIP) has set a target to produce 1.26 EJ by 2030 for all sectors [18]. However, this falls short of the required 5 EJ that will be needed to meet the demand for all sectors, Figure 16.

If all LNG-powered vessels (current and orderbook as of 2023 excluding LNG carriers) were to use liquefied biomethane, the demand could be approximately 0.56 EJ by 2030, which is in line with the estimated average from this review of 0.53 EJ by 2030. However, this is still higher than the total supply of biomethane in 2018, which was only 0.12 EJ.

If the estimated demand for biomethane in shipping materialises, it could represent approximately 50% of the demand for biomethane in all transportation sectors, which is expected to reach 1 EJ [17]

Figure 16 Biomethane in shipping compared to other sectors' demands by 2030.



To satisfy the anticipated need for liquefied biomethane in the shipping industry, production facilities must undergo significant expansion. As other industries begin to request biomethane, stakeholders must work together to identify opportunities for collaboration and overcome any barriers in the supply chain.

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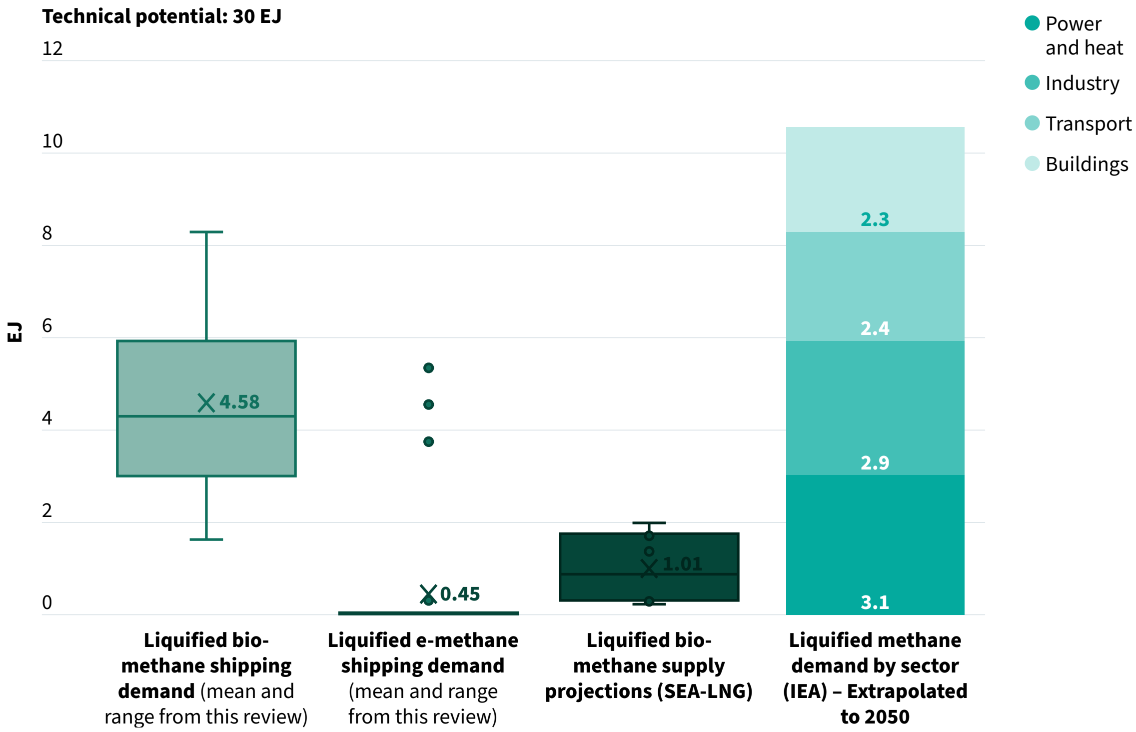
Liquefied biomethane demand and supply in 2050

In the long term, liquefied biomethane faces challenges to meet the projected shares suggested by existing scenarios.

