Scaling Up Hydrogen: The Case for Low-Carbon Methanol

A BNEF and Climate Technology Coalition White Paper

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Section 1. Background to this White Paper

This paper was commissioned as part of BloombergNEF's work as research partner for the *Bloomberg New Economy Climate Technology Coalition*. The Coalition was formed in 2022 by a global group of stakeholders that are well placed to provide insights on approaches to industrial decarbonization. It has set an agenda to identify and support the rapid scale-up of the next generation of climate-critical green technologies that will be instrumental in achieving the world's goals to avoid climate catastrophe. The planet simply cannot wait for polluting industries to slowly shift strategy and technologies.

This initiative seeks to inspire and lead by example. It will take getting into specifics to make any tangible progress and, to that end, the Coalition – composed of technology specialists, researchers, financiers, industrialists and public sector experts – is initially focused on tackling roadblocks to scaling up the clean hydrogen ecosystem, and further on decarbonizing 'hard-to-abate' sectors (where cleaner alternatives are currently lacking or prohibitively expensive) through initiatives on low-carbon ammonia, methanol and steel.

Coalition members have given insight into their own projects and efforts in these areas, some of which can be found in this BNEF-produced report. The Coalition finds it encouraging that BNEF's thorough analysis shows potential for decreasing green hydrogen costs, identifying pockets of demand, and increasing clean hydrogen and methanol production capacity.

As is noted on occasion in this report, existing methanol prices do not include their social costs. This research paper considers alternatives where the social costs are either included in full or de minimis in the alternative offerings ("green products"). For completeness, the Coalition is sharing this research paper without taking a view, nor making any recommendations, on the pricing of existing or contemplated methane products.

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Section 2. The case for low-carbon methanol

225

Number of methanol dual-fuel ships ordered as of the end of 2023, identified by BNEF

16%

Planned low-carbon methanol capacity as a percentage of total gray methanol production in 2023, as of January 2024

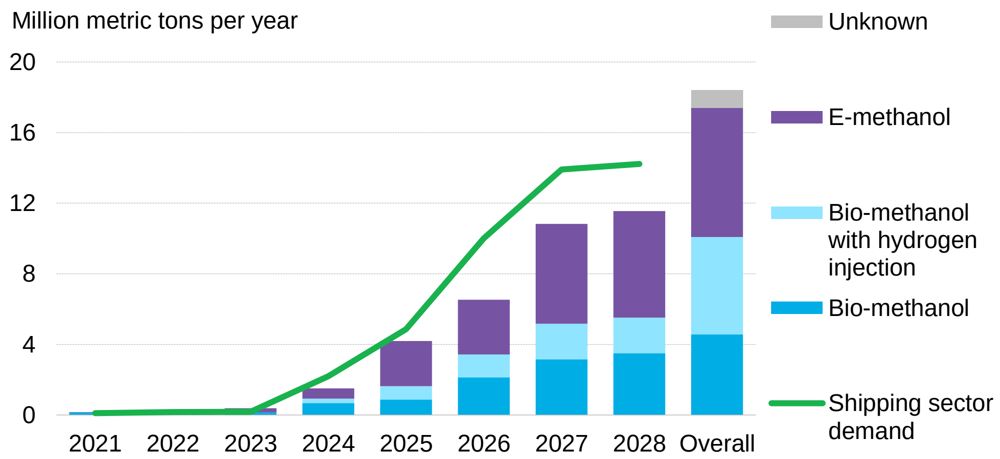
$610-748 per metric ton

BNEF's estimate of the cost of green hydrogen-based bio-methanol today

Low-carbon methanol could become the most important source of demand for clean hydrogen in the near term. Not only is it a large chemical market that needs decarbonizing, but low-carbon methanol is also the most readily available option for the shipping sector to reduce its emissions. Regulations in the European Union and the net-zero goal of the International Maritime Organization are pushing the shipping sector to procure green fuels. BNEF estimates the planned capacity of low-carbon methanol projects globally could consume 1.65 million metric tons of clean hydrogen annually. This BNEF and Climate Technology Coalition whitepaper provides an overview of hydrogen's role in methanol production, and outlines potential commercial and policy considerations that, if implemented, could bring forward the timeline for cost-competitive clean methanol.

- **Production of 'gray' methanol, which is derived from natural gas or coal, is relatively centralized, with almost 70% of supply coming from China.** The end uses are extremely diverse, but almost half of production is driven by methanol-to-olefin demand in China, and the need for formaldehyde, mostly from the construction and automotive sectors. Some 80% of methanol is traded via contracts and at a premium compared to the spot market.
- **Today, methanol is made from fossil fuels and its production is responsible for 0.7% of global CO_2 emissions.** The sector could be decarbonized in three ways – either by using biomass feedstock (bio-methanol), by combining low-carbon hydrogen and capturing the CO_2 (e-methanol), or a combination of the two (bio-methanol with hydrogen injection).

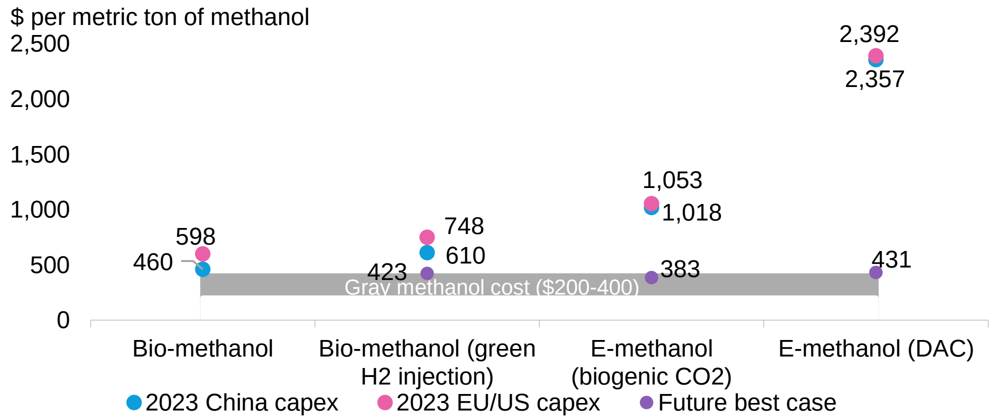
Figure 1: Cumulative supply of low-carbon methanol based on project pipeline, and estimated demand from the shipping sector



Source: BloombergNEF. Note: Project pipeline is as of January 5, 2024. Methanol demand from the shipping sector assumes all ordered methanol dual-fueled vessels uses low-carbon methanol.

- **Hydrogen can play an important role in both bio-methanol and e-methanol production.** Injecting hydrogen into biomass syngas could double the methanol yield while reducing biomass use. This could offer the most scalable pathway for clean methanol production, with relatively low costs. E-methanol is still expensive today, with low-carbon hydrogen being one of the biggest cost drivers. Reducing hydrogen costs will be important in scaling future e-methanol supply, alongside increasing CO_2 feedstock availability.
- **Clean methanol supply is expected to grow to 11 million tons** per year by 2028 (Figure 1). The total announced pipeline of 19 million tons could potentially consume 1.65 million tons of green hydrogen. Almost 60% of the capacity is planned in China and most of these projects intend to produce bio-methanol using agricultural residues with green hydrogen injection, which could become the cheapest source of clean methanol globally. For projects outside China, two-thirds of the capacity plans to produce e-methanol, with biogenic CO_2 (from the combustion of biomass) being the most popular type of CO_2 feedstock.
- **Clean methanol demand in the shipping sector could potentially outstrip supply, based on the current project pipeline**. Shipping companies have ordered 225 methanol dual-fuel ships as of March 2024, which would theoretically use over 14 million tons of low-carbon methanol by 2028. The main driver of these purchases is the EU's carbon market, which puts a price on ships' CO_2 emissions, and the FuelEU Maritime regulation, which mandates low-carbon fuel use. However, the EU regulations only cover 18% of global shipping fuel demand.
- **The chemicals sector has been slow to switch to low-carbon methanol**. The EU's Renewable Energy Directive (RED III) would only result in 200,000 tons of green hydrogen used for existing methanol plants by 2035, while China's environmental regulations, which have driven some coal chemical producers to blend green hydrogen, are quite discretionary.
- **Low-carbon methanol production costs today can be as little 1.2 times, or as much as 12 times, more than fossil-fuel-based methanol,** depending on the feedstock. In the future, with technology improvements and economies of scale, low-carbon methanol could reach cost parity with gray methanol (Figure 2).

Figure 2: Estimated cost of bio-methanol and e-methanol



Source: BloombergNEF. Note: 2023 costs assume $100 per metric ton for biomass, $4 per kilogram for green H_2, $125/ton for biogenic CO_2 and $1,100/ton for direct air capture (DAC). 'Future best case' assumes costs of $100/ton biomass, $1/kg for H_2, $75/ton for biogenic CO_2 and $110/ton for DAC. Assumes Western capital expenditure is 2.2 times more expensive than in China. Bio-methanol costs are for biomass gasification pathway.

- To encourage early volumes of low-carbon methanol and scale commercial demand, the Climate Technology Coalition **has identified the following potential commercial actions and policy interventions.** These focus on making low-carbon methanol more affordable for shipping companies, while kickstarting some early demand in the chemicals sector:
  - **Engage with fuel suppliers upstream and cargo owners downstream to work out potential viable economics.** To avoid shipping companies bearing the full cost of adopting green fuels, they could engage actively with upstream suppliers to scale the supply chain and drive down costs. Maersk and COSCO represent two different approaches to this. Meanwhile, shipping companies could also identify cargo owners that understand the value of, and want to procure, zero-emissions shipping services.
  - **Target some early offtakers in downstream chemical sectors.** Commercial customers in the chemicals sector most likely to adopt low-carbon methanol will have a target for their Scope 3 emissions (those from their value chain), control or have strong influence over their supply chain, and most importantly consider methanol as a significant part of their product's carbon footprint. We identified three types of customers that have shown signs of being early offtakers: medical companies, furniture product makers and renewable equipment manufacturers.
  - **Keep feedstock sources flexible to optimize for local supply chains and costs**. To get a scalable and cheap supply of feedstock, methanol producers need to be flexible with their sources of biomass and CO_2 to optimize for local supply chains and economics. Projects in China often opt for agricultural waste, while projects in the Nordics have used biogenic CO_2 captured from biomass power plants due to favorable economics. Low-carbon methanol producers could also keep their output flexible, perhaps choosing to convert methanol to other derivatives such as jet fuel, where demand dictates.
- The **policy actions** focus on matching supply and demand side policies. Specifically:
  - **Customize demand-side regulations by sector**. Demand-side regulations are necessary to scale low-carbon methanol demand and could take various forms for different sectors. Consumption mandates are the most effective option for the chemicals sector, while setting targets for the carbon intensity of fuel is the recommended regulation for the shipping sector, which has yet to settle on the fuel mix for a net-zero future.
  - **Ramp up incentives and support for producers.** Demand-side regulations should be coupled with corresponding supply-side incentives, otherwise companies might decide to pay the penalty rather than switch to clean fuels. Supply-side incentives should focus on the hydrogen feedstock, which is one of the biggest cost drivers for e-methanol today. Policymakers could consider a combination of supply-side incentives, including not only direct subsidies for feedstocks but also loan guarantees and infrastructure grants. The US incentives for sustainable aviation fuel are a good example.
  - **Establish a clear standard for carbon utilization in green molecules**. Policymakers need to develop a comprehensive carbon management strategy, as well as address the type of carbon sources that qualify as 'green' and the surrounding carbon intensity accounting rules. This would give both methanol producers and buyers more clarity so that they can start locking in long-term supply today. The EU has proposed its first ever Industrial Carbon Management Strategy, but there is still some regulatory ambiguity and uncertainty left to be addressed.
- *(The color coding of Table 1 on page 18 was corrected on June 20, 2024.)*

Section 3. Overview of the methanol sector

Methanol – chemically CH_3OH – is one of four critical basic chemicals alongside ethylene, propylene and ammonia. Global methanol production capacity stood at 183 million tons in 2023, while actual production was 110 million tons, according to data from the Methanol Institute. Almost all methanol is currently made from natural gas or coal, which is used to produce gray hydrogen and fossil-fuel-based carbon as the feedstock for methanol. The methanol sector uses around 14 million tons of gray hydrogen per year.

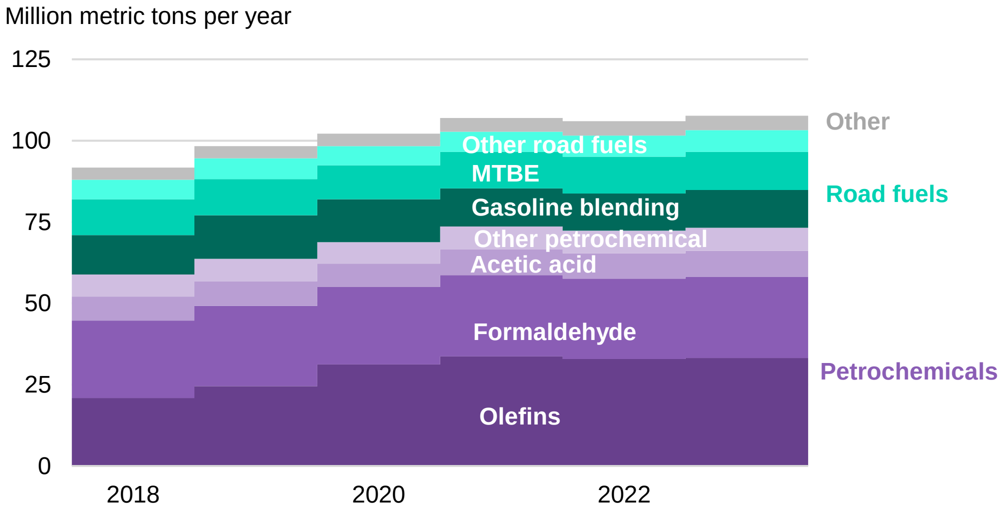
3.1. Which sectors consume methanol?

Close to 70% of methanol is used in the petrochemicals sector

Close to 70% of methanol is used in the petrochemicals sector and most of the remaining volume for road transport (Figure 3). Four specific products make up the bulk of methanol demand, used in a wide range of industries – from construction, to household products, to transportation:

- **Olefins:** These are hydrocarbon molecules that contain at least one double bond between carbon atoms. The most-used olefins are ethylene, propylene and butadiene, which are mainly used to create polymers that form plastics, textiles and other synthetic materials. While they are typically produced via steam crackers or as a byproduct of the oil refining process, the methanol-to-olefin pathway offers another route that has been commercialized over the past decade, although exclusively in China.[1]

Figure 3: Methanol demand, by sector



Source: BloombergNEF, Methanol Institute. Note: MTBE refers to methyl tert-butyl ether.

Four specific products make up the bulk of methanol demand

- **Formaldehyde**: This is a derivative of methanol used to produce plywood, textiles, coatings, household products and other items. Formaldehyde is particularly important for the automotive and construction industries.

[1] See BNEF's *Understanding Petrochemicals, Plastics and Oil Demand* (web | terminal) for more.

