The Success of Synergies

The complementary potential of pairing American ethanol producers with e-methanol production

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1. Foreword

In today's rapidly evolving energy landscape, creating synergies within the energy industry has become foundational to fostering sustainability, efficiency, and resilience. In the energy sector, synergies entail the strategic integration and collaboration between different energy sources, technologies, and stakeholders.

During times of transition, finding synergies between established infrastructure and new solutions becomes increasingly more important. As newer technologies struggle to achieve economies of scale and net zero emission targets draw nearer, the challenge in how to transform the world's energy systems has changed. It is no longer a question of what technological solutions are missing, but how can we deploy the solutions we have in today's pre-existing infrastructure to start driving change now?

By identifying and establishing synergies within the energy sector, traditional industries can leverage newer technologies to adapt to new standards and lower their own carbon emissions. They can also evolve their operations to access the entirely new markets dedicated to reducing emissions across industrial sectors. In doing so, industries could limit global greenhouse emissions and simultaneously create new business cases. These business cases potentially open additional revenue streams, and tap into new markets primed to grow exponentially to meet decarbonization ambitions.

This paper explores the synergies that exist within the emerging e-fuels market and pre-existing industries. It specifically focuses on the complementary nature between e-methanol production and the ethanol industry.

First, this paper explores the various factors that are shaping the upcoming e-fuels market and the unique role that e-methanol has within this field. Second, this paper identifies the unique drivers that affect the cost of e-methanol production. It illustrates how the specific factors of localized renewable energy costs, limited biogenic CO_2 resources and the price of emergent decarbonization technologies can pose challenges to making e-methanol cost-competitive.

However, these factors can be mediated. This paper will illustrate how e-methanol production can become financially viable and an additional revenue stream. It will examine combining numerous different tax incentives for e-fuel production. The paper will also illustrate the advantages of situating e-fuel production plants in areas with built-out renewable energy grids. Lastly, it will explore pairing e-methanol production with industries whose processes already produce a ready supply of biogenic CO_2 (notably ethanol production).

2. Introduction to methanol

Methanol (CH3OH) has long been a key product within the chemical industry. It most commonly goes into the production of formaldehyde, acetic acid and plastics.

Traditionally produced through steam reforming natural gas into syngas and then catalytically converting the syngas through a reactor, methanol is currently produced at a rate of 98 million tons per annum[1]. This production could rise as a result of methanol's wide range of applications and its potential as an alternative fuel source. In fact, it has doubled in the past decade and could reach 500 million tons a year by 2050[2].

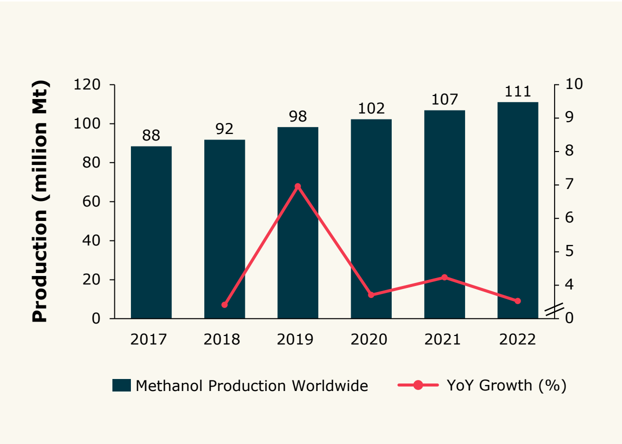


Figure 1: Consistent Yearly Growth in the Methanol Market[3]

These trends show the opportunity that exists within the methanol industry. However, if fossil fuel-based feedstocks exclusively meet this demand, production on this scale will result in 1.5 gigatons of CO_2 emissions annually[4]. This emittance level will not be tenable with the parallel growth of carbon taxation and efforts to meet net zero carbon emissions by 2050.

Luckily, while current methanol production relies heavily on natural gas and fossil fuel feedstocks, there are many different pathways to creating this molecule. These pathways include renewable biomethanol produced from sustainable biomass feedstocks (forestry waste, biogas etc.) and e-methanol. This paper focuses specifically on e-methanol. It also looks at potential synergies it may have with pre-existing industries, specifically the ethanol market in the United States.

As opposed to the traditional methanol production process, e-methanol production involves an electrochemical process using renewable electricity, green hydrogen and captured biogenic CO_2. This process typically combines green hydrogen with biogenic CO_2 to synthesize e-methanol. As a result, the e-methanol emits 90 percent less CO_2 than its fossil fuel-based counterpart[5].