The review of the biofuels scenarios suggests that liquefied biomethane reaches on average 4.58 EJ in 2050, Figure 17. This will make the shipping industry the main user of biomethane as 4.58 EJ is higher than any other global sectoral demands. This raises questions as the transport sector (including shipping) is expected to require 2.4 EJ by that same year (derived from [17]).

The technical potential to produce biomethane from sustainable feedstock is approx. 30 EJ [17]. However, when considering what would be practically harvestable and potentially allocated to shipping the biomethane supply could be between 0.3 and 2 EJ [19]. This suggests it is unlikely that liquefied biomethane will become a dominant fuel in shipping due to its supply limit.

Figure 17: Liquefied biomethane in shipping compared to other sectors' demands by 2050. Source: [19][16].



By 2050, shipping may become one of the largest consumers of biomethane. Meeting the increasing demands will be a challenge for the supply to respond promptly and expand accordingly because of the limit on the amount of biomethane that can practically be harvested and allocated to shipping.

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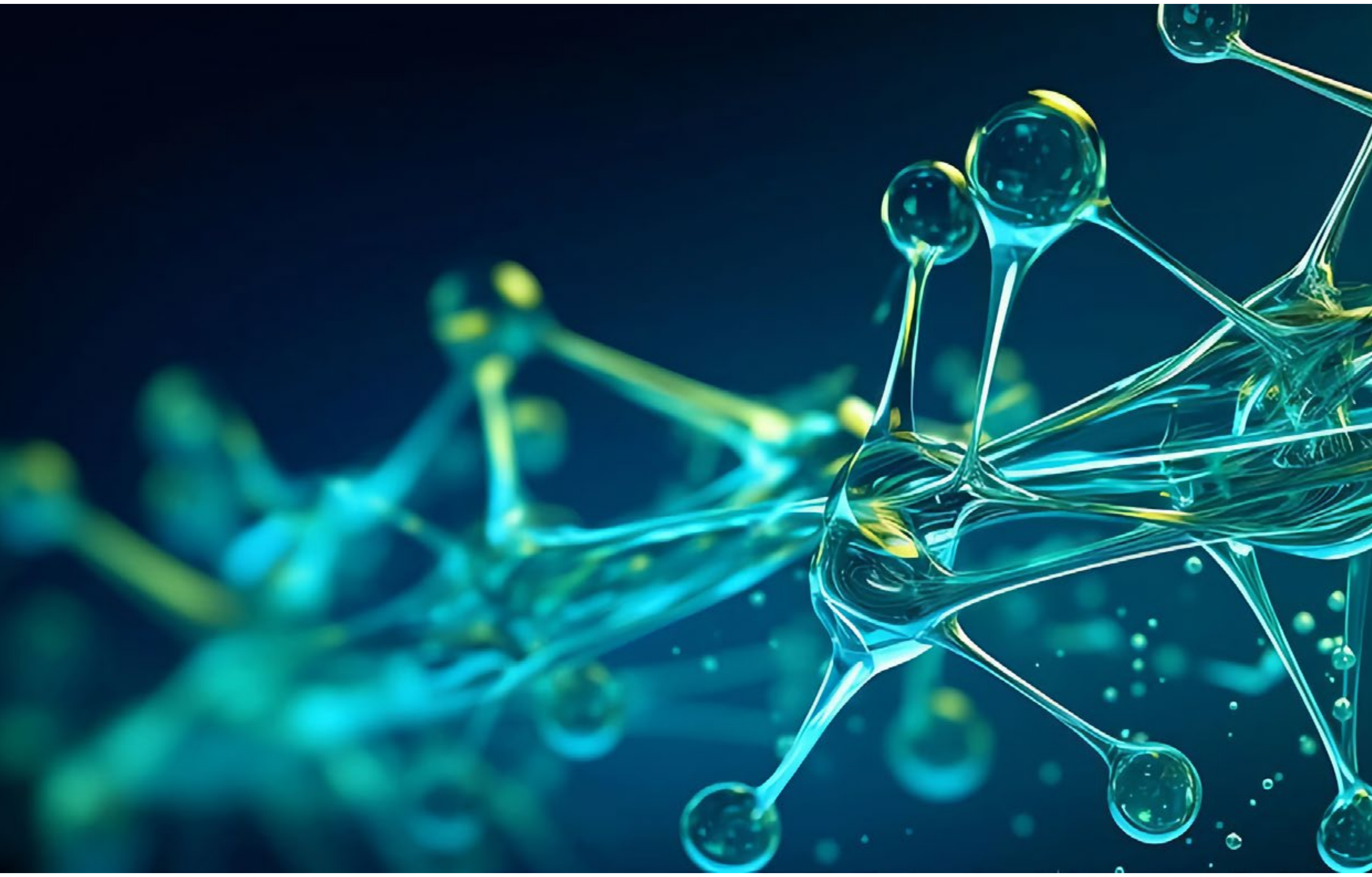