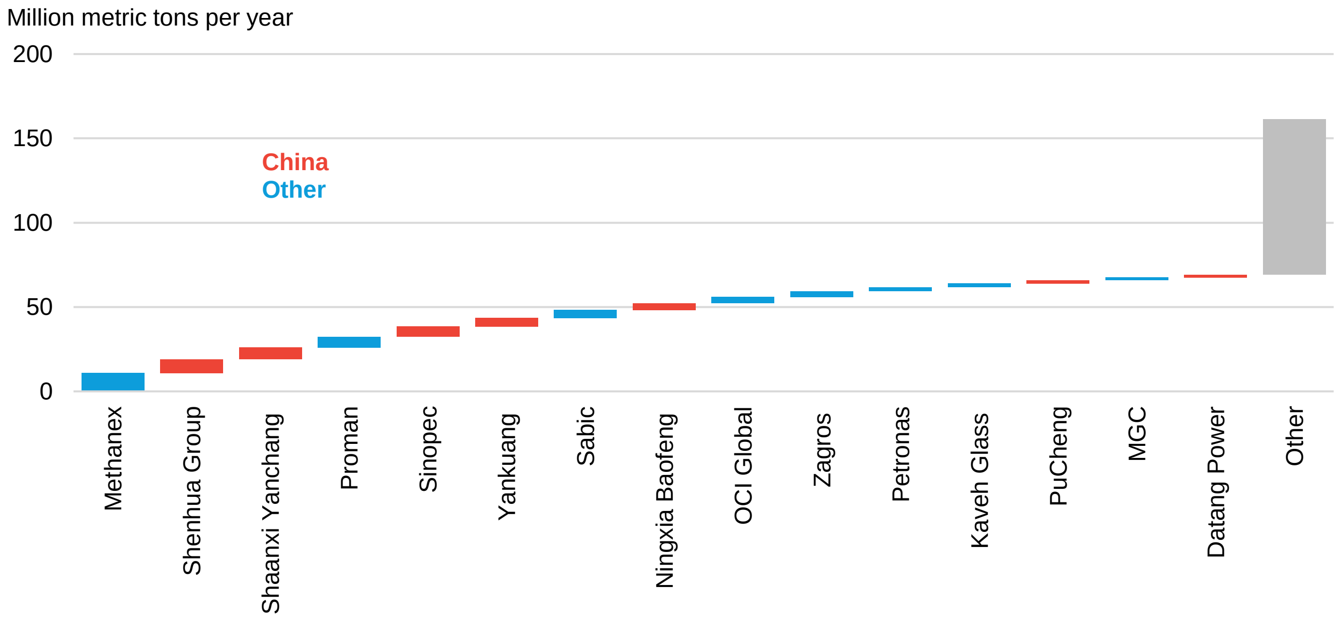
- **Acetic acid:** Most acetic acid is used to produce paints, adhesives, coatings and textiles, and as a solvent for polyethylene terephthalate (PET), which is a key intermediate for polyester and synthetic fibers. Other uses include as a food additive and preservative.
- **Methyl tert-butyl ether (MTBE)**: MTBE is an important additive for motor gasoline, helping the fuel burn more completely and, in turn, reducing its tailpipe emissions. The US has largely moved away from using MTBE as a fuel additive and replaced it with ethanol since 2005 due to health concerns. The rapidly rising share of electric vehicles in developed economies further limits the future market potential of MTBE.

3.2. Which companies are the major players?

The five largest producers account for a quarter of methanol capacity

The methanol sector is relatively centralized. We have identified more than 300 different players in the market, but the five largest producers together account for roughly 24% of all production capacity (Figure 4). For comparison, in the ammonia and steel sectors, the top five and top 10 companies hold a 14% and 18% share of global output, respectively.[2]

Figure 4: Methanol nameplate capacity, by company



Source: BloombergNEF, Nexant, company reports, various public sources. Note: MGC refers to Mitsubishi Gas Chemical. The OCI Global number is equity capacity.

About half of the largest methanol companies are Chinese and operate exclusively in China. The largest producers outside of China are Methanex, Proman and Saudi Basic Industries Corporation (Sabic). Methanex and Proman are the biggest companies operating globally, having about 9 million tons and 7 million tons per year of capacity, respectively. Sabic is the largest methanol-producing company in the Middle East with about 5 million tons per year of capacity, all in Saudi Arabia.

[2] See BNEF's *Ammonia Market Primer* (web | terminal) *and Decarbonizing Steel: Corporate Strategies* (web | terminal) for more.

Most other big methanol firms are specialized chemicals producers, such as Mitsubishi Chemical Group, Zagros Petrochemical Company, or OCI Global. There are only a few oil majors among the world's largest methanol producers, such as Petronas, Eni, Sinopec and PetroChina.

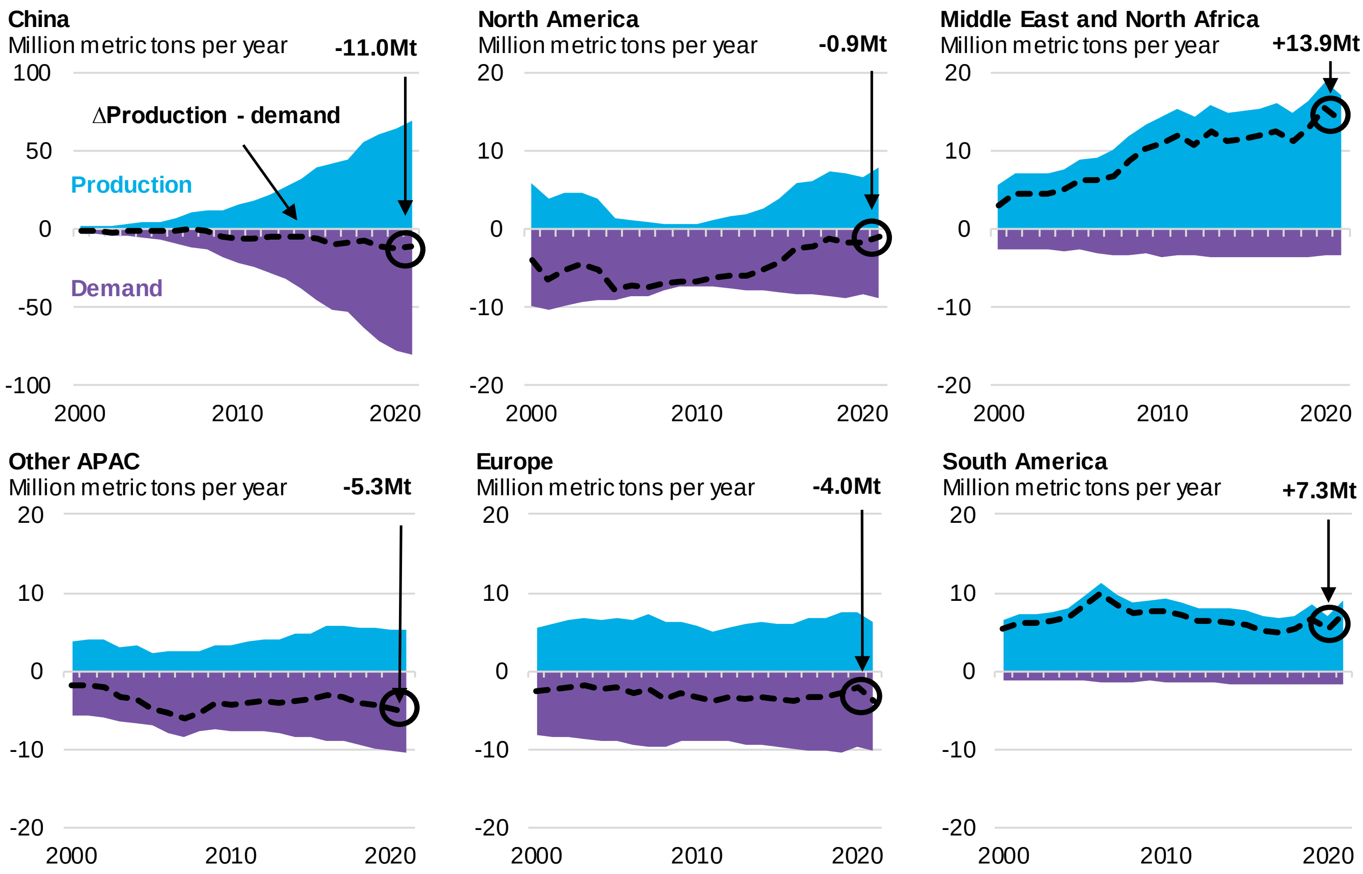
3.3. Methanol global trade

The total net trade flow of methanol was 21 million tons, as of 2021, or about 20% of global production. Total trade is slightly higher, at roughly a third of all production, given some countries might import and export again, according to the Methanol Institute. This compares to only 10% of ammonia being traded globally, although significant volumes are also traded as urea – an ammonia derivate.

Methanol trade is heavily centered around China

Methanol trade is heavily centered around China, which is by far the largest producer and consumer of methanol globally, making 69.7 million tons per year, and consuming 80.7 million tons per year, as of 2021 (Figure 5). The demand gap is mostly filled by imports from the Middle East.

Figure 5: Methanol production and demand, by region



Source: BloombergNEF, Nexant.

The Middle East and Latin America are the major exporters of methanol, together comprising 21% (or 26.3 million tons per year) of global supply in 2021 but only consuming 4%. Within those regions, Saudi Arabia, Iran and Trinidad and Tobago are by far the largest producers. Iran, in particular, aims to further increase its methanol production, bolstered by its cheap and abundant gas reserves and the difficulties it faces in selling its oil abroad amid sanctions.

North America, Europe and other parts of Asia are net importers, only contributing to 15% of global methanol supply, but consuming 23% as of 2021. However, North America has been closing the gap between its domestic supply and demand over the past decade due to the surge in cheap domestic shale gas. By contrast, higher gas prices put a slight dent in Europe's methanol supply – a trend that could continue in the years ahead, amplified by a ramp-up of carbon prices under the EU Emissions Trading System.[3]

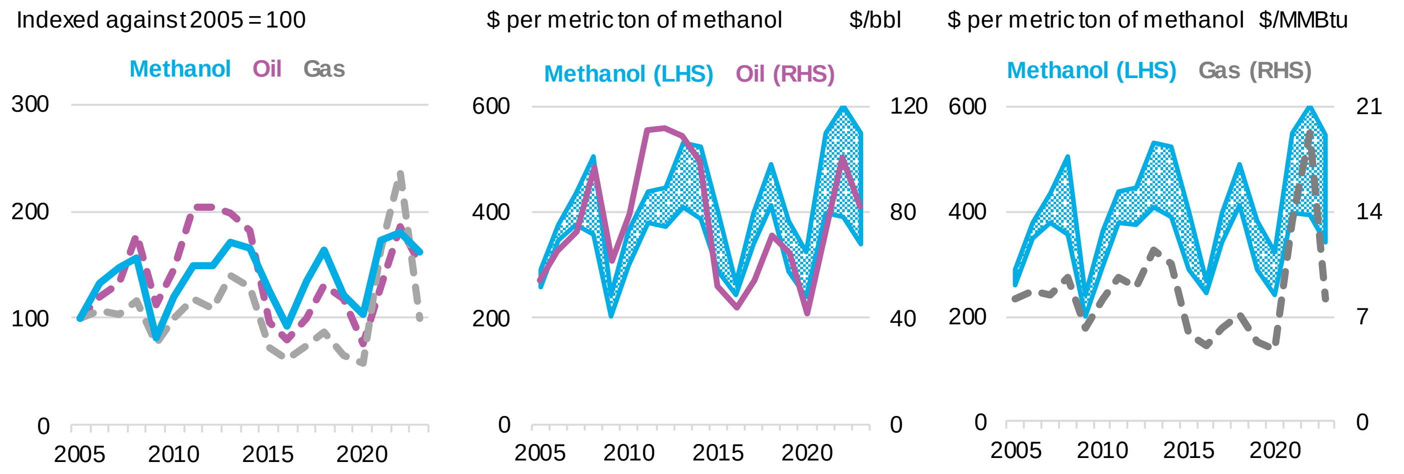
3.4. Methanol markets and pricing

Most methanol – around 80% – is traded via contracts, while the remainder is sold on the spot market. Many contracts are agreed on a monthly basis. However, industry players have reported that contracts can last longer, from one to three years. Either way, the methanol market seems to operate mostly on relatively short-term contracts.

Most methanol is traded via contracts, which are priced at a premium to spot prices

While contract prices are typically about 15-25% higher than spot prices, locking in the price can help to hedge against energy cost volatility. Energy costs comprise around 80% of the total costs of methanol production. Accordingly, methanol prices move in tandem with oil and gas prices (Figure 6). Many companies, such as Methanex and Proman, have contracts for their feedstock supply that hedge against spikes, via a fixed price or a gas pricing mechanism coupled to the methanol price. This mitigates peaks in methanol prices following surging fossil-fuel prices.

Figure 6: Methanol, gas and oil prices



Source: BloombergNEF, Nexant. Note: Takes Dated Brent for the oil price and the average of spot prices from Europe, the US and Asia for methanol. Takes an average of Title Transfer Facility (Europe), Japan-Korea Marker (Asia) and Henry Hub (US) for the gas price. MMBtu is million British thermal units. LHS = left-hand side, RHS = right-hand side.

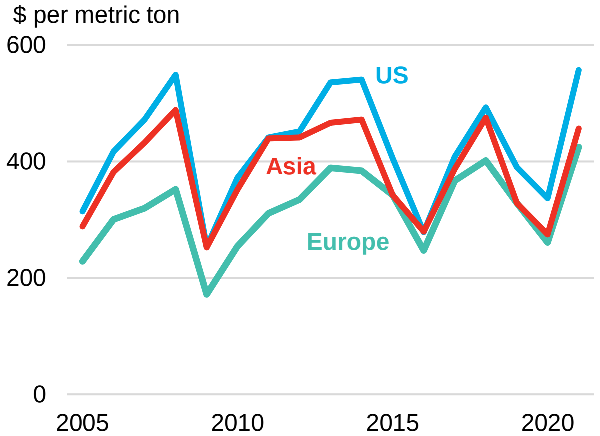
Methanol prices differ by region. Asian methanol prices are typically lower than those in Europe and the US (Figure 7). Asian facilities have among the highest production costs – including the coal-based production in China. This means that amid periods of high feedstock prices or low

[3] See BNEF's *EU ETS Market Outlook 1H 2024: Prices Valley Before Rally* (web | terminal) for more.

profitability, those facilities are also the first to be pushed out of the market, leading to lower utilization rates in Asia (Figure 8).

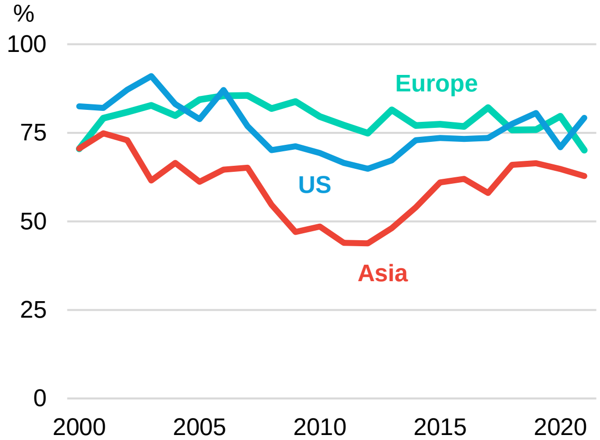
With the US and Middle East ramping up low-cost methanol production – enabled by their access to cheap gas – some of the higher-cost Asian and European producers run the risk of being pushed out of the market.[4]

Figure 7: Methanol contract prices by region



Source: BloombergNEF, Nexant.

Figure 8: Methanol plant utilization rate



Source: BloombergNEF, Nexant.

4 See BNEF's *Methanol Markets Primer* (web | terminal) for more.

Section 4. Hydrogen's role in methanol decarbonization

Hydrogen can play an important role in making low-carbon methanol – both bio-methanol and e-methanol. Injecting hydrogen into biomass syngas could increase the methanol yield while reducing biomass use, making it easier to scale bio-methanol production. E-methanol is still expensive today, and low-carbon hydrogen is one of the biggest cost drivers. Reducing clean hydrogen costs will be important in scaling future e-methanol supply, alongside available carbon sources.

4.1. Why do we need low-carbon methanol?

Methanol production accounts for 28% of primary chemical production emissions

Conventional methanol production is heavily reliant on fossil fuels. Methanol production accounted for 261 million tons of CO_2 in 2022, according to the International Energy Agency, equivalent to around 28% of primary chemical production emissions.[5] Producing methanol from coal is estimated to emit 160 grams of CO_2 per megajoule, four times the 40g of CO_2 per MJ emitted when using natural gas. However, if methanol is used as a fuel, it would emit another 69 grams of CO_2 when burned. This means using gray methanol as a fuel emits 110-230g of CO_2 per MJ on a lifecycle basis.

Bio-methanol and e-methanol can eliminate methanol's production phase emissions. For the lifecycle emissions of methanol as a fuel, the source of carbon determines if the methanol is considered low-carbon or net-zero (Figure 9). Bio-methanol as a fuel often has a carbon intensity of 5-30g of CO_2 per MJ, according to the International Renewable Energy Agency. E-methanol fuel produced from biogenic or direct air captured carbon could almost entirely eliminate the fuel's carbon footprint. However, if the carbon comes from point-source CO_2 captured from an industrial process, the methanol fuel might at best be considered low-carbon, as the CO_2 emissions are only delayed rather than eliminated.

There is no international consensus on what is considered 'low-carbon methanol', although some national and corporate-led standards are emerging. The EU defines renewable fuels of non-biological origin (RFNBO) as fuels that have at least 70% lower emissions than fossil fuels, as per the Renewable Energy Derivative (RED). As fuel oil has a lifecycle carbon intensity of around 94g of CO_2 per MJ, the carbon intensity of RFNBO would be around 28g of CO_2 per MJ (Figure 9). This means some bio-methanol with higher carbon intensity might not be considered a RNFBO. RED has a more lenient carbon intensity criteria for biofuel, with a greenhouse gas emissions saving threshold of 50% to 65%, depending on the project's commissioning date.