1. Innovation Outlook: Renewable Methanol (irena.org)
2. Ibid.
3. Global methanol production 2022 | Statista
4. Innovation Outlook: Renewable Methanol (irena.org)
5. https://www.methanol.org/wp-content/uploads/2022/01/CARBON-FOOTPRINT-OF-METHANOL-PAPER_1-31-22.pdf, (p.14)

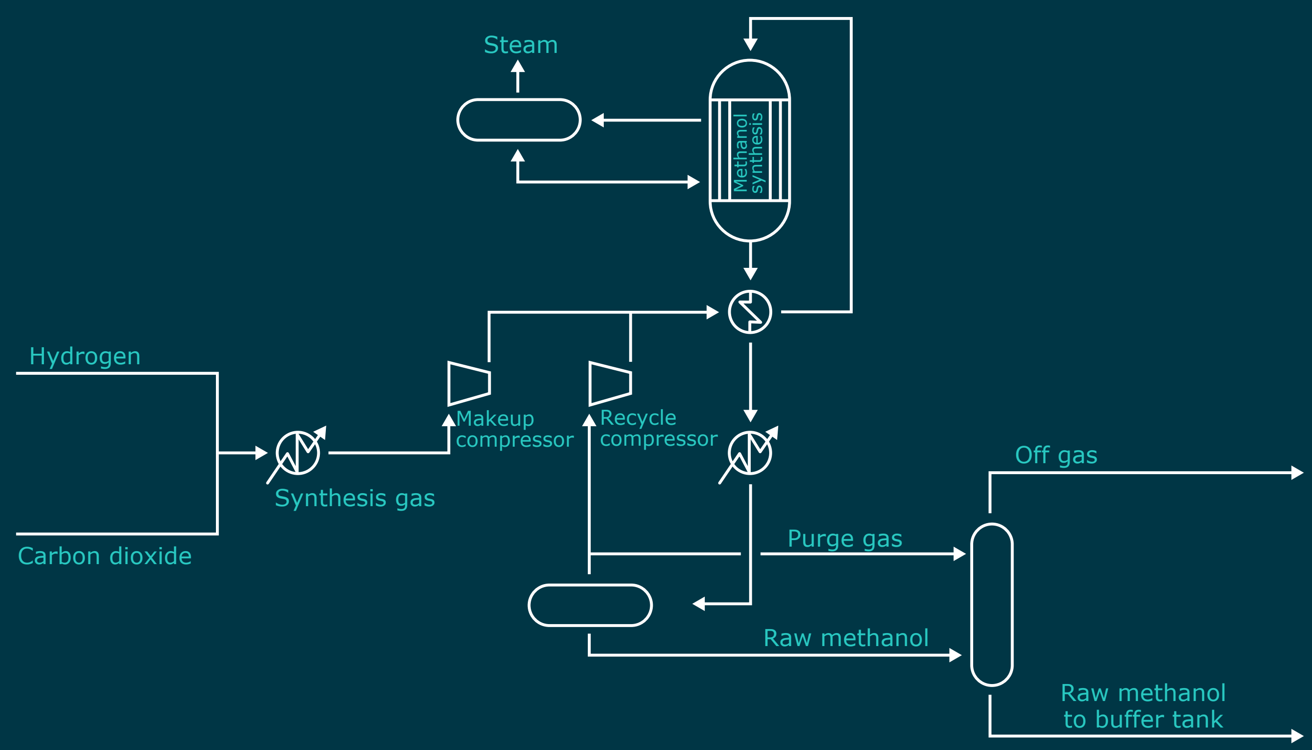


Figure 2: Green e-methanol Production in Detail

Description:

The diagram above illustrates e-methanol synthesis based on Topsoe's methanol loop technology. Renewable hydrogen and carbon dioxide enter the loop through the form of syngas, which is pressurized through a makeup compressor to reach loop pressure. It then passes through a feed/effluent heat exchanger to reach synthesis temperature, all before entering the methanol synthesis reactor.

Within the methanol synthesis reactor, Topsoe's MK- 417 SUSTAIN™ e-methanol catalysts, composed of copper, zinc oxide and aluminum oxide, enable low-temperature reactions. It also actively suppresses byproduct reactions to favor methanol formation. Hydrogen, carbon dioxide and carbon monoxide (stemming from the reverse water-gas-shift reaction in the reactor) then combine to create methanol.

The heat resulting from this exothermic reaction exits as steam generation to ensure that the reactor maintains an optimal temperature.
This enables high conversion and a favorable reaction equilibrium.

A mixture of syngas and methanol exits the reactor, flowing through the feed effluent exchanger and a series of other heat exchangers to cool down the gas stream to below its dewpoint. Finally, the condensed raw methanol collects in a knock-out drum and then pumped to day-storage before entering the distillation section.
The unconverted gas returns to the recycle compressor, where it mixes with fresh make-up gas and fed to the reactor again. This restarts the loop's journey from the beginning.

3. The drive towards e-fuels

In the global energy transition, e-fuels and e-chemicals will be essential components in enabling decarbonization efforts across industrial sectors. Their applicability ranges from storing and transporting renewable energy by leveraging high energy density, to offering near immediate alternatives to fossil-based fuels due to their ability to serve as drop-in fuels. Due to the latter, some e-fuels will be key drivers in the immediate future of decarbonizing hard-to-electrify sectors.

The International Energy Agency reports that "rapid deployment of low-emission fuels during this decade will be crucial to accelerate the decarbonization of the transport sector". It describes e-fuels as a viable pathway to decarbonization with massive scaleup by 2030[6].

The drive to expand the e-fuel sector sets the foundation for massive expansion in the e-methanol market. Much of this drive centers around e-methanol's inherent versatility. According to the International Renewable Energy