Methanol demand and supply

Often methanol is categorised in these scenarios as biomethanol and e-methanol. It is important to note that there is more confidence in biomethanol in the hydrogen-fuels scenarios rather than in the biofuels scenarios. This is because it is expected that the vessels using biomethanol will eventually switch to e-methanol.

To examine the implications of using methanol in shipping, this report applies a similar approach to the previous demand and supply analysis. First, it estimates the demand for bio and e-methanol on an energy basis (EJ), then compares it to the current and expected supply. For e-methanol, this analysis also estimates the amount of carbon needed. However, it excludes the analysis of hydrogen required to produce e-methanol as it has similar considerations as per the analysis of ammonia.

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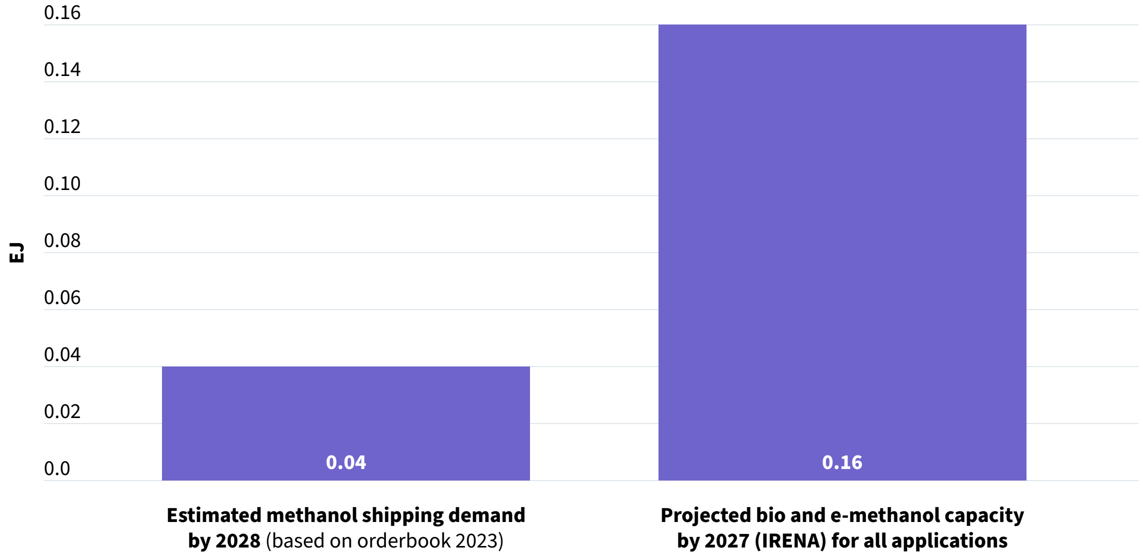
Methanol demand and supply in 2030

Several dual-fuel methanol vessels have been ordered, which will drive an increased demand for methanol in maritime. The potential demand for methanol from the dual-fuel vessels could reach up to 0.04 EJ by 2028 (based on orderbook 2023). This is approximately 25% of the total methanol projected capacity by 2027, (0.16 EJ [20] and 0.18 EJ by 2030 [7]), Figure 19, suggesting that there could be enough supply. It's important to keep in mind that the estimated capacity of both bio and e-methanol might be speculative as many projects must reach the final investment decision or could be affected by delays.