Defining low-carbon methanol for this report

In this white paper, the terms 'low-carbon methanol' or 'clean methanol' are used for:

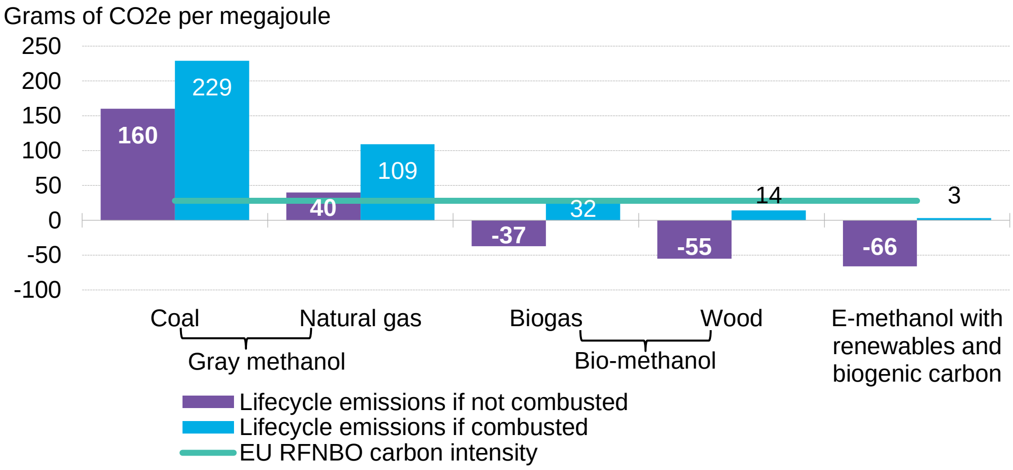
- Bio-methanol produced using biomass, municipal solid waste and biogas.
- Bio-methanol, as above, but also with hydrogen injection where the hydrogen is low-carbon.

[5] Primary chemical is a collective term for methanol, ammonia, ethylene, propylene, benzene, toluene and mixed xylenes.

- E-methanol, where the methanol is made with low-carbon hydrogen and captured CO_2 – either biogenic CO_2, industrial point source CO_2, or CO_2 captured from the atmosphere.

It is technically possible to use 'blue' hydrogen as the feedstock for both bio- and e-methanol, and the resulting methanol would still be called low-carbon as per the EU regulations. Blue hydrogen is produced by reforming natural gas and capturing the carbon emissions. However, this report does not focus on blue methanol as most low-carbon methanol projects use 'green' hydrogen today, produced by splitting water using electrolysis.

Figure 9: Lifecycle emissions of methanol as a chemical and fuel, by feedstock



Source: BloombergNEF, International Renewable Energy Agency, International Energy Agency. Note: The above estimates are only for reference and actual carbon intensity might differ depending on how the biomass is sourced and transported.

4.2. The role of hydrogen in clean methanol production

Hydrogen will play a crucial role in methanol decarbonization. There are two categories of low-carbon methanol: e-methanol and bio-methanol (Figure 10).

By virtue of its composition, hydrogen will play a crucial role in methanol decarbonization

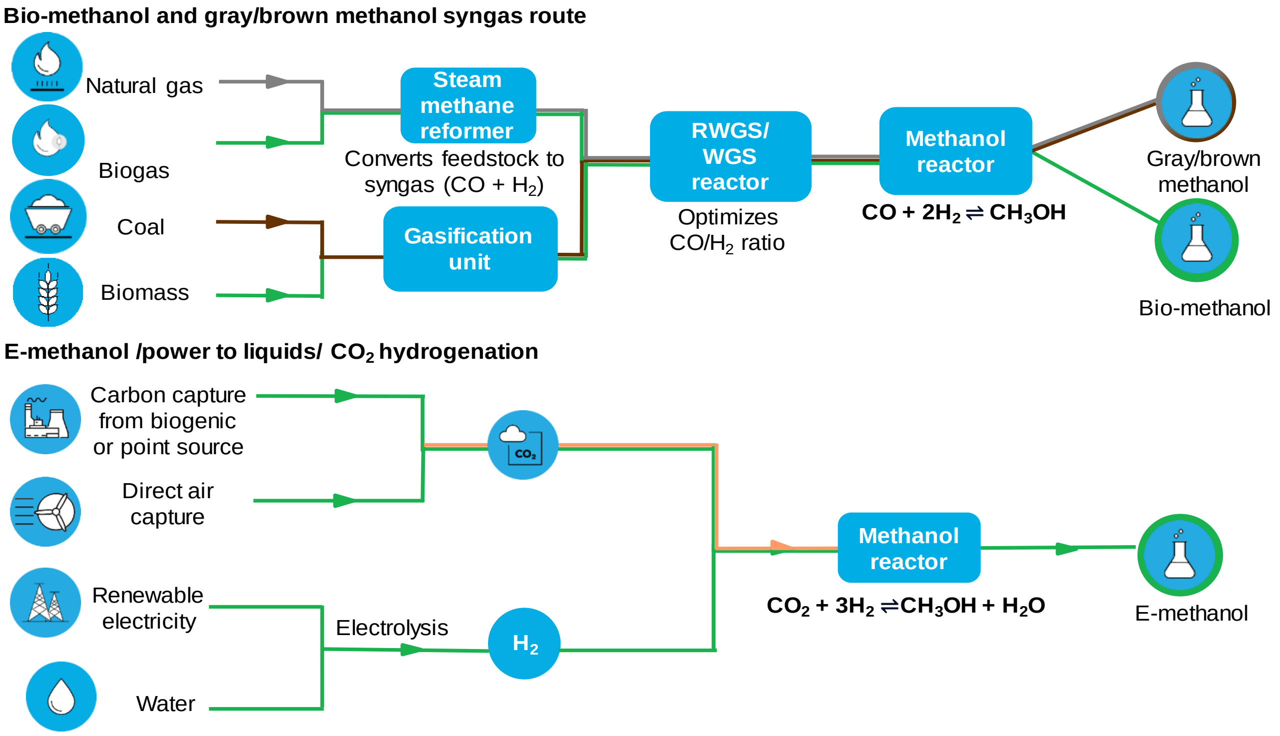
E-methanol is produced via an electrified process known as CO_2 hydrogenation, which converts captured CO_2 and low-carbon hydrogen into methanol. This technology is quite mature, and the synthesizer capital expenditure is around $30 million to $70 million for a 100,000 ton per year facility. The main constraint limiting the size of e-methanol plants is mostly around feedstock scale. E-methanol production requires a reliable clean electricity supply and supply of CO_2. Either battery or hydrogen storage might need to be added, which will ultimately increase the cost of production.

Bio-methanol is derived from biomass feedstock, including solid biomass from forestry and agricultural waste and municipal solid waste, or from biogas produced from the anaerobic decomposition of biomass. There are two processes for producing bio-methanol and they are determined by the nature of the feedstock:

- When biogas is the feedstock, which consists mainly of CH_4 (methane) and CO_2, it is processed in a similar manner to natural gas – via the steam methane reformer to produce syngas, which is then converted to bio-methanol.

- Alternatively, solid biomass and waste require a gasification step, in which syngas is produced from the waste via high temperatures in the presence of an oxidizing agent such as air, in a similar process to gray methanol production from coal. Further cleaning and refining steps are required as biomass can contain sulfur and could lead to impurities such as hydrogen sulfide.

Figure 10: Production routes of methanol



Source: BloombergNEF. Note: RWGS stands for reverse water gas shift and WGS stands for water gas shift. Although it is technically possible to use blue hydrogen, we have not tracked any projects using blue hydrogen so have omitted it from the chart.

Injecting hydrogen into biomass syngas can increase the methanol yield while reducing biomass use

The overall capex for biomass-based methanol production is around four times that of e-methanol (excluding feedstock). When biomass is gasified, the hydrogen to carbon monoxide (CO) ratio in the syngas is around 1, while the optimal ratio to produce methanol is 2 ($2H_2 + CO \rightarrow CH_3OH$). In this case, only 30% of the biogenic carbon is utilized for methanol production, making the process expensive. Traditionally, the reverse water gas shift and water shift reaction are used to optimize the H_2/CO ratio. However, some plants are exploring a new process to inject green hydrogen to hit this ratio and double the carbon utilization rate.

Injecting green hydrogen into the bio-methanol production process is increasingly being explored by projects across the world and could become a major driver for green hydrogen demand in the near term. However, as one ton of bio-methanol only requires 0.063 tons of hydrogen, compared to 0.188 tons of hydrogen demand for e-methanol, the total hydrogen demand from bio-methanol production would not be game-changing. See section 6.2 for details.

When low-carbon hydrogen costs get low enough, producers can increase the hydrogen injection rate to make use of the carbon dioxide formed during gasification as well ($3H_2 + CO_2 \rightarrow CH_3OH + H_2O$). The methanol produced through this process is considered a combination of bio- and e-methanol, which could potentially have a higher value than bio-methanol. In this case, for every ton of biomass, the methanol production could more than double.

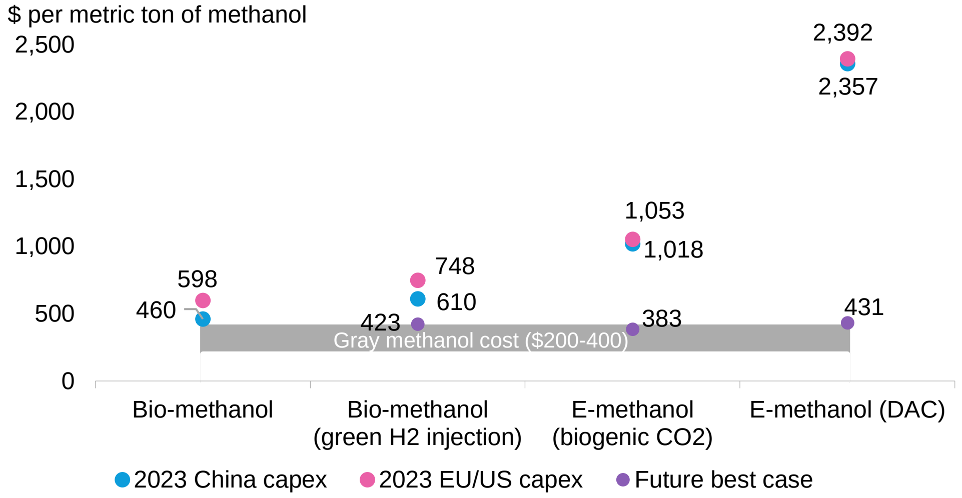
4.3. The costs of clean methanol

The cheapest way to produce low-carbon methanol, for now, is feeding biogas into an existing gray methanol production facility (Figure 11). Biogas is among the lowest-cost forms of biomass, and could be produced in the US at around $10-15 per million British thermal units in the cheapest case. This is in a parallel range to the natural gas available in the EU in 2023, but still much more expensive than gas in the US, which costs around $3 per MMBtu. However, due to the limited supply of biogas, this is not considered a mainstream pathway, so we have not included this in the bio-methanol cost range below.

Bio-methanol with green hydrogen injection could become the most scalable way of producing low-carbon methanol

The most common way to produce bio-methanol is through gasifying biomass or municipal solid waste. The cost of biomass-based methanol could range from $450-700 per ton today, assuming a biomass feedstock cost of $100 per ton. This is close to the high end of current gray methanol production costs. Despite a cost advantage, bio-methanol might have a higher carbon footprint than e-methanol and it is challenging to scale the supply chain. See Section 6.2 for more discussion on the biomass supply chain.

Figure 11: Estimated cost of bio-methanol and e-methanol



Source: BloombergNEF. Note: Assumes costs of $100 per metric ton for biomass, $4 per kilogram for green H_2, $125/ton for biogenic CO_2 and $1,100/ton for direct air capture in 2023. Assumes costs of $100/ton of biomass, $1/kg of H_2, $75/ton of biogenic CO_2 and $110/ton for DAC in 'future best case'. Assumes Western capital expenditure is 2.2 times more expensive than in China.

When biomass resource is limited, injecting green hydrogen can improve yields but may raise costs. We estimate the cost of bio-methanol with green hydrogen injection could be around $600-800 per ton today, assuming $4 per kilogram green hydrogen costs. This technology pathway could become the most scalable way of producing low-carbon methanol (due to biomass constraints) with a relatively low cost in the near term.

Synthetic methanol using carbon from direct air capture (DAC) is not an economic pathway at the moment. With a DAC cost of around $1,100 per ton today, low-carbon methanol costs are extremely high, at around $2,300 per ton. In a 'future best scenario', where DAC costs come down close to $100 per ton, the cost of synthetic methanol might hit the high end of the gray methanol cost. Even then, producing synthetic fuels from DAC might not be the best approach as it is more expensive than burning fossil fuels directly with DAC offsets.[6]

A more economical way to produce e-methanol today is to use biogenic or even industrial carbon as the feedstock. For example, industrial low-concentration carbon sources (such as cement and steel) have a capture cost of between $70-80 per ton,[7] while biogenic CO_2 can be captured at over $100 per ton.[8] Producing e-methanol with biogenic CO_2 costs around $1,000 per ton today.

Cost breakdown

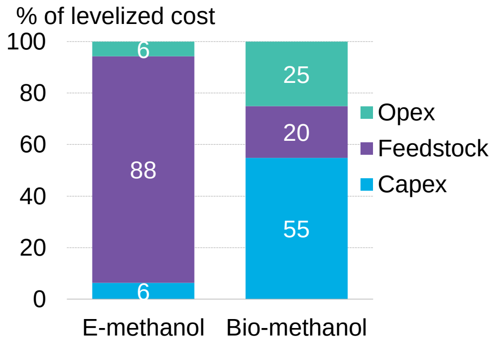
Capex is the main component of bio-methanol costs today, accounting for almost half the levelized cost of bio-methanol (Figure 12). This makes bio-methanol in countries with low engineering and construction costs, such as China, particularly competitive. Building a bio-methanol plant in China costs less than half that of a similar plant in the US.

Feedstock costs, including hydrogen and carbon costs, account for almost 90% of e-methanol costs today

Feedstock costs, namely the cost of green hydrogen and carbon, account for close to 90% of the cost of making e-methanol using biogenic CO_2 feedstock. This percentage would be much higher if DAC carbon were used.

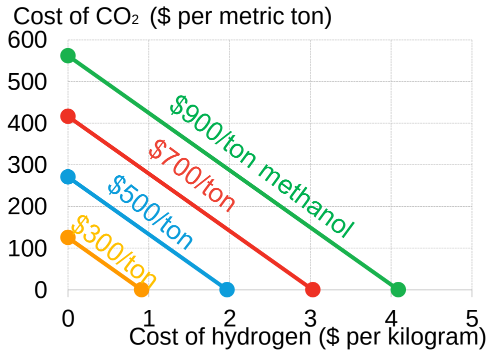
A fall in feedstock costs is essential for low-carbon methanol to ultimately compete with gray methanol. In the 'future best case', the cost of bio-methanol and e-methanol could decline to the high range of gray methanol costs today, to around $400 per ton. However, for e-methanol to compete with the lower range of gray methanol costs, green hydrogen costs need to drop below $1 per kg, and the CO_2 feedstock cost must be close to zero, which is nearly impossible to achieve (Figure 13).

Figure 12: Cost breakdown of bio-methanol and e-methanol using biogenic CO_2



Source: BloombergNEF. Note: Assumes costs of $4 per kilogram for H_2, $125 per metric ton for CO2 and $100/ton for biomass, and Western capex.

Figure 13: Cost of e-methanol by feedstock cost



Source: BloombergNEF

[6] See BNEF's *E-Fuel Touted as Ticket to Clean Aviation Needs a Tailwind* (web | terminal) for more.

[7] See BNEF's *Carbon Capture Cost Breakdown: Industrial Sources* (web | terminal) for more.

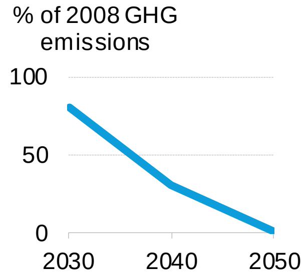
[8] See BNEF's *Bioenergy with Carbon Capture: Costly Negative Emissions* (web | terminal) for more.

Section 5. The expanded role of clean methanol

The shipping sector is faced with a pressing timeline to decarbonize under EU regulations and International Maritime Organization (IMO) proposals. Low-carbon methanol is one of the clean fuels the sector is looking into, alongside biofuels and ammonia. While it is still unclear whether clean methanol will become the dominant fuel for shipping in the long term, it is definitely one of the most readily available options in the short term.

5.1. Shipping faces regulatory and consumer pressures to decarbonize

Figure 14: IMO's greenhouse gas reduction targets



Source: International Maritime Organization, BloombergNEF. Note: Shows the IMO's base target. GHG refers to greenhouse gas.

The IMO has set a target for the shipping industry to reach net-zero greenhouse gas emissions by 2050. An interim goal calls for at least 5% of energy used to be zero or near-zero emissions by 2030, equivalent to a 20% greenhouse gas emissions reduction by the same year (Figure 14). These are hefty demands for a sector in which companies are only now beginning to slowly adopt cleaner fuels and technologies, and whose assets have a long lifetime.

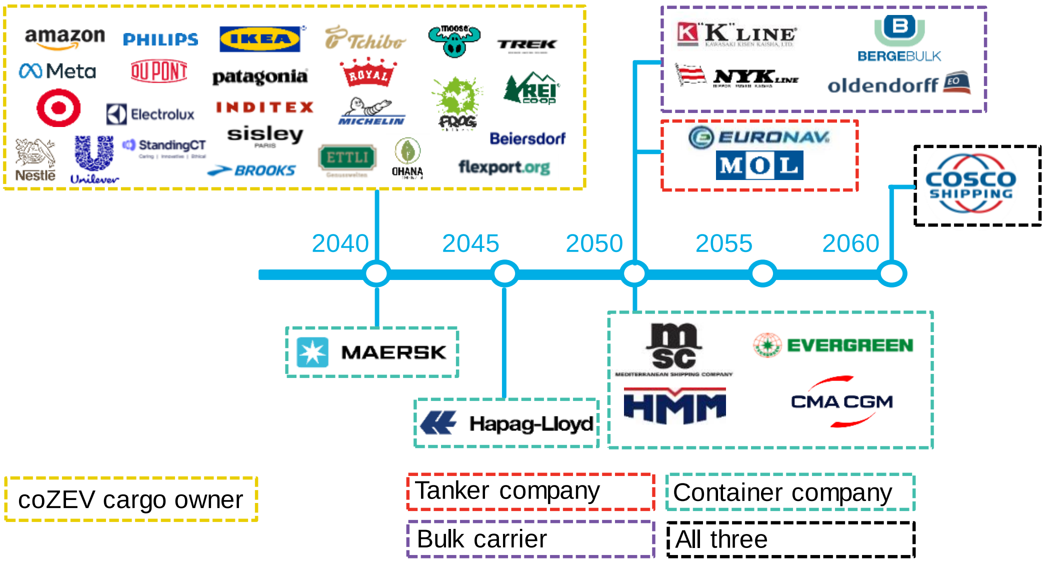
The strongest shipping decarbonization regulation globally is in the EU. The bloc has established two sets of strict rules to drive down emissions from vessels operating through its ports. The bloc's carbon market, known as the EU Emissions Trading System (EU ETS), is incorporating the sector's emissions from 2024, then from 2025 the greenhouse gas emissions intensity of shipping fuel will have to decline continuously under the FuelEU Maritime policy. See Section 6.1 for details.

Still, global policymakers' urgency to decarbonize shipping roughly ends there. Some large fleet and cargo owners are separately setting their own ambitious objectives to reduce emissions from maritime trade (Figure 15). These companies, mostly pressured by their own customers, have shown commitment to these targets with orders for new vessels and fuel offtake agreements (Section 6.3).

Cargo owners' desire to decarbonize is one of the important drivers beyond policy regulation for the shipping sector to adopt clean fuels. Maersk reported back in 2021 that more than half of its 200 largest customers, such as Amazon, Disney and Microsoft, have set, or are in the process of setting, targets to cut supply chain emissions. This means they have shown an increasing demand for green products and want to procure zero-emissions shipping services. Amazon is one of the 212 customers of Maersk that have signed up for its ECO Delivery service to deliver goods through biofuel-powered vessels.

One alliance launched by cargo owners for shipping decarbonization is Cargo Owners for Zero Emission Vessels (coZEV), initiated by the Aspen Institute. It consists of 25 global brands that have committed to zero-emissions shipping for their maritime freight by 2040, such as Amazon, Patagonia and Ikea. Companies in this alliance are concentrated in the consumer goods, fashion and food and beverage industries (Figure 15).

Figure 15: Net-zero targets of shipping companies and coZEV alliance members



Source: BloombergNEF, company press releases, Aspen Institute. Note: coZEV refers to Cargo Owners for Zero Emission Vessels.

Only 20% of shipping fuel used each year is covered by a net-zero emissions target

Ships that fall under the EU ETS regulations consumed 44 million tons of heavy fuel oil-equivalent fuel in 2022,[9] which is around 18% of the 240 million tons of total fuel consumption of the shipping sector.

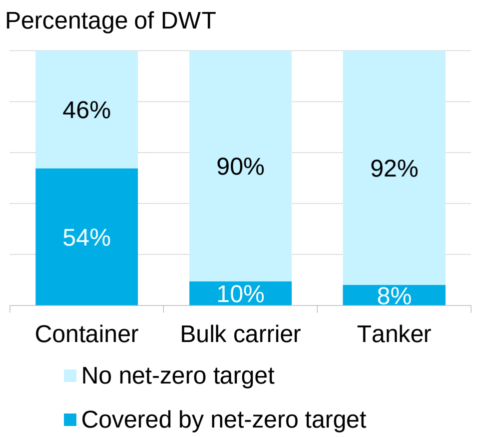
Ships that fall under the EU regulations consume 18% of shipping fuels

The fraction of shipping companies with corporate net-zero targets is quite small. The seven container shipping companies with net-zero goals account for 54% of container vessel capacity globally, which is the highest percentage among all ship categories (Figure 16). But container ships only account for 27% of the total fuel consumption of the shipping sector. While the bulker and tanker sectors combined represent over 50% of ship fuel consumption, only five bulker carriers and three tanker companies have net-zero targets, accounting for 10% and 8% of capacity for their respective vessel types. The lack of differentiation among bulk and chemical products implies that a large portion of cargo owners could be reluctant to recognize the higher value of green fuels.

Using the percentage of vessel capacity as a proxy for fuel consumption in each vessel type, we estimate that 20% of total shipping fuel consumption is covered by a net-zero target.

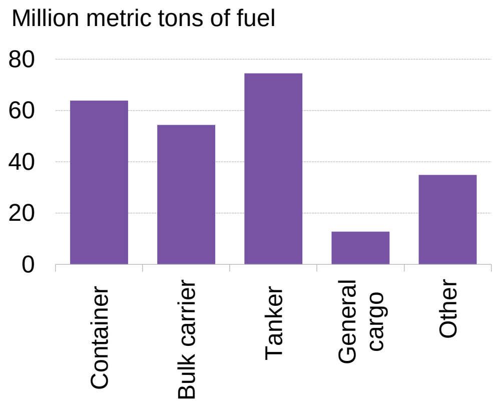
9 See BNEF's *EU ETS Shipping Compliance Database* (web | terminal) for more.

Figure 16: Percentage of vessel capacity covered by corporate net-zero targets



Source: BloombergNEF. Maersk Mc-Kinney Moller Centre for Zero Carbon Shipping, Clarkson. Note: DWT refers to deadweight tonnage.

Figure 17: Volume of heavy fuel oil-equivalent fuel consumption by vessel type



Source: BloombergNEF, International Maritime Organization's Fourth Greenhouse Gas Study.

5.2. Methanol as an alternative shipping fuel

The most viable near-term options for decarbonizing shipping consist of various low- and net-zero carbon fuels, such as biofuels, low-carbon methanol, low-carbon ammonia and other synthetic fuels. All these come with unique challenges related to availability, sustainability, cost and safety. While digital technologies are a real opportunity for sizable efficiency gains and emission reductions, they can only decrease fuel consumption rather than eliminate emissions. Options such as sails and other propulsion modes remain at a far earlier stage of development, despite their long-term potential.

Low-carbon methanol is a more readily available option than other alternative fuels and has been one of the main choices, alongside biofuels, in shipping companies' decarbonization plans. Ammonia is also considered a potential clean shipping fuel due to its advantage in the feedstock supply chain, and low carbon intensity. See Table 1 for a comparison of the different clean shipping fuels.

In the context of limited overall supply of cleaner fuels, and competition from other transportation sectors, a potential question is whether the industry may settle on a single or multi-fuel future. Both options come with their own challenges. Supply constraints may limit the availability of an individual fuel, while differences in infrastructure, vessel and engine design could make a multi-fuel future tricky.

Table 1: Comparison of different clean shipping fuels

Fuel	Clean methanol	Clean ammonia	LNG
Long-term cost estimate ($ per gigajoule)	23	22	6
Energy density (megajoules per liter)	16	11 (liquid)	21
Carbon intensity (grams of CO_2 per megajoule)	2-30	<5	72*-90
Engine technology	Pilot phase	Research and development phase	Commercial phase
Safety of use	Medium, low flashpoint	Toxic, low flashpoint	Medium, risk of cryogenic freeze/gas leaks

*Source: BloombergNEF. International Council on Clean Transportation. Note: All CO_2 intensity measurements are based on a 100-year basis. *LNG carbon intensity is based of its emissions from combustion in a steam turbine engine. Long-term fuel cost assumes $1 per kilogram of H_2, $100 per metric ton of CO_2 and $600-$800/ton of marine fuel including carbon costs. Green filling means most favorable to shipping companies, while red means least favorable.*

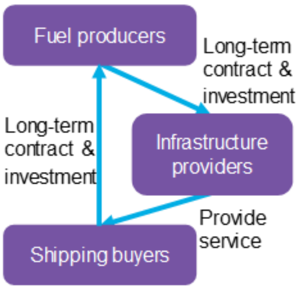
5.3. Infrastructure affects future fuel portfolio

While vessel engines could be retrofitted to accommodate methanol, bunkering infrastructure – essentially the storage tanks, refueling equipment and barges in the port – could be a more important factor in determining which fuel will dominate in a net-zero future.

As a more widely traded commodity than ammonia, methanol may be seen to have an edge over ammonia, with more ports readily equipped with methanol storage tanks. It is also easier to retrofit gasoline or oil tanks to store methanol, compared to ammonia. However, for methanol to be widely used as a shipping fuel, the existing infrastructure is far from enough and significant investment in new infrastructure, both existing and new bunkering ports, is needed.

Methanol might also have a first-mover advantage over ammonia to occupy and lock in port infrastructure as the first batch of low-carbon methanol projects start to sign offtake agreements. Once the methanol fuel producers secure long-term offtakes or investment from shipping buyers, they could then approach the port infrastructure providers to secure storage space or even co-invest in the infrastructure expansion (Figure 18). The below case study illustrates how stakeholders are developing and partnering on bunkering infrastructure in Rotterdam.

Figure 18: Stakeholders for bunkering infrastructure



Source: BloombergNEF. Note: This is an illustrative chart on what needs to happen to scale bunkering infrastructure.

Bunkering partnerships in the port of Rotterdam

The port of Rotterdam reported it bunkered 1,500 tons of methanol in 2022, and expects to be a regular methanol bunkering hub from 2023.

The partnerships are happening somewhat organically in Rotterdam. As shipping companies such as Maersk and X-press Feeders announce plans to procure and bunker low-carbon methanol in the port of Rotterdam, fuel producers such as OCI Global are starting to engage with bunkering stakeholders. The activity in Rotterdam could be a useful template for other large ports:

- **Getting regulatory approval**: The port of Rotterdam only requires an advance notice for methanol bunkering, which is more straightforward than some other ports that have not bunkered methanol before and might require longer engagement with the port authority.
- **Partnering with bunkering operators**: Fuel suppliers often pay bunkering operators on demand, but some have gone further. For example, OCI Global has partnered with Unibarge, one of the largest bunkering operators in Rotterdam, to charter its barge for bunkering services.

  Securing storage infrastructure: Fuel producers will need to secure some sort of storage infrastructure in the port. As one of the largest methanol trading hubs, Rotterdam has around 500,000 cubic meters (around 400,000 tons) of methanol storage infrastructure. Fuel producers often need to sign some sort of contract, usually one to three years in length, with storage infrastructure providers to justify their upfront investment. This happens for other types of green fuel already, such as the ones by Vopak in Los Angeles and in Rotterdam for sustainable aviation fuels. As most gasoline and chemical tanks are easy to retrofit to store methanol, some storage tank owners could go ahead and expand their methanol storage without needing long-term fuel contracts. For example, EVOS announced plans to expand its methanol storage sites in Rotterdam.

Section 6. State of the low-carbon methanol market

The EU is the only region globally to have adopted a carbon price and a fuel carbon intensity target for the shipping sector

Clean methanol demand is mostly driven by policy regulation, especially in the EU. The EU ETS and FuelEU Maritime regulation combined could potentially make low-carbon methanol cost competitive with conventional shipping fuels in the next decade. Some parts of the shipping sector have already begun to respond to these policies by ordering methanol dual-fuel vessels and procuring low-carbon methanol globally. BNEF estimates ships could use 14 million tons of clean methanol by 2028. The chemicals sector, the largest user of gray methanol today, is subject to moderate regulations and has been slow to adopt low-carbon methanol or green hydrogen. But even if the chemicals sector consumes little clean methanol, demand from the shipping sector alone could potentially outstrip supply, based on current project pipelines.

6.1. Policy incentives

The EU is the only region globally to have adopted a carbon price and a fuel carbon intensity target for the shipping sector. While some parts of the US and Asia have adopted a compliance carbon market, not all cover industrial sectors, none cover shipping, and few have a carbon price high enough to incentivize action in these sectors. The EU and China have applied some regulations to gray methanol producers, but the impact scope is quite narrow so far. In this section, we focus primarily on demand-side regulations.

Supply-side subsidies

While there are no subsidies specifically for low-carbon methanol production, some countries provide subsidies for the underlying feedstock – such as for carbon capture and hydrogen production. The US has the 45Q tax credit for carbon capture, utilization and storage projects and 45V tax credit for hydrogen projects. Meanwhile, the European Hydrogen Bank offers a subsidy of as much as €4.5 per kg ($4.9 per kg) of hydrogen in the EU[10], while the UK's first low-carbon hydrogen auction offers an average subsidy of $10.1 per kg[11]. BNEF's *Hydrogen Subsidies Tracker* tracks a total of $363 billion funding going to low-carbon hydrogen projects globally[12].

Carbon markets

BNEF estimates the EU ETS could cost shipping companies €12 billion every year

The EU is the only market that puts a carbon price on the shipping sector. In March 2023, the bloc announced the sector's inclusion in its emissions trading system, covering all voyage emissions within the bloc, as well as 50% of emissions from journeys to or from an EU port of call for vessels of at least 5,000 gross tonnage.[13] Shipping companies have to pay for 40% of their emissions from 2024 and 100% from 2026. The EU ETS will make the use of fossil fuels in shipping more

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[10] See BNEF's *EU Hydrogen Bank Winners Will Need Deep-Pocketed Buyers* (web | terminal) for more.

[11] See BNEF's *High UK Green Hydrogen Prices Reflect Power and Grid Costs* (web | terminal) for more.

[12] See BNEF's *Hydrogen Subsidies Tracker* (web | terminal) for more.

[13] The proposal excludes methane and nitrous oxide emissions, offshore ships and vessels below the 5,000 gross tonnage thresholds, which mostly includes fishing boats and warships. These ships currently make up less than 15% of shipping emissions. The bloc is looking to include them from 2026.

expensive, and therefore bring the use of clean fuels, such as low-carbon methanol, closer to cost parity. BNEF estimates this policy could cost the shipping sector €12 billion ($13 billion) for compliance in 2030.[14]

Methanol producers in the EU will, from 2026, be increasingly exposed to the full carbon cost

The EU ETS will soon have another impact on the methanol sector. Free allowances for chemical producers under the EU ETS currently mean that methanol producers are insulated from paying the bloc's carbon price, but the benchmarks are set to tighten from 2026, increasingly exposing the sector to the full carbon cost. However, carbon pricing alone is not enough to incentivize methanol producers to switch to clean feedstock. The carbon price required for bio-methanol (which is cheaper to produce than e-methanol) to be cost competitive with gray methanol in a 'high gas price scenario' is above BNEF's projected 2030 EU carbon price (Figure 19).