Figure 18 Estimated demand of methanol based on orderbook compared against expected supply by 2027 and 2030.



This review suggests that e-methanol used in shipping by 2030 is on average 0.07 EJ, but it also reaches more than 0.3 EJ in the most optimistic scenarios, Figure 19. The average is in line with the projected capacity of e-methanol by 2027 (0.09 EJ) [20], although this capacity is for all sectors. This suggests that if demand is higher than the estimated average, supply may fall short.

In regards to biomethanol, it reaches on average up to 0.03 EJ, but it also reaches more than 0.25 EJ in the most optimistic scenario. The average is in line with the projected capacity of biomethanol, although this capacity is for all sectors. This suggests that if demand is higher than the estimated average, supply may fall short.

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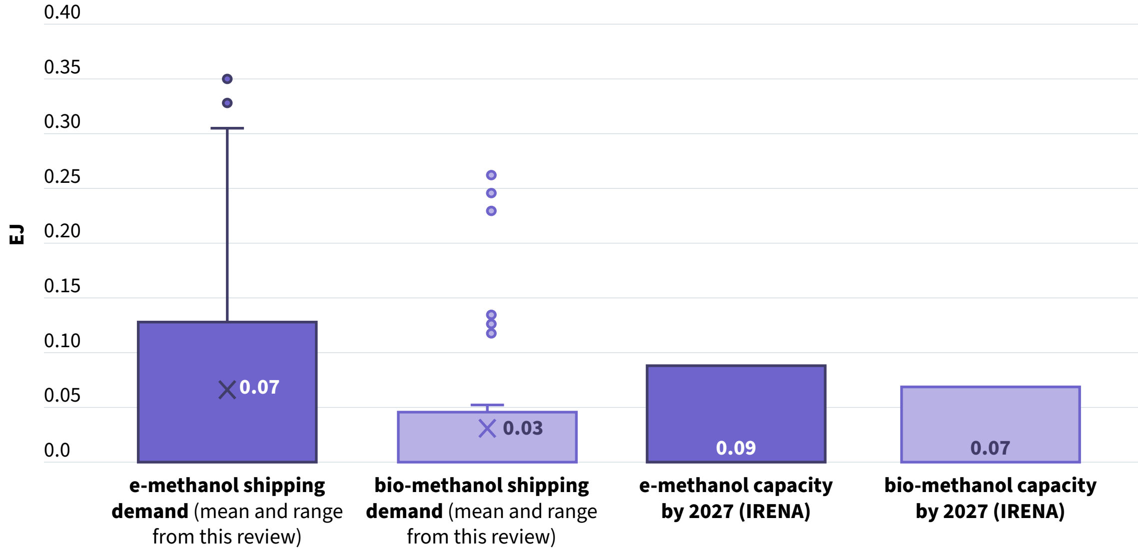
Figure 19 Methanol in shipping compared to expected supply in 2030. Methanol capacities from [20].



Bio- and e-methanol production can diversify energy sources and create synergies, especially in the short term. The current orderbook suggests that demand could be met by the expected production capacity. However, demand is also projected to increase, so projects in the pipeline must reach final investment decisions.

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Methanol demand and supply in 2050

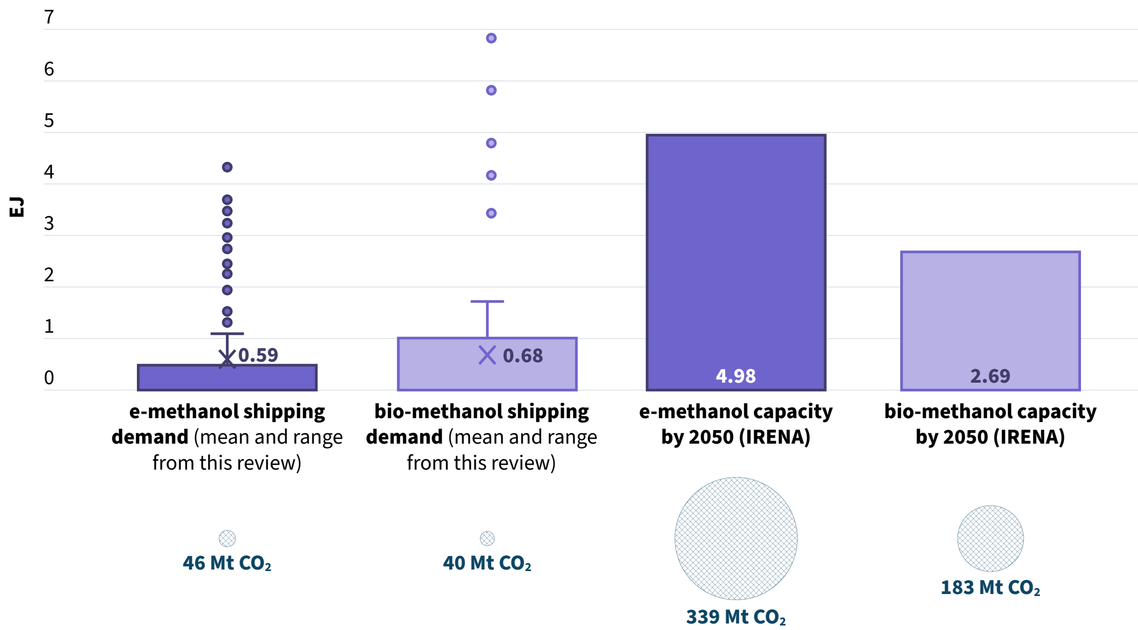
On average, the scenarios analysed in this review (both hydrogen-fuels scenarios and biofuels scenarios) project a modest amount of methanol in shipping by 2050 compared to ammonia and biomethane.

Combined bio and e-methanol captures are projected to be on average 1.8 EJ by 2050. Biomethanol emerges as more popular than e-methanol by 2050, as it is projected to be 0.7 EJ and e-methanol 0.6 EJ. The most optimistic projection for biomethanol is approximately 6.82 EJ, Figure 20.

However, this demand compared to the expected supply still accounts for approximately 25% of the total expected production. If we consider the most optimistic projection, this would be 89% of the total expected production for all sectors.

In addition to hydrogen, methanol will require a significant amount of CO2 to be sourced, up to 86Mt for an average value of 1.3 EJ. Due to the limited availability of biomass, it may be necessary to produce methanol increasingly from CO2 that is captured from the air. This process mimics nature's CO2 recycling through photosynthesis [20]. Research suggests that if the costs of DAC and BECCS technologies decrease significantly within the next 10 years, methanol could potentially replace ammonia as the preferred fuel.

Figure 20 Methanol in shipping compared to expected supply in 2050.



Long-term projections for methanol are on average lower compared to ammonia and biomethane due to concerns about the cost of sustainably sourced carbon. Similarly, for ammonia and liquefied biomethane, production facilities must undergo significant expansion in line with the expected capacity.

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Conclusions and recommendations

Findings from the review of fuel mix projections

This study explored 25 fuel mix projections, categorising them into two major categories: hydrogen-fuels scenarios and biofuels scenarios.

These scenarios highlight the potential of both biofuels and e-fuels for the maritime industry. However, each fuel faces specific challenges that need to be addressed for successful adoption. A common message can be derived from these scenarios:

- A large uptake of biofuels, including liquefied biomethane, biomethanol and various biodiesels and renewable diesel, depends on the capability to demonstrate that these fuels can reach zero or near-zero GHG emissions, and at the same time be available at scale, while maintaining competitiveness in the long-term.