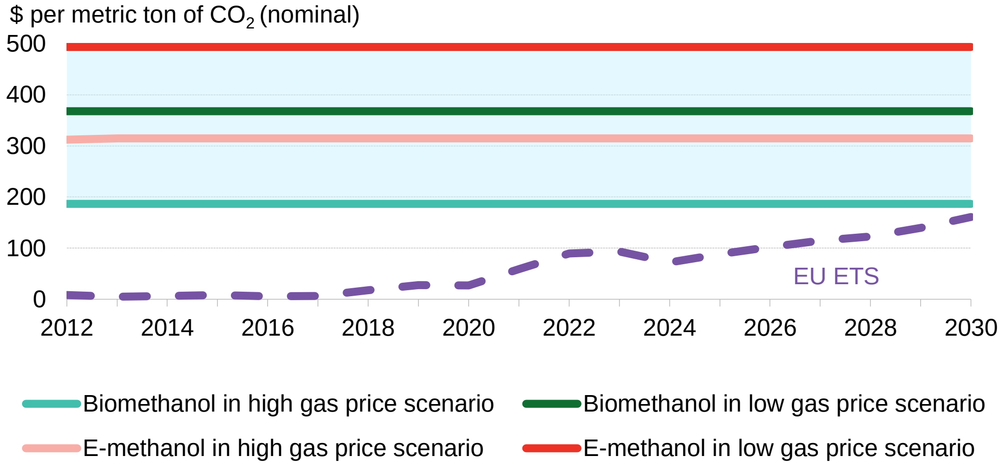
How does the EU Emissions Trading System work?

The EU ETS is a cap-and-trade carbon market. An upper limit, or cap, on emissions covered by the program is set by lawmakers. Allowances are created up to the cap, where one allowance is equal to one metric ton of CO_2 equivalent. The allowances are then auctioned or distributed to compliance entities as free allocation. Entities covered by the scheme must purchase allowances to cover their emissions on an annual compliance cycle, for their obligation outside any free allocation. The allowance price is dynamic and reflects the supply and demand drivers in the market.

China, another country with a national carbon trading scheme, has been delaying its plans to include industrial sectors

The carbon pricing schemes in California and Canada also offer free allocation to the chemicals sector, due to the concern of 'carbon leakage' and the economic downside of industrials relocating their plants to regions with no or less stringent carbon pricing. Canada, for example, provides free allocation that covers 88% of industrial sector emissions in 2022, declining by 1% every year. China, another country with a national carbon trading scheme, has been delaying its plans to include industrial sectors.

Figure 19: Carbon price required for low-carbon methanol to be cost competitive with gray methanol in 2030



Source: BloombergNEF. Note: Exchange rate as of December 27, 2023 (€1 = $1.1). Carbon prices from BNEF's EU ETS Market Outlook 1H 2024: Prices Valley Before Rally (web | terminal). Assumes costs of $2/kilogram for green hydrogen, $90/metric ton of biogenic CO_2 and $100/ton

[14] See BNEF's *EU Makes First Move to Crack Down on Shipping Emissions* (web | terminal) for more.

of biomass in 2030. Assumes $5/million British thermal units in low gas price scenario and $10/MMBtu in high gas price scenario.

Renewable transport fuels obligations

The EU RED II has driven some early and small offtakes for low-carbon methanol in road transport

The EU adopted the Renewable Energy Directive II in 2018, requiring 14% of the total energy used in the transport sector to be from renewable sources by 2030. Electric vehicles, biofuels and renewable fuels of non-biological origin (RFNBO), such as e-methanol, could all contribute to this target. In 2021, the bloc further adopted the Fit for 55 package to align RED II with its 2050 carbon neutrality target. This led to the later adoption of RED III in 2023, which included a binding quota for the transport sector in March 2023 to replace 5.5% of its fuel on an energy content basis with advanced biofuels or RFNBO by 2030.

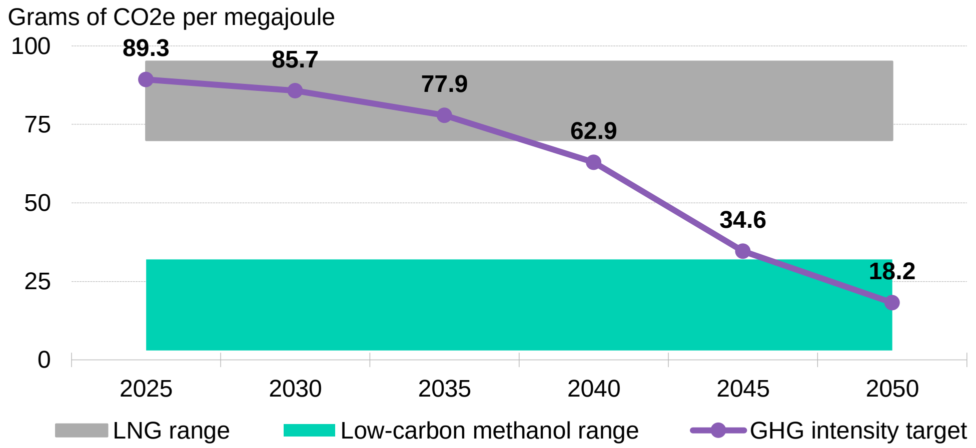
These renewable fuel targets have driven some early demand for low-carbon methanol in the road transport sector, but the volume is very small. Some of the first low-carbon methanol offtakes, mostly under 100 tons, are almost exclusively for the road transport sector in the EU and the Nordics, where customers use methanol as a drop-in fuel for gasoline or biodiesel.

The fuel standards in different countries could also limit the market size for methanol use in the road transport sector. The EU's Fuel Quality Directive allows methanol blending up to 3% in gasoline, while China has a national standard for 85% methanol blending in gasoline and pure (100%) methanol as a car fuel. Chinese automaker Geely is the biggest champion of methanol cars, but the market remains niche.

LNG still remain a compliant low-carbon fuel in the EU until 2040, in the best case, and has been the most used alternative shipping fuel by far

The shipping sector is also subject to a separate renewable fuels mandate. The FuelEU Maritime initiative, adopted by the EU in July 2023, requires all vessels subject to the EU ETS to comply with a greenhouse gas emissions intensity metric starting from 2025. This is measured in grams of CO_2 equivalent emissions per megajoule of fuel and calculated on a lifecycle emissions basis. The target is subject to a reduction every five years, and non-compliant fuels will face a fine of around $69 per gigajoule (in real 2021 US dollars). Low-carbon methanol could be compliant with the FuelEU target until 2045-2050, while liquefied natural gas has a range of carbon intensities depending on where it is produced and whether it is being shipped around the world. While in the worst case LNG might become non-compliant as soon as 2025, it could still stay compliant until 2040 in the best case and has been the most used alternative shipping fuel by far (Figure 20).

Figure 20: FuelEU Maritime initiative carbon intensity target, and lifecycle emissions of LNG versus low-carbon methanol



Source: BloombergNEF. Note: Low-carbon methanol includes bio-methanol and e-methanol. Assumes LNG contains 2.75 grams of CO_2 equivalent per gram of fuel, or 50g of CO_2e per megajoule carbon content, plus 20-45g of CO_2e per MJ additional emissions from production and transportation, based on the International Maritime Organization's Fourth GHG Study. GHG refers to greenhouse gas.

EU hydrogen mandates for industry

While the EU industry mandates are effective, the methanol sector is very small

The EU adopted the world's first binding green hydrogen quotas in March 2023, mandating that existing gray hydrogen users in the fertilizer, methanol and refining sectors utilize renewable hydrogen. The quotas require 42% of industrial hydrogen demand to be renewable by 2030, rising to 60% by 2035.[15]

The methanol sector in Europe is relatively small, consuming only 341,238 tons of hydrogen in 2020. The quota would translate to around 205,000 tons of renewable hydrogen demand by 2035. Most methanol producers are concentrated in a few countries, namely Germany, the Netherlands, Romania and Sweden.

China's environmental permit quota on heavy-emitting plants

China's strengthening regulations on polluters have driven some chemical producers to adopt green hydrogen. China's Ministry of Ecology and Environment launched a policy in 2021 to tighten the environmental permit quotas for industries of "high emission and high energy consumption", following the country's commitment to a net-zero target. The policy singled out a few industries, including coal chemicals, which methanol production falls under, and required them to reduce coal consumption as much as possible.

China's environmental permits for coal chemical producers are quite discretionary

Some methanol-to-olefin producers, such as Baofeng, have been struggling to get environmental permits for their new-build facilities and have therefore decided to blend green hydrogen into the process to lower coal consumption. However, the regulations are very discretionary and do not apply universally to all coal chemical producers. The coal chemical producers affected so far seem to be mostly private sector producers. See Section 6.4 for more details.

6.2. Low-carbon methanol supply

As of early 2024, low-carbon methanol production capacity is negligible and currently makes up less than 1% of the 110 million tons of methanol production today. However, there are 18 million tons worth of low-carbon methanol projects in the pipeline, which, when commissioned, would consume 1.65 million tons of hydrogen. This is around 16% of existing gray methanol production today. Of these plants, 11 million tons per year of capacity is due online by 2030 (Figure 21).

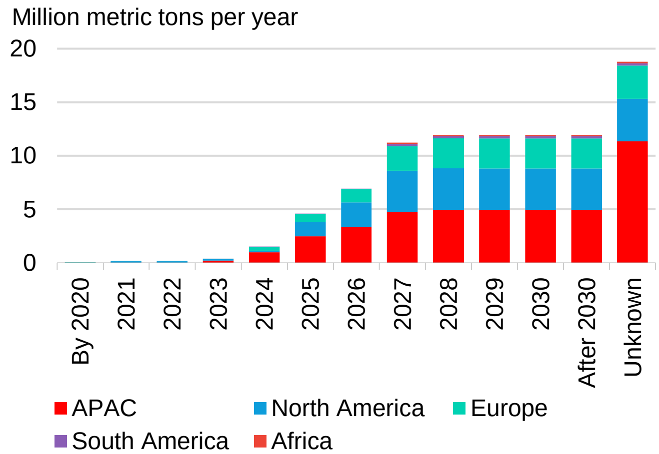
Low-carbon methanol supply is expected to ramp up to 11 million tons per year by 2030

China dominates the low-carbon methanol production pipeline, although half the capacity planned is quite early stage and has not disclosed a commissioning date. Around 60% of the capacity planned in China will produce bio-methanol with green hydrogen injection, a technology route almost entirely adopted in China. This is because lots of the bio-methanol projects are planned as add-ons to already announced green hydrogen projects, which are struggling to sign hydrogen

15 See BNEF's *EU Hydrogen Quotas Raise Global Demand for Green Molecules* (web | terminal) for more.

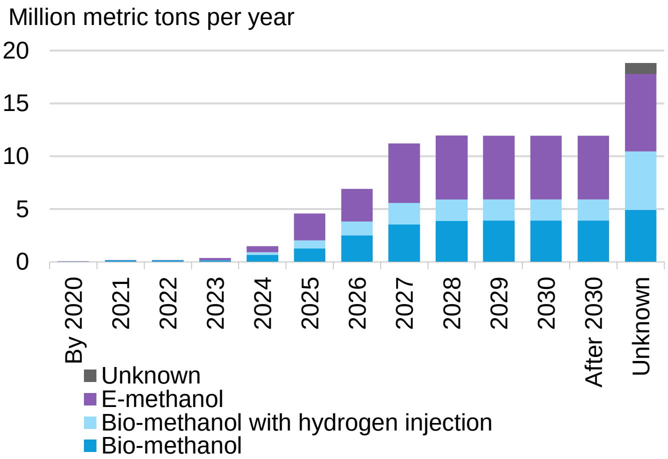
offtakes in China. For methanol projects outside China, two-thirds of the capacity is planning to produce e-methanol, while one-third aims to produce bio-methanol (Figure 22).

Figure 21: Low-carbon methanol production pipeline, by country



Source: BloombergNEF. Note: Data as of January 5, 2024. APAC refers to Asia Pacific.

Figure 22: Low-carbon methanol production pipeline, by technology



Source: BloombergNEF. Note: Data as of January 5, 2024.

Feedstock cost and availability will play a crucial role in the ability of low-carbon methanol to scale up. Biogenic CO_2 seems to be the most commonly pursued feedstock for e-methanol so far, accounting for a third of the e-methanol capacity tracked (Figure 24). However, biogenic CO_2 availability seems to be highly regional. For example, ethanol production, when carbon capture is applied, is a good biogenic CO_2 source but plants are highly concentrated in certain regions, including the US and Brazil, and not all carbon captured from ethanol plants are eligible sources of biogenic CO_2 under the EU RED.

Biogenic CO_2 could also be available in the Nordics and certain European countries, where bioenergy power plants are incentivized to capture their carbon emissions. Around 20% of the planned e-methanol capacity will rely on point-source CO_2 captured from nearby industrial facilities. This might allow plants to scale up quickly with the intention of installing direct air capture onsite in the coming decades.

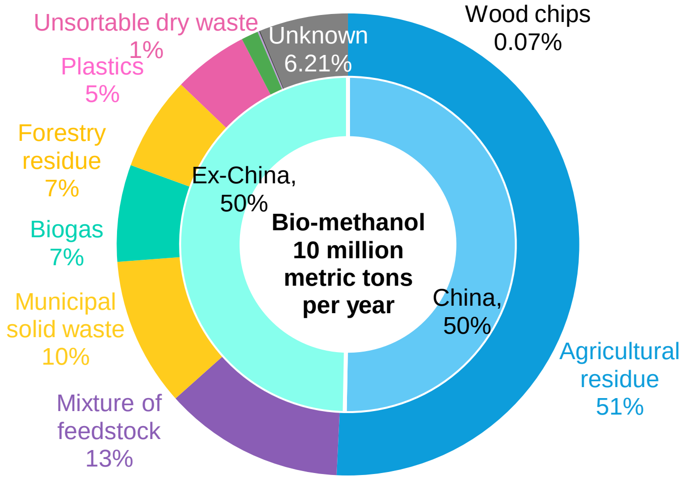
Bio-methanol plants in China use almost exclusively agricultural residue, while those outside China have a mix of feedstock

There are currently a handful of operational e-methanol plants. One notable example is Carbon Recycling International's Shunli plant in China, commissioned in 2022, with an output of 110,000 tons per year. This facility produces low-carbon e-methanol, not net-zero, as the facility recycles 160,000 tons of CO_2 per year from a nearby steel facility. Another commissioned facility is HIF Global's Haru Oni demonstration plant in Chile, which is capable of producing net-zero methanol from a biogenic source.

The gas-to-liquids process for producing bio-methanol is compatible with many carbon-containing sources. As a result, there is a wider selection of feedstock available, which includes municipal solid waste, agricultural waste, forestry waste, biomass and biogas (Figure 23). Almost all bio-methanol with hydrogen injection facilities in China use agricultural residue, a widely available type of biomass in China. For projects outside of China, municipal solid waste seems to be the most popular source of bio-methanol feedstock, although a significant number of projects are planning to use a mixture of feedstock. The gasification unit is able to take a mixture of waste feedstock with only minor process changes.

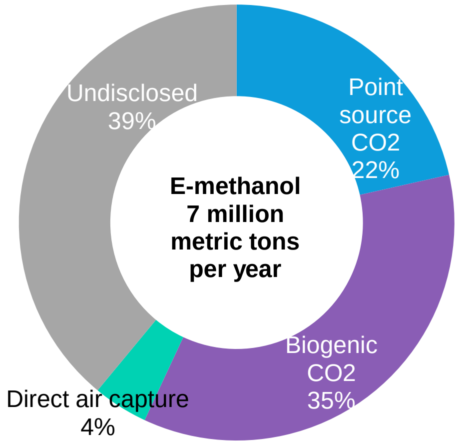
Currently, there are several large gas-to-liquids facilities producing bio-methanol, such as Enerkem's Edmonton facility in Canada, which has been operational since 2014 and converts 100,000 dry tons of municipal solid waste into 30,000 tons of bio-methanol and cellulosic ethanol per year.

Figure 23: Bio-methanol feedstock type for announced projects



Source: BloombergNEF. Note: Data as of January 5, 2024.

Figure 24: E-methanol carbon feedstock type for announced projects



Source: BloombergNEF. Note: Data as of January 5, 2024.

Challenges with feedstock

Securing scalable and long-term supply of feedstock is the top priority for any bio-methanol producer. Three particular challenges exist for bio-methanol feedstock supply:

Scaling up biomass feedstock would require a higher logistics cost that could comprise 20-50% of delivered costs

- Scale: Conventional bio-methanol plants require 2-3 tons of harvesting/processing residues for every ton of methanol output. This means for any large bio-methanol plants with up to 300,000 tons per year of output, they could consume 600,000 tons of biomass every year. This is roughly equivalent to the biomass consumption of a 50 megawatt biomass power plant, while most biomass power plants are an average of 20MW.[16]
- Cost: There is a trade-off between scale and logistics costs. Scaling up biomass feedstock volumes would probably mean higher logistics costs. Transporting this biomass via trucks is very expensive and can push the price of feedstock up to $350 per ton.[17] Depending on the distance, bulk density and moisture content, transport costs represent 25-50% of the total delivered cost.
- Uncertainty: For some types of biomass, such as agricultural waste, availability is often seasonal and intermittent, making it difficult to manage. Long-term supply contracts for agricultural waste are rare and often require a team dedicated to supply chain management.