- E-ammonia faces safety concerns, and e-methanol requires a reliable, sustainably sourced carbon supply.

- The majority of the studies are in consensus that direct hydrogen and batteries show promise for short-haul shipping using small to medium-sized vessels. However, further demonstration is needed to fully understand the safety implications of their uses onboard vessels and any other supply constraints.

The statistical analysis of the fuel shares from these scenarios has highlighted the following trends:

- It is not likely that the future fuel mix will be dominated by any one fuel, with 16 of the 25 scenarios projecting that no fuel would have a share over 50% in 2050.

- Among the hydrogen-fuels scenarios, e-ammonia is expected to be the most popular maritime fuel in the long term. On average, the share of e-ammonia is projected to be 35% in 2050. Most studies estimate that e-ammonia will make up between 20% and 50% of the marine fuel market, with the most optimistic outlier projections reaching over 79%.

- In the biofuels scenarios, biodiesel and liquefied biomethane are expected to be the most popular maritime fuels. On average, liquefied biomethane is projected to have a 34% share in 2050. Most studies suggest that liquefied biomethane will make up between 27% and 46% of the marine fuel market, with the most optimistic outlier projections exceeding 50%.

- The scenarios analysed in this review, both hydrogen fuels and biofuels scenarios, suggest a modest amount of methanol in shipping by 2050, with a projection on average up to 8%. However, the most optimistic scenarios foresee shares of up to 43% for biomethanol and 27% for e-methanol.

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Findings from the analysis of expected supply and demand

Drawing from the review of fuel mix projections, this study compared the expected demand for three of the most promising fuels – ammonia, biomethane and methanol – with their respective demand from other sectors and expected supply.

This comparison has highlighted the following:

- Shipping could become the main user of ammonia. Its demand is projected to increase on average from 0.79 EJ in 2030 to 6.06 EJ in 2050. The split between e-ammonia and blue ammonia is in favour of a bigger amount of e-ammonia in 2050. Demand for blue ammonia is projected to be 0.47 EJ in 2030 and 1.47 EJ in 2050, while demand for e-ammonia is projected to be 0.32 EJ in 2030 and 4.76 EJ in 2050. This expected ammonia shipping demand could be met by the expected supply. However, the shipping industry will need to drive most of the demand for clean ammonia and show leadership in securing the adequate scaling of the supply.

- Supplying ammonia means supplying hydrogen. The hydrogen required to supply ammonia for the shipping industry is projected to increase from 0.92 EJ in 2030 to 7.18 EJ in 2050. Current analysis suggests that the expected supply of hydrogen in accordance with governments' pledges falls short of the necessary levels of hydrogen to achieve net-zero carbon emissions in all sectors. The demand for hydrogen for producing ammonia for shipping could represent 3.7%-7 % of the expected total global hydrogen demand in 2030 and reach 8.3%-17.5 % by 2050. This poses pressure to scale hydrogen infrastructure to meet increasing demand from the shipping industry at the required pace. There is no supply constraint as hydrogen's technical potential is much bigger than expected demands, so the challenges are associated with the technical and economic constraints to scale at the required pace rather than a limit of the energy sources.

- Demand for liquefied biomethane is projected on average to increase from 0.5 EJ in 2030 to 4.58 EJ by 2050. This will mean the shipping industry becomes the main user of biomethane by 2050. However, the expected supply of biomethane that would go to shipping will fall short. This is estimated to range between 0.3 EJ and 2 EJ in 2050. Consequently, liquefied biomethane is unlikely to become a dominant fuel in shipping due to its supply limit, unless there is a significant shift to the shares allocated to other sectors.

- Demand for methanol is projected to increase on average from 0.15 EJ in 2030 to 1.8 EJ by 2050. The expected supply should be able to meet the expected demand. However, the demand estimates are relatively low as the scenarios analysed in this review projected a lower level of uptake for methanol compared to ammonia and biomethane. This is in contrast with the increasing trend towards ordering dual-fuel methanol vessels. If this trend continues, then the demand for methanol would be higher. A few outliers' scenarios analysed in this review given an upper bound of 6.8 EJ, meaning expected supply will also need to scale significantly further.

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In summary, the analysis of supply and demand for the most promising fuels highlights the critical importance of scaling production in each of the fuels to meet the expected demands from a range of potential end-users. The scenarios analysed in this review project a considerable shipping demand. The role of shipping in leading the global demand for these new fuels could become crucial. Therefore, it is evident that investors need to consider the role of shipping's demand to unlock the necessary scaling up of the infrastructure. However, for these demand projections to materialise, effective policies are required to deliver the IMO's GHG strategy to reach net zero by 2050.

Discussion of the findings and recommendations for actions

The IMO (through MEPC 80) has set new GHG emissions reduction goals for the shipping industry and further analysis will be required to assess how zero or near-zero GHG emissions fuels could meet these goals. There are, however, existing scenarios that already provide insight into where consensus lies and imply required actions.

Policy remains a key driver for change

This analysis illustrates that scaling fuel production is imperative in all scenarios, as no projection shows expected supply meeting projected demands irrespective of the chosen fuel. However, the expected fuel demands are projections. Their real-world uptake in the future will still depend on the deployment of effective policies. Policymakers need to design effective policies that will enable clear commitments. This in turn will define the potential aggregated demands and unlock production scaling.

In addition, as fuel production scales up, it will have to meet certain sustainability criteria in line with ongoing work on LCA guidance and be consistent with similar initiatives in other sectors. Therefore, effective policies must also be designed in a way that ensures consistency across multiple sectors demanding the same fuels (e.g. alignment of fuel specifications and sustainability criteria).

The role of the shipping industry in the global energy transition can be crucial

The shipping industry can take an active role in developing the required fuel infrastructure to ensure a successful energy transition. The shipping industry is at a crossroads in determining the role it can play in the wider decarbonisation. A potential disconnection between supply and demand is evident, and shipping's demand for clean energy sources holds considerable significance.

The role of shipping in the energy transition will hinge on its relative position concerning the two main energy sources: hydrogen-based fuels and biofuels. Scenarios with a more balanced mix of fuel options may require the identification of synergies within and outside the shipping industry. Balanced scenarios may be better positioned to scale effectively as they rely on different energy sources. In contrast, polarised scenarios (either a larger share of hydrogen-based fuels or biofuels) may require stronger leadership from the shipping industry in leading the development and securing the supply to scale and meet decarbonisation goals by 2050.

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The shipping industry has the potential to lead the way in clean hydrogen infrastructure investment as hydrogen is a key input for the production of clean ammonia and e-methanol. Scaling up the hydrogen supply will enable the industry to meet the growing demand for clean ammonia and e-methanol and significantly contribute to expanding hydrogen infrastructure. It's an opportunity for stakeholders to identify synergies with other hard-to-abate sectors such as cement and steel, and overcome potential supply barriers, ultimately facilitating the necessary infrastructure scaling.

Shipping also has the opportunity to explore and expand the use of liquefied biomethane, given the growing LNG-powered fleet. However, to tap into this potential, production facilities must undergo significant expansion. As other industries begin to request biomethane, stakeholders must work together to identify opportunities for collaboration and overcome any barriers, especially on GHG emissions and potential supply limits. There is a certain consensus that no combination of biofuels will be able to meet the growing shipping demand. Therefore their biofuel deployment will need to be aligned with the deployment of other fuels to ensure that the remaining demand for zero or near-zero GHG emissions fuels in shipping is met.

In any case, the shipping industry's dual role as both a transporter and user of clean energy sources offers a unique opportunity to generate a positive synergy. It is evident that shipping can play a significant role as a user of new clean fuels. Therefore, by utilising and transporting new fuels, the industry can accelerate its learning curve and play a crucial role in developing the required infrastructure.