For e-methanol production, the same issue of scale applies to biogenic CO_2 sources, although it could be easier to secure a stable supply of feedstock. For example, biogenic CO_2 could be

16 See BNEF's *Biomass incineration economics: seeing the wood from the trees* (web | terminal) for more.

17 See BNEF's *Bioenergy with Carbon Capture: Costly Negative Emissions* (web | terminal) for more.

secured from the emissions of bioenergy carbon capture and utilization projects (BECCU). These projects could have an incentive to sign long-term contracts for carbon utilization, as an alternative to permanent CO_2 storage, while storage infrastructure is still undeveloped. Industrial point-source CO_2 could be a more scalable solution than biogenic CO_2. For example, an average cement plant can capture 1 million tons of CO_2 every year,[18] which is enough to supply to an e-methanol plant of 730,000 tons per year, compared to an average biomass power plant of 20MW that produces only around 150,000 tons of CO_2 each year. The most scalable source of CO_2 will eventually be from direct air capture, but BNEF does not expect DAC to be commercialized until the 2030s and prices for DAC CO_2 will likely remain above those for BECCU or industrial point-source capture for many years.

6.3. Shipping sector offtake

Most methanol-fueled ships in operation now are also carrying methanol as a chemical

Just under 30 vessels that can use methanol as a fuel are already in operation. Most are relatively small tankers of about 50,000 deadweight tons dedicated to transporting methanol as a commodity. They are owned by Japanese, Norwegian and Swedish companies, including Mitsui O.S.K Lines, NYK Line, MSea Capital, Stena Line and Proman. In the next few years, the global methanol-capable fleet will grow rapidly and its make-up will change drastically due to policy and environmental compliance costs.

EU regulation may soon make methanol container ships competitive

The economics of methanol-powered ships are unlikely to approach those of equivalent vessels using marine fuel oil. The total cost of ownership – an all-in figure including capital, fuel and operating costs – of container ships using low-carbon methanol will remain higher than those using marine fuel oil throughout the 2030s. The declining costs of hydrogen will gradually close that gap, but even by 2050, when H_2 could potentially be produced for as little as $1 per kilogram, the total cost of ownership of low-carbon methanol ships would still be higher than those running on fuel oil.

Taking into account the environmental costs of burning fossil fuels can alter this picture, making low-carbon methanol as economic as, and even cheaper, than marine fuel oil. Such conditions currently exist only in the EU as a result of the bloc's carbon price and the fines associated with the FuelEU Maritime rule.[19] See Section 6.1 for more details on both policies.

The EU ETS and FuelEU Maritime regulation might make low-carbon methanol as economic as fuel oil soon

Any shipper that must purchase allowances to cover their emissions under the EU ETS, and also be subject to the fine for non-compliance with the FuelEU Maritime rule, will find that operating green methanol-powered ships within the EU becomes the cheapest option, even within this decade (Figure 25). The methanol economics for routes that connect EU and extra-EU ports could break even with those using marine fuel within the 2030s (Figure 26).

Shipowners might be able to remain compliant in the near term by adopting some efficiency improvements or deploying LNG-powered ships. The economics of methanol-powered container ships might not apply for tankers and bulkers for extra-EU voyages, which have a lower total cost

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18 See BNEF's *Carbon Capture Cost Breakdown: Industrial Sources* (web | terminal) for more.

19 Non-compliant fuels will face a fine of around $69 per gigajoule (in real 2021 US dollars). See BNEF's *2024 Marine Fuel Outlook: Methanol Sets Sail* (web | terminal) for more.

of ownership. Overall, the CO_2 emissions that collectively fall under these two EU rules are only around 14% of global shipping emissions[20] – not significant.

Figure 25: Containership total cost of ownership for intra-European Economic Area voyages

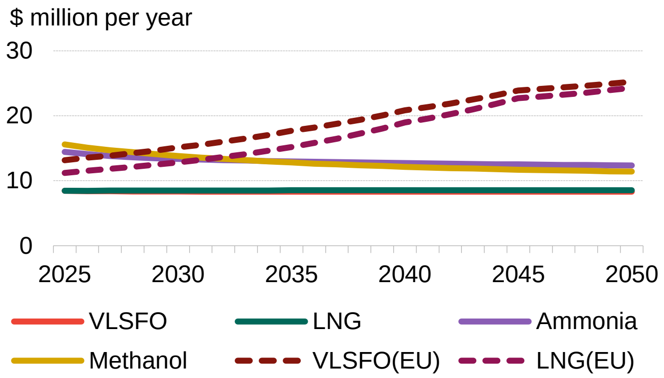
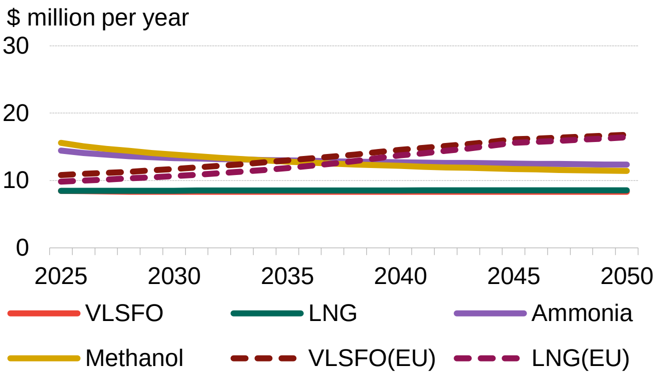


Figure 26: Containership total cost of ownership for extra-European Economic Area voyages



Source: BloombergNEF. Note: VLSFO is very low sulfur fuel oil; LNG is liquefied natural gas; VLSFO(EU) includes the impact of the EU Emissions Trading System and FuelEU Maritime; 100% of the emissions are covered for voyages between ports within the EU or European Economic Area. While 50% of the emissions are covered for voyages between ports within the EU or EEA and external ports, outside of the EEA. EEA includes EU countries and Iceland, Liechtenstein and Norway.

Challenges with shipping offtake

For ships affected by the EU's regulations, the increasing compliance and fuel-switching costs are putting a financial burden on shipping companies. While a hike in freight rates saw the sector generate a record-high profit of over $200 billion in 2022, according to Sea-Intelligence estimates, it is common for shipping companies to have low single-digit, or even negative, profit margins. Fuel is the main cost driver for the sector, accounting for 20-30% of a container shipping company's total expenses. Doubling fuel expenses could tip operating margins into the negative.

To bear the weight of the increasing costs of shipping, companies are trying to identify corporate customers that understand the value of green products and want to procure zero-emissions shipping. Quite a few international brand owners do want to commit to green shipping services to reduce their scope 3 emissions (see Section 5.1).

What does the higher cost of green shipping fuels mean for shipping companies and cargo owners?

The average unit cost of Maersk's container shipping business was $2,444 per forty-foot-equivalent unit (FFE) in 2022, of which fuel accounted for 26%, at $611 per FFE. Using the analysis in Figure 11, bio-methanol in the ship could escalate the freight rate by around 20-30% of the average 2023 rate.

While this cost of green shipping might not have a significant impact on high-end goods, products of a low value and large size will be more sensitive to shipping costs. For example, on average, shipping and insurance account for 24% of the cost of industrial raw materials, and on that basis a 20% increase in shipping costs would translate to an overall 5% cost increase for industrial raw materials.

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[20] See BNEF's *Shippers Scramble to Go Green as EU Carbon Crackdown Dawns* (web | terminal) for more.

The shipping industry is very competitive, with shipping companies often winning customers based on price. This means shippers might choose to absorb the higher shipping costs internally rather than trying to find customers wanting to procure net-zero emissions transportation. Despite a small group of international brands (shown in Figure 15) having committed to net-zero shipping services, it is not yet clear how any incremental costs of green shipping will be allocated across the distribution chain.

Methanol demand in shipping

Around 225 vessels equipped with methanol dual-fuel engines were on order as of March 2024 and are set to be delivered within five years (Figure 27). Economic, policy and corporate strategy reasons mean most of these are container ships and ordered by the largest liners, such as Maersk, CMA CGM, Evergreen and COSCO. These vessels are set to be built in South Korea and China, with only a handful to come out of Japanese yards.

Table 2: Container lines' methanol vessel orders

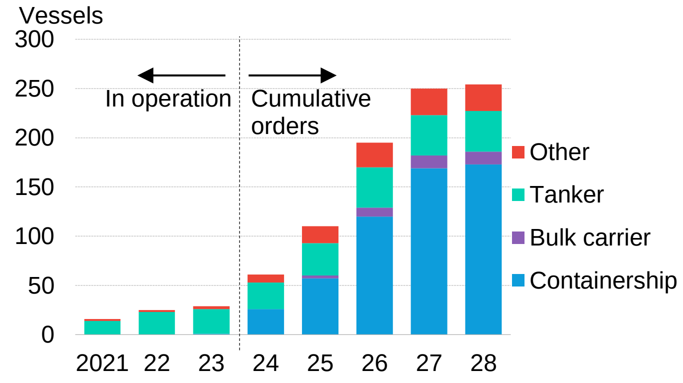
Company	% of fleet	% of TEU
Maersk	4.4%	10.5%
CMA CGM	3.5%	9.7%
COSCO	2.4%	7.6%
Evergreen	8.5%	15.6%

Source: BloombergNEF, company announcements. Note: TEU is twenty-foot equivalent unit.

For some of these containership owners, the stakes are high, as a sizable share of their capacity will be dedicated to methanol-powered vessels (Table 2) and they are likely to drive demand for the fuel in the future. The rest of the orderbook for methanol-capable vessels consists of chemical and crude tankers, a few bulk carriers and several more specialized vessels, such as car carriers and those used in offshore operations.

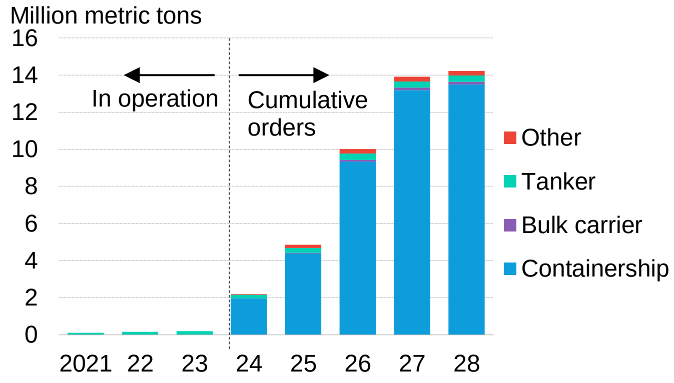
We estimate the maximum volume of methanol required by the current methanol fleet does not exceed 200,000 tons annually. But delivery of the methanol vessels in the orderbook means that methanol demand in shipping could explode in the next few years. We estimate around 14 million tons of the fuel would be needed annually by 2028, assuming all the dual-fuel methanol ships use methanol only, with practically all of it going to meet the demand of container liners (Figure 28). Maersk and COSCO are already trying to lock in fuel supply and seem willing to assume the risk of going further up the energy supply chain to secure the quantities they need (Section 7.1).

Figure 27: Methanol vessels in operation and on order



Source: Bloomberg, BloombergNEF, DNV. Note: Shows the fleet of vessels on the water in each year. Data as of March 1, 2024.

Figure 28: Methanol demand from existing and future fleet



Source: Bloomberg, BloombergNEF, DNV, MAN. Note: Shows consumption from the fleet of methanol vessels in each year, assuming they only use methanol. Data as of March 1, 2024.

Around 44 million tons of shipping fuel consumption falls under the EU regulations, as discussed in Section 5.1. Assuming low-carbon methanol displaces all of this, demand could reach close to 80 million tons of methanol.

Calculation of methanol demand in shipping

Annual fuel demand depends on vessel size, utilization and engine efficiency. Where ship details have been announced, we use engine and efficiency data for similar vessels, with adjustments for some lower methanol efficiency, and real-world consumption. Where no characteristics are available, we assume the type and size of a ship will be similar to a company's existing fleet. Finally, we assume these vessels have an 80% utilization rate. With these assumptions, the largest vessels in the orderbook, such as a 15,000 - 20,000 twenty-foot equivalent container ship can consume between 200-300 tons of methanol per day.

6.4. Chemical and downstream sector offtake

Existing gray methanol producers have been slow to decarbonize

Existing chemical sectors have been slow to adopt low-carbon methanol to decarbonize their internal processes and products. While some of the largest methanol producers, such as Methanex and OCI Global, are investing in low-carbon methanol projects, they are mostly targeting the marine fuel market. The few chemical sector offtakes BNEF tracks are largely driven by policy.

Challenges with chemical sector offtake

The biggest challenge for the chemicals sector in adopting low-carbon methanol is the lack of incentives for commercial customers to procure green products. The end-use sectors of methanol are extremely broad – from household products to industrial resins and construction materials.

While some sectors might be less sensitive to costs and have stronger incentives for supply chain decarbonization, they may consider methanol as less of a priority in their overall product carbon footprint. For example, methanol is the feedstock for various plastic resins used in automotives. However, one average vehicle contains around 630 pounds of plastic resins, far less than the 900 kilograms of steel used in an average vehicle. Most automotive makers with Scope 3 emission targets are prioritizing the decarbonization of the steel materials they procure.

Methanol could be less of a priority for the overall carbon footprints of end products

Another significant challenge is the long value chain for methanol end-use sectors. Methanol producers often sell to chemical distributors, who then supply to formaldehyde or other specialty chemical producers, who then distribute to downstream product producers (such as particle wood, or plastic products), who finally sell to brand owners. The value chain can be shorter in some cases, where the specialty chemical producers own the downstream product manufacturing, or the downstream product producers own the upstream chemical production. One example is Foresa, which produces wood products, as well as intermediate formaldehyde-based resins.

Current offtake in Europe and China

In Europe, less than 10 low-carbon methanol projects are planned by existing gray methanol or downstream chemical producers. It is unknown how many of these projects are driven by the EU industry mandates. However, the ones making progress seem to be propelled mostly by supply-side subsidies instead. For example, the EU Innovation Fund – a bloc-wide fund supporting the commercialization of low-carbon technologies – has granted funding to a couple of e-methanol projects, some of which are co-developed by formaldehyde producers that are also the likely offtakers. This includes Green Meiga and Triskelion, both of which are in Spain and have formaldehyde producers Foresa and Forestal del Atlántico involved, respectively.

In Europe, less than 10 low-carbon methanol projects are planned by existing gray methanol or downstream chemical producers

In China, the government's tightening environmental permitting regulation has forced some private chemical producers to blend green hydrogen into their coal chemical processes. Coal-based methanol is produced via gasification, which is very inefficient and energy intensive compared to natural gas-based methanol. Coal-based methanol emits 3.3 tons of carbon per ton of output, almost four times that of natural gas-based methanol. The major reason for its high carbon footprint is because the syngas produced from gasifying coal has a H_2/CO ratio of 1, similar to biomass syngas, as explained in Section 4.2. Therefore, additional coal is needed to produce the hydrogen required for methanol synthesis, which, if replaced by green hydrogen, can significantly reduce the coal consumption and carbon footprint of methanol and olefins production.

BNEF estimates that the green hydrogen demand driven by China's regulation is quite small, as hydrogen injection would only partially replace coal use. One million tons of coal-based methanol capacity would only use 62,000 tons of green hydrogen. BNEF tracks 11 green hydrogen usage projects in China potentially linked to this regulation, including those developed by Baofeng and Dongming Plastic.

Section 7. Commercial actions

Scaling low-carbon methanol requires efforts from both buyers and producers

Commercial actions to increase the usage of green products could focus on both scaling demand and lowering the production cost of low-carbon methanol. On the demand side, low-carbon methanol buyers could identify commercial customers who recognize the value of adopting green products, while engaging with upstream producers to build the supply chain. On the supply side, low-carbon methanol projects would benefit from a flexible feedstock supply chain customized to local conditions. Considerations could be:

- Engage with fuel suppliers upstream and cargo owners downstream to make green fuels more affordable for the shipping sector
- Target some early offtakers in the chemical downstream sectors
- Keep feedstock flexible to optimize for local supply chain and cost

7.1. Shipping: Go upstream and downstream to make green fuels more affordable

Context

While the shipping sector has ordered enough ships to consume over 14 million tons of low-carbon methanol within the next five years, there is significant uncertainty surrounding the supply chain. As discussed in Section 6.3, the shipping sector is struggling to absorb the additional costs of alternative fuels. This is slowing the development of low-carbon methanol projects, which would require binding offtakes and a decent return to justify the upfront investment. Without demand commitments, low-carbon methanol producers and ports might also be hesitant about investing in methanol bunkering infrastructure, further negatively impacting shipping companies' ability to rely on low-carbon methanol as their primary fuel.

Consideration

Underinvestment in methanol bunkering infrastructure will negatively impacting shipping companies' ability to rely on low-carbon methanol

One way to secure a low-cost and stable supply of clean methanol would be for shipping companies to go actively upstream in developing the green fuel supply chain. This would help spread the demand signal across the supply chain, accelerating the project financing timeline and possibly driving down costs. The below case studies illustrate two approaches – one by Maersk focusing primarily on building a network of fuel suppliers, the other by COSCO through joint ventures and co-investing to take a stake in the supply chain.

Building a larger volume of suppliers, and getting shipping companies involved in fuel sourcing and producing, can potentially reduce costs in a few ways: the more production there is, the greater the competition on prices; the greater the market size, the better the economies of scale due to the fact supply chains mature faster; and the involvement of shipping companies might help reduce the project risk profile for investors, thereby reducing the cost of capital.

Shipping companies could also look downstream to identify the cargo owners that want to procure zero-emissions shipping services. A book-and-trade system, where cargo owners can easily claim the emissions reduction from voyages powered by green shipping fuels, would be a good model to explore. The third case study discusses how a cargo owner-led initiative for zero-emissions shipping services might help to achieve that.

A caveat is that ship owners are not traditionally in the business of making fuels or financing technologically risky projects, or of running book-and-trade schemes, so there is no guarantee their involvement will help these activities succeed.

Case studies

Maersk: Focusing on building a supplier network

Maersk, one of the largest container shipping companies in the world, has ordered 25 methanol ships.[21] The biggest decarbonization driver for the company is tightening emissions regulation, especially in the EU. BNEF estimates Maersk needs to pay a carbon bill of up to $200 million every year from 2026, if it continues to use heavy oil. The EU ETS implies a $310 carbon cost for every ton of heavy oil used by 2030,[22] which would raise the bunkering cost from $500-750 per ton to $810-1,060 per ton. As methanol has half the energy density of heavy oil, zero-emissions methanol could be competitive at $420-520 per ton under the EU ETS. This is lower than today's estimated production costs of low-carbon methanol, but 'future best case' costs could match this price (Figure 11).

The EU ETS could drive shipping companies to procure low-carbon methanol at up to $520 per ton

BNEF tracks 12 strategic partnerships or memorandums of understanding that Maersk has signed with suppliers in Europe, the US, China and Australia. This move not only sends a strong demand signal to the market, but also drives Maersk's potential suppliers to compete on cost reduction. Maersk has signed the world's first large binding offtake contract, with a Chinese project by Goldwind, for 500,000 tons of bio-methanol and e-methanol per year. China's most competitive renewable resources could reach as low as $25 per megawatt-hour, which implies a green hydrogen cost of close to $3 per kg.

In additional to engaging with third-party suppliers, Maersk has recently begun to develop its own project. Parent company AP Moller Holding acquired green fuel project developer C2X, which is building low-carbon methanol projects in Egypt and Spain. C2X targets 1 million tons per year of low-carbon methanol production by 2030. By funding the project itself, Maersk might be able to achieve a faster commercialization timeline than other projects that needs to go to the market to raise equity financing.

Maersk is driving its potential suppliers to compete on cost

COSCO China: Establishing a value chain partnership with fuel suppliers

COSCO, the biggest shipping company in China, is also investing in the low-carbon methanol supply chain. It has ordered 18 methanol dual-powered ships and retrofitted another four ships with methanol engines.

Contrasting Maersk, COSCO seems to be quite selective with its green fuel partners. The company announced it will establish a joint venture with Jilin Electric, a subsidiary of China's largest renewable developer SPIC, and Shanghai International Port Group, to co-develop the low-carbon methanol supply chain in China. Jilin Electric owns 55% of the joint venture, while COSCO owns 35% and Shanghai International Port the remaining 10%.

COSCO is quite selective over its green fuel partners

This venture serves multiple purposes for COSCO. As an equity investor, it might be able to get better terms securing the project's output. By partnering with the largest renewable developer in China, it may gain insight into the cost structure and development process of renewable projects,

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21 See BNEF's *Low-carbon methanol Offers Container Ships a Net-Zero Lifeline* (web | terminal) for more.

22 Assuming a carbon price over $100 per ton based on and 3.1 tons of CO_2 per ton of bunker oil according to the International Maritime Organization.

and potentially apply them to other projects it might want to develop internally in the future. By partnering with the port of Shanghai, it could also secure buy-in and infrastructure support from the only port in China where methanol bunkering is currently approved.

ZEMBA: Identifying cargo owners who value zero-emission shipping

The Aspen Institute launched an initiative called Cargo Owners for Zero Emission Vessels (coZEV), which consists of 40 global brands actively engaged in efforts to accelerate the transition to zero-emissions shipping. Some 25 of these have set a public ambition to use only zero-emissions shipping for their maritime freight by 2040. As part of this initiative, the Aspen Institute also co-founded a Zero Emission Maritime Buyers Alliance (ZEMBA), with nearly 30 corporate members, including Amazon, Patagonia and Tchibo (see Figure 15).

The goal of the ZEMBA auction is to aggregate demand for zero-emissions shipping services, from cargo owners

In September 2023, this buyers' group announced a Request for Proposals for zero-emission container shipping services to be delivered starting in 2025. The goal is to aggregate demand from cargo owners, sending a signal to the shipping industry about customers' interest in zero-emission shipping services. The competitive tender also allows ZEMBA members to achieve economies of scale and harness competition to minimize the additional costs associated with zero-emission shipping. For the purposes of this first tender, ZEMBA defines zero-emissions shipping as voyages that achieve at least a 90% greenhouse gas emissions reduction on a lifecycle basis compared to vessels powered by heavy fuel oil. The mechanism is outlined below:

- Shipping companies would vie for the aggregated demand of ZEMBA members, expected to reach more than 200,000 twenty-foot containers (TEUs) annually, benchmarked to a transpacific voyage (Shanghai to Los Angeles). This volume is close to 0.8% of the loaded volume of Maersk every year, which was around 23.8 million TEUs in 2023. The total tendered volume would be around 1.15 billion per TEU-mile, which translates to 100,000 tons of methanol demand.[23]
- The Aspen Institute kept all submitted volumes of cargo owners anonymous from the other bidders and conducted the review process independently. These and other features were intended to keep the auction compliant with antitrust laws.
- ZEMBA will likely award the demand to one winner, which will then sign direct bilateral contracts with each ZEMBA member. The length of cargo contracts is often one year, but ZEMBA tendered for up to three-year contracts, for as much as 600,000+ TEUs in total, to give shipping companies more demand certainty.
- ZEMBA will deploy a book-and-trade system, meaning shipping companies do not necessarily have to use green fuels in the exact voyages carrying the freight of ZEMBA members.

The ZEMBA initiative could help to establish a transparent market for zero-emissions shipping services, and ultimately for scaling corporate-led demand for green shipping fuels. Shipping companies could also try to aggregate the supply of zero-emissions shipping services to engage with cargo owners who are currently less interested in the value of green shipping.

[23] Assuming container ships use around 41 grams of marine fuel for each twenty foot equivalent unit mile traveled, according to Ship & Bunker.

7.2. Chemicals: Target early offtakers in certain downstream sectors

Context

The chemicals sector has been slow in adopting low-carbon methanol mainly due to 1) the lack of incentives for its commercial customers to procure green products; 2) the fact that methanol is less of a priority for the end products' carbon footprint; 3) the long value chain between methanol and end-use sectors. See Section 6.4 for more.

Consideration

To accelerate the adoption of low-carbon methanol in the chemicals sector, low-carbon methanol producers could target certain types of end customers that 1) aim to decarbonize their supply chain; 2) consider methanol a significant part of the product's carbon footprint, and 3) own or are involved in multiple parts of the supply chain. The below case studies illustrate three types of customers that might tick those boxes – brand owners using high-purity plastics, furniture product makers, and renewable equipment manufacturers.

Case studies

Novo Nordisk: High-quality plastic packaging

Recycled plastics are not pure enough for the medical sector, so Novo Nordisk settled on low-carbon methanol as feedstock

Novo Nordisk, a medical company based in Denmark, has recently signed an offtake agreement with European Energy for an undisclosed amount of e-methanol. The e-methanol will be used to produce formaldehyde, and further to produce polyoxymethylene (POM), a type of plastic Novo Nordisk uses in its injection pens for medicine.

Novo Nordisk says roughly 95% of its emissions come from upstream materials, a big part of which is plastic use. In order to reach the company's 2045 net-zero target, it has explored a few options to decarbonize plastic use. While recycling plastic is a common route for other industries, it does not work for the medical industry as the recycled products are not pure enough to be directly used. Novo Nordisk also looked into alternative materials to replace plastic use in injection pens, but that takes a long time for research and development, and commercialization. The company then settled on the use of green feedstock, in this case low-carbon methanol, as a viable option to decarbonize its plastic use.

Novo Nordisk is working directly with plastic suppliers, which will have to use the e-methanol it procures as the feedstock. To increase the procurement volume, the company partnered with another Danish firm, Lego, which uses the same type of plastic for is products, to sign the offtake with e-methanol producer European Energy.

Furniture brands: Decarbonizing formaldehyde in plywood

Using low-carbon methanol could reduce the carbon footprint of particle wood boards by 30-50%

Particle wood board is produced by mixing wood residues with resin, wax and other additives to form panels. Resin contains formaldehyde, which is one of the main downstream products of methanol. Particle board could be a good end product to target for low-carbon methanol offtake as it seems to meet all three criteria listed in the beginning of this section:

- Brand owners in the furniture industry, such as Ikea, have begun to procure green materials to decarbonize their supply chains. Similar to the automotive sector, individual consumers might be willing to pay for more expensive products with a lower carbon footprint.

- The particle board industry, in some cases, is more vertically integrated than other sectors. Some formaldehyde producers, such as Foresa, also produce downstream products like particle wood board in Europe.
- More importantly, low-carbon methanol can bring a significant reduction in the carbon footprint of final products. Research studies indicate the carbon intensity of particle board or similar wood composite panels are 400-700kg of CO_2 per square meter, and 1m^2 of particle board requires 68kg of formaldehyde-based resin, which accounts for 10% of the total product mass. One kilogram of resin has 2.5-3kg of CO_2 emissions, therefore accounts for 30%-50% of the total emissions of particle boards.

One caveat here is that particle wood itself is a very low-carbon product. It emits only 10% the CO_2 of cement or 4% that of steel for the same weight of material and could even, if treated as a carbon sink, qualify for negative emissions. Companies using particle wood might not have many incentives to further shave their emissions.

Low-carbon methanol producers in China could target solar and battery manufacturers eyeing export markets

China's export manufacturers: Reducing the carbon footprint of energy equipment sold abroad

Shenghong Petrochemicals, a private petrochemical company in China with 2.8 million tons per year of aromatics and 1.1 million tons per year of olefins production, has commissioned the country's first e-methanol project.

The project captures carbon from the company's own petrochemical processes and combines it with green hydrogen produced from solar power, to make 100,000 tons of e-methanol per year. The plant uses e-methanol synthesis technology from Carbon Recycling International. The e-methanol output is being used in Shenghong Petrochemicals' existing methanol-to-olefin facilities, to produce ethylene and further for ethylene-vinyl acetate copolymer (EVA), which is used as a glue for solar modules.

EVA is an important part of solar modules, accounting for 15% of the cell-to-module cash costs and around 9-10% of the total solar module costs.[24] Chinese solar module manufacturers targeting the overseas market are increasingly being scrutinized for their product's carbon footprint, with France and South Korea being the first two markets to introduce a carbon footprint requirement on imported solar products.[25] Although sourcing renewable power is the most effective measure for lowering the product's carbon footprint, some might go further to address upstream emissions in products such as EVA.

In addition to solar manufacturers, battery manufacturers could also be potential customers for low-carbon methanol producers. Dimethyl carbonate is a downstream product of methanol used mostly in the electrolyte of lithium iron phosphate batteries. EU's move to regulate battery life-cycle emission shall create incentives for battery manufacturers around the world to decarbonize their material use.

7.3. Producers: Keep feedstock and output flexible

Consideration

As it is challenging to get a scalable, stable and cheap supply of sustainable biomass or CO_2, low-carbon methanol producers need to be flexible enough to accept different types of feedstock,

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24 See BNEF's *Solar Cell and Module Efficiency Improves Steadily* (web | terminal) for more.

25 See BNEF's *Leading Solar Makers Ramp Up Decarbonization Claims* (web | terminal) for more.

depending on local policies and resource availability. Producers will also need to size the plant to match local supply availability, because scaling production capacity might come at the expense of escalating costs and logistics difficulties. Especially when it comes to biomass feedstock, there should be an optimal size for low-carbon methanol plants depending on the local conditions.

Low-carbon methanol producers need to be flexible with their approach to their CO_2 and biomass feedstock

A similar approach could be applied to the project output, which could help solve part of the offtake challenge. Developers could produce multiple hydrogen derivatives rather than only low-carbon methanol, as the demand for different types of green fuels is still fluid. Even for the shipping sector, low-carbon methanol might not be the sole answer and some green hydrogen projects in China are planning to integrate both ammonia and methanol production in response to a multi-fuel future. Pure-play low-carbon methanol producers could also consider processing methanol into other types of fuels, such as sustainable aviation fuel.

Case studies

Liquid wind: BECCU feedstock in the Nordics

Liquid Wind is an e-fuel developer in Europe. It has launched four projects and an additional three projects in its pipeline across the EU to be announced by 2025. The company disclosed the following cost targets and business models it plans to implement in its e-methanol projects:

- Feedstock: Liquid Wind plans to use CO_2 captured from biomass power plants (bioenergy with carbon capture and utilization, or BECCU), as well as biogenic CO_2 from municipal solid waste (MSW). The Nordics is home to plentiful boreal forests, intensively managed to avoid wildfires and improve carbon sinks, which could be used for biomass power plants.
- Cost: Liquid Wind is looking for renewable electricity at costs of $30-35 per MWh. If it achieves these costs, it could produce green hydrogen at $5 per kg in 2028. It is planning to source CO_2 feedstock with an interesting model.
  - Liquid Wind covered the initial capex and operating costs of the carbon capture equipment for the municipal combined heat and power (CHP) plants. This removed any upfront investment risk the utility had to bear for carbon capture.
  - Liquid Wind paid the CHP plants for the steam generated as a source of heat for the low-carbon methanol production, and also transports any excess process heat back to the CHP plant as a source of district heating.
  - In return, it gets the CO_2 feedstock at very near the capture cost itself, without having to buy the carbon potentially at a premium from an open market, although the $60 per ton of BECCU capture cost seems to be lower than our estimate of around $90 per ton.[26]

Liquid Wind built the carbon capture facility for a municipal combined heat and power plant to secure the biogenic CO_2 feedstock

- Supply stability: Liquid Wind owns the carbon capture facility and hence is guaranteed the long-term CO_2 feedstock supply. As the transportation and permanent storage network for carbon has not been well developed, utilities might have more incentive to sell the carbon for utilization. BNEF estimates that with a carbon cost of $100 per ton, BECCU is already a competitive route to power production at $72 per MWh[27] in the Nordics region, due to cheap feedstock and the proximity to biomass.

[26] See BNEF's Carbon Capture Cost Model: Power (CCP 1.0) (web | terminal) for more.

[27] See BNEF's *Bioenergy with Carbon Capture: Costly Negative Emissions* (web | terminal) for more.

SPIC: Harvesting waste feedstock in China

SPIC acquired one of the largest bioenergy power producers in China to take advantage of its biomass supply chain

SPIC is one of the largest green hydrogen developers in China and has six low-carbon methanol projects in the pipeline, totaling 635,000 tons of capacity per year.

- Feedstock: The company is looking to use agricultural residue as feedstock. Some 600-800 million tons of crop residues are potentially available in China.
- Cost: Crop residues are abundant and cheap in the northeast part of China, with the cheapest at around $40-50 per ton ($2-2.5 per MMBtu). The phase-down of bioenergy plant subsidies in China has squeezed many power producers out of the supply curve and freed up some biomass available for other applications. Low-carbon methanol costs can theoretically be as low as $430 per ton, using the cheapest source of biomass coupled with the cheapest source of green hydrogen (assuming $3 per kg) available in China. One caveat is that the biomass supply chain is still immature and the marginal cost of biomass could increase as demand scales.
- Supply stability: SPIC acquired one of the largest biomass power suppliers in China in 2023. The company manages a supply chain of agricultural and forestry waste of 10 million tons per year and has a strong relationship with local government. This allows SPIC to take advantage of the already established biomass supply chain for green fuel production.