In summary, investors need to consider the potential role of the shipping industry in offering economies of scale for the demand for clean energy, unlocking broader investment cases at the company, national and regional levels.

Competition and cooperation in the race to sustainable shipping

The shipping industry may face potential competition for fuels from other sectors, as well as opportunities to collaborate to ensure access to the most promising fuels. These contrasting effects depend on the relative willingness to pay the premium across potential multiple end-users. In the short term, when willingness is low, there will be more opportunities for cooperation to aggregate demand and bring down prices. As fuel infrastructures are large investments, much of these fuels will be pre-sold before the Final Investment Decision (FID), which also needs to be factored into short-term strategies. In the mid-term, as demand consolidates, there will likely be more competition as more end-users demand these fuels and are willing to pay a premium. In the long-term, up to 2050, competition will be dictated by the global supply and demand market with the supply likely catching up and meeting increasing demand.

Therefore, fuel procurement practices and strategies must fundamentally change. In the short term, both buyers and sellers need to explore additional strategies, including risk sharing, the involvement of key interested stakeholders and potentially increased strategic partnerships. First movers' initiatives, such as green shipping corridors, could be the ideal environment where this can be explored further, improving understanding of fuel supply dynamics at the regional and global scale.

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Further areas of exploration

The scenarios analysed in this study were created before MEPC 80. Going forward, new projections must demonstrate how the projected fuel mix aligns with IMO checkpoints and new targets. By doing so, stakeholders must assess and demonstrate the potential of each fuel in reducing its carbon intensity at appropriate levels and ensure that total GHG emissions align with the IMO strategy.

Integration of fuel supply dynamics

As shipping prepares itself to switch fuel, it becomes crucial to better understand its current and future interactions with the global energy system. To effectively assess and demonstrate fuel potential, new evaluations must integrate fuel supply dynamics while considering potential limitations and barriers. This will lead to credible projections and better resource allocation. A comprehensive assessment requires integrating fuel supply dynamics across national, regional and global scales.

This assessment of a diverse set of projections has led to the identification of several key factors that should be taken into account when fuel supply is represented in models. For example:

- Ammonia supply must account for realistic time and costs to deploy systems that overcome safety challenges across the entire supply chain and use on board, as well as impact on time and cost of public acceptance of the solution as an established fuel transported and accessible worldwide.

- Methanol supply must ensure a carbon-negative supply to balance the onboard emissions to be considered sustainable. The associated costs and scalability barriers to meet the expected demand will also need to be assessed (e.g. Direct air capture to be used to offset the use of fossils rather than produce synthetic hydrocarbons). Methanol offers diversification advantages and integration across diverse clean energy sources, as moving from biomethanol to e-methanol could be a promising pathway. Therefore, understanding biomethanol's broader role in the short and long term becomes crucial.

- Biomethane supply must account for biomethane's supply limit and the ability to achieve zero or near-zero GHG emissions while remaining competitive in the long term The implications of shipping demand exceeding expected allocated supply needs to be assessed. In assessing the potential availability of biomethane for shipping, the cost-effectiveness of its use in other sectors in remote regions should also be considered.

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Further assessments and multi-sectors' perspective

This analysis has identified the need for further assessment that takes into account a multi-sector perspective. For example:

- Better understanding of the relationship between carbon intensities of the fuels and associated costs considering several production methods (e.g. different carbon capture rates or whether fuel is produced from 100% renewable or the grid)
- Understanding the potential impact of new policies that try to establish a certain demand for zero or near-zero GHG fuels in line with the new IMO GHG strategy goals. The sustainability of the supply must also be accounted for because current fuel mix projections rarely consider this. This should be done in a way that accounts for multi-sector alignment.
- There is a need to assess aggregated demand across all industry sectors at the global and regional level to better understand short-term and long-term willingness to pay across sectors.
- Understanding the potential synergies and role of the shipping industry as a transporter and user of such fuels is also important.
- Analyse the suitability of different fuels and energy systems based on ship types, trades and geographies.

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