Abel Energy: Biogenic CO_2 from forestry residue in Australia

Forestry residues could be a good feedstock in countries where forests are actively managed

Abel Energy is partnering with Iberdrola to develop a low-carbon methanol plant of 200,000-300,000 tons per year in Tasmania. The plant has secured land from Hydro Tasmania and procured methanol production equipment from SunGas and Johnson Matthey. It plans to export low-carbon methanol for shipping, most likely to the Melbourne port in Australia, which is in talks with Maersk and other shipping companies for methanol bunkering.

- Feedstock: The project is planning to use biogenic CO_2 from forestry residues as the feedstock, with the potential to add direct air capture carbon in the future. The Bell Bay region exports over 2 million tons of wood chips per year and likely has a plentiful supply of woody residue. However, forestry residues seem to be the most competed over for biomass feedstock.
- Cost: The project plans to use a process called oxy-fuel combustion to burn the biomass in an oxygen-rich environment to get 94% high-purity CO_2.The oxygen is coming from the water electrolysis process used to produce green hydrogen. The total cost for delivered biomass is estimated to be between $50 to $80 per ton in Bell Bay. Assuming one ton of wood biomass emits 1.8 tons of CO_2, and the carbon capture for high-concentration streams is much simpler than BECCU, the CO_2 cost could potentially be lower than traditional BECCU. The heat generated through the biomass combustion could also be used for the electrolysis and methanol synthesis to improve efficiency.
- Supply stability: ABEL energy is partnering with Foresion on a logistics model to optimize the biomass supply chain.

OCI will be using biogas and renewable natural gas as the feedstock for its Beaumont methanol plant

OCI: Biogas feedstock in the US

OCI plans to double its existing methanol facility of 200,000 tons per year in Beaumont Texas, to 400,000 tons per year, and replace the current natural gas feedstock with renewable feedstock.

- Feedstock: The plant will be using renewable natural gas, made from landfill biogas, with additional green hydrogen injected into the process to increase yields.

- Cost: The project requires no capex investment as the renewable natural gas feedstock will continue to feed into the existing Steam methane reforming (SMR) facility for methanol production. In this case, the renewable methanol produced could potentially be very cost competitive (see Section 4.3 for more details).
- Supply stability: OCI secured a long-term contract with the Beaumont city government for a stable supply of landfill waste.

HIF Global: Methanol to jet and gasoline in the US

HIF Global is planning two methanol-to-X plants in Texas, US. A methanol-to-gasoline plant is expected to start construction in 2024, while the other methanol-to-jet project was announced in 2023. HIF contracted Topsoe for its methanol-to-gasoline technology and is partnering with Honeywell UOP to explore converting e-methanol to olefins and further to jet fuels.

Producers are exploring a new pathway to convert methanol to other green fuels

Today, sustainable aviation fuel is mostly made by hydroprocessing vegetable oils, waste cooking oil or other bio-oil feedstock. However, using a food feedstock makes the product expensive (and environmentally challenging) and the supply chain for waste cooking oil is difficult to scale and increasingly competitive. Making synthetic fuels through a Fischer-Tropsch process is an alternative but often comes with an upper limit for jet fuel products, at around 50-60% of the total output. The methanol-to-jet (MTJ) process could provide a new pathway for scaling zero-emissions jet fuel, potentially with a more efficient and flexible technology, although it is not yet approved by the American Society for Testing and Materials.

Depending on the relative demand for methanol in shipping versus aviation, a plant's output mix can be fine-tuned flexibly. For low-carbon methanol producers, adding an MTJ process can ease some demand risks and increase the chance of securing full offtake for the project.

Section 8. Policy considerations

A clear policy framework for supply, demand and standards is needed to scale low-carbon methanol

Scaling the uptake of low-carbon methanol faces challenges on both the supply and demand side. Some view existing demand-side regulations as not yet sufficient for the chemical sector to adopt low-carbon methanol, and supply-side policies as currently too weak to incentivize production. Policymakers may consider complementing the commercial actions in the previous section by:

- Customizing demand-side regulations by sector
- Ramping up incentives and support for producers
- Establishing a clear standard on carbon utilization for green fuels

8.1. Customize demand-side regulations by sector

Context

Demand-side policies could take various forms. Carbon pricing could be one of the most effective tools for the decarbonization of some industries, but prices must be high enough. When carbon prices alone are not enough to drive decarbonization, consumption mandates could be an appropriate complement, having an immediate impact on demand for low-carbon fuels or products. However, consumption mandates may be more effective if the sector in question develops in a way that one clear technology or pathway emerges for decarbonization. Otherwise more neutral policies, such as carbon pricing or emissions intensity targets, could be more reasonable because they do not pick technology winners.

Consumption mandates could work well if the sector has a clear technology winner

Consumption mandates could be a good policy to encourage the chemicals sector to adopt green hydrogen. As methanol's downstream value chain is long and fragmented, any demand-side policy applied to the end products, such as Scope 3 emission regulations, could be weak and have little impact on the upstream decarbonization of methanol. On the other hand, the methanol industry is very concentrated, with the 10 largest producers accounting for over 30% of global capacity (Section 3). Therefore, putting a consumption mandate on methanol producers to replace gray hydrogen with green – where there is a large enough concentration in few markets – may be an effective policy mechanism to drive decarbonization in the chemicals sector. A good example is the EU's hydrogen consumption mandate for industry.

The FuelEU Maritime and IMO regulations, both of which set a carbon intensity target for shipping fuels until 2050, are currently some of the most effective demand-side policies for that sector's decarbonization. As the shipping sector has not reached a consensus on which fuel will dominate in a net-zero future, providing a guide for carbon intensity could provide different fuels a fair playing field to compete on, and allow shipping companies to figure out the best fuel portfolio for compliance.

Policy considerations

Chemicals sector

Countries with large existing chemical demand for methanol, such as China, could consider introducing a mandate for chemical producers to use green hydrogen or green feedstock. The mandate could be to ensure a certain percentage of methanol production uses green hydrogen or green feedstock, which could rise over time. Policymakers can start with a few large state-owned producers, similar to the trial phase of the clean hydrogen power mandate implemented in South Korea, and then expand to the broader industry.

Shipping sector

Setting carbon intensity targets could give different fuels a fair playing field on which to compete

Countries could adopt a similar mechanism as the FuelEU Maritime initiative, or commit to the IMO regulation, to set shipping fuel carbon intensity targets over time. In fact, the Federal Maritime Commissioner in the US has called for clearer standards and benchmarks on alternative shipping fuels to incentivize industry action. Policymakers could consider complementing their carbon intensity targets with some sort of consumption mandate to kick off early demand, ideally focused on a portfolio of fuels closer to commercialization, such as low-carbon methanol and biofuels.

8.2. Ramp up incentives and support for producers

Context

The combination of supply-side subsidies and demand-side mandates has proven effective in scaling low-carbon technologies, such as renewable energy and electric vehicles. While demand-side mandates, such as the EU ETS and FuelEU Maritime scheme, are pushing shipping companies to look for green fuels globally, they may not be sufficient to effect decarbonization on their own.

Without supply-side incentives, shippers might choose to pay the penalties rather than adopt green fuels

As discussed in Section 7.1, shipping companies are looking downstream to identify the cargo owners that want to procure zero-emission shipping services, but to date this group has been somewhat limited in size and does not extend to tankers and bulkers. Many shipping operators are therefore looking at buying green fuels at a price lower than what most projects can produce at, and at a much larger scale as well. If low-carbon methanol costs above $500 per ton, shipping companies might find it more financially suitable to pay the carbon price on their emissions rather than buying green fuels, at least up until 2030.

Feedstock is the biggest constraint for low-carbon methanol cost and scale, as shown in Section 4.3. Feedstock accounts for almost 90% of the levelized cost of e-methanol and almost 40% of the cost of bio-methanol. High feedstock costs are mostly driven by the cost of today's green hydrogen. Lowering the cost of green hydrogen by $1 per kg could contribute to $200 per ton of cost reductions for e-methanol (Figure 13). As hydrogen is used not only in methanol but also in ammonia production, which could be part of the fuel mix for the shipping sector in a net-zero future, government support for hydrogen is important for the sector to scale green fuel supply.

Subsidies for hydrogen, one of the biggest cost drivers for green fuel, are important

Case studies

The supply-side subsidies available for renewable fuels in the road transport and aviation sectors could provide an example for how to scale green shipping fuels.

Cap and trade system

The Clean Fuel Regulations (CFR) in Canada require fuel producers and importers whose fuel has a higher emissions intensity than the CFR targets to buy credits from those with a lower carbon intensity. The CFR aims to reduce the carbon intensity of gasoline and diesel by 15% by 2030 compared to 2016 level.

The fuel producers can comply through producing sustainable aviation fuel (SAF), biofuels, or clean hydrogen, and if they produce more clean fuels than they need, they can sell credits to their peers for revenue. BNEF expects that after 2026 there will be a shortfall in credit supply, thereby pushing up credit prices and encouraging new renewable fuels production capacity.[28] This is a good example of combining demand-side regulations with supply-side incentives for clean fuel producers. Currently, the fuel oil, which is used in the shipping sector, is not included in the scheme.

Direct subsidy

The US has set a combination of tax credits that could potentially make e-kerosene cost competitive

The US has set a target to produce 3 billion gallons of SAF by 2030. To support that, the US has implemented a few incentive schemes, which combined could potentially make SAF and synthetic fuels very competitive:

- The 40B tax credit from 2023-4: Biomass-based SAF producers are eligible for a tax credit of $1.25 per gallon, if the fuel's greenhouse gas emissions are 50% lower than conventional jet fuel. A deeper emissions reduction could lead to a higher credit, with the ceiling capped at $1.55 per gallon.
- The 45Z tax credit from 2025-7: The Clean Fuel Production credit is available for fuels used in highway vehicles or aircrafts, which would include both SAF and synthetic fuels made from hydrogen and carbon. Jet fuel producers can get a tax credit of up to $1.75 per gallon, if the carbon intensity of the fuel is less than 50kg of CO_2 per MMBtu. As conventional jet fuel is around $2.5 per gallon and SAF is around $6.7 per gallon in the US, this subsidy could cover around 40% of the difference.
- The 45V tax credit for clean hydrogen production: Although 45Z theoretically does not allow the same facility to get the 45V hydrogen credits, they can practically be stacked together if the hydrogen and synthetic fuels are made by two separate facilities. In that case, synthetic jet fuels could benefit from a subsidy as high as $5.4 per gallon,[29] assuming the highest hydrogen subsidy of $3 per kg. This could be high enough to make the costs of e-kerosene parallel to its conventional peer.
- Loan guarantee: The US Department of Energy's Loan Programs Office (LPO) is offering up to $3 billion in loan guarantees. Commercial-scale SAF projects can apply for the loan guarantees under the LPO's Title 17 Innovative Energy Loan Guarantee Program.
- Other infrastructure grants: The US has also allocated $245 million in funding to SAF infrastructure.

Policy considerations

Policymakers may need to focus on supply-side subsidies for shipping fuels, especially for the hydrogen feedstock

Policymakers could consider offering more supply-side subsidies to reduce the feedstock cost for low-carbon methanol production. As hydrogen accounts for the biggest portion of e-methanol costs, and possibly also for hydrogen-injected bio-methanol costs, support for it should be prioritized to match the demand-side regulations on shipping. This could be delivered in the form of an auction or contract for difference. Policymakers may need to consider a few factors to set the subsidy level:

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[28] See BNEF's *Credit Shortfall Looms in Canada's Clean Fuel Program* (web | terminal) for more.

[29] Assumes 0.58 tons of hydrogen use per ton of synthetic kerosene.

- The cost of demand-side compliance. If the carbon cost and other compliance mandates are only enough to raise the cost of fossil fuels by a certain amount and there is still a gap for green fuels to be cost competitive, then supply-side policies should aim to cover this gap.
- Other complementary supply-side support. The US provides a good example of how to subsidize renewable fuel production through a set of complementary policies. Policymakers could adopt a similar approach for shipping, using not just direct subsidies but also loan guarantees and infrastructure grants to lower the delivered cost of green shipping fuels.
- The interest from cargo owners in procuring zero-emissions shipping. Airlines have found their corporate and individual end customers have an appetite for carbon offset purchasing – for example, Lufthansa's Green Fares program. However, unlike airlines, shipping companies cannot access individual end customers directly, and the majority of their corporate customers are not as interested in green services as airline customers. Shipping might require more supply-side subsidies for the low-carbon transition.

8.3. Establish a clear standard on carbon utilization for clean molecules

Context

There is not yet a clear standard globally for carbon utilization in chemicals and fuels. The main open question is whether policymakers will approve the use of point-source captured fossil-fuel-derived CO_2 in synthetic fuels, or if the CO_2 must be biogenic or captured from the atmosphere. While this remains undetermined, producers of e-methanol will be indecisive with regards to their feedstock supply chain. Another open question is whether governments will try to support CO_2 utilization over support for permanent CO_2 storage, as this could significantly affect how much available CO_2 there is to make synthetic fuels and chemicals.

The new EU carbon management strategy needs to address some outstanding issues if it is to kick-start investment into clean molecules

The EU has set a binding quota for the transport sector to use 5.5% of advanced biofuels or renewable fuels of non-biological origin (RFNBO) by 2030. RFNBO refers to fuels "derived from renewable energy sources other than biomass or biogas, with greenhouse gas emission savings of at least 70% compared to fossil fuels". This includes green hydrogen and its derivatives such as green ammonia and e-methanol. The greenhouse gas emissions are calculated on a lifecycle basis, so whether the captured CO_2 from combusting fossil fuels counts as 'avoided carbon' matters a lot. The EU currently recognizes such carbon as avoided emissions until 2040, as long as they are already covered under a carbon pricing scheme. E-methanol produced using industrial point-source CO_2 would therefore qualify as RFNBO up until then if the emissions are covered under the EU ETS.

A broader issue is around governments' stance and support for carbon utilization versus carbon storage. The EU recently proposed its first ever Industrial Carbon Management Strategy, which proposes a target for 44% of CO_2 captured in 2050 to be utilized rather than stored.[30] The document seems to confirm that point-source CO_2 can still be used to make synthetic fuels up until 2040, but a few issues have yet to be addressed:

- Additional measures are needed to recognize the potential climate benefits of industrial recycled CO_2 used as feedstock in chemicals, because the CO_2 will still be stored more

30 See BNEF's *EU Climate Plans Long on Ambition, Short on Policy Support* (web | terminal) for more.

permanently than if it were turned into a fuel. This could positively affect the chemical sector's offtake of low-carbon methanol.

- The upcoming 2026 review of the EU ETS will determine whether the carbon footprint of point-source CO_2 is calculated at the point of capture, or the point of emission, in the case of synthetic fuels using recycled carbon. This would determine who in the synthetic fuel value chain would bear the carbon costs. It would also assess potentially including municipal waste incineration in the EU ETS, which could affect low-carbon methanol projects planning to use municipal solid waste (MSW) as feedstock.
- A clear carbon accounting system needs to be established to ensure traceability and transparency in the carbon utilization value chain.

The regulatory uncertainty is holding developers and buyers back from settling on certain feedstocks

The regulatory ambiguity and uncertainty seem to be holding some developers and buyers back from settling on any long-term binding agreements. Many e-methanol producers in the EU are not considering industrial point-source CO_2 as a feedstock and will often buy carbon offsets to account for the fossil-fuel CO_2 derived from plastics, if they use the CO_2 captured from municipal solid waste power plants. Shipping companies like Maersk are also cautious and are trying to avoid industrial point-source carbon for their green fuel supply for now.

The US government seems to be more supportive of carbon utilization. The 45Q provides $35-60 of tax credits per ton of CO_2 for carbon capture and utilization, including for clean fuel production, although the credit value for carbon capture and storage is higher. However, the lack of a carbon management and accounting strategy means EU shipping companies might be cautious about sourcing clean fuels from the US.

Policy considerations

Policymakers need to set a clear framework for carbon utilization strategies. Large-scale permanent carbon storage projects face geographical constraints, permitting challenges and long construction timeframe (7-8 years). Encouraging carbon utilization in the near term could help improve the revenue streams, and therefore bankability, of carbon capture projects.

However, there should be a rigorous standard at a global level to ensure the recycled fossil-fuel-derived CO_2 is sustainable and ensures genuine emission reductions. One way of doing this is for a high enough carbon price to be paid on those emissions before they can be recycled for fuel production. In the EU, free allocation of emission allowances is available for industrial sectors such as steel, chemical and cement, and will not be completely phased out until 2034. This creates ambiguity for any e-fuel projects planning to use fossil-fuel-derived CO_2. Ultimately, if the fossil-fuel-derived carbon is used for fuel production, it would only reduce rather than eliminate carbon emissions.

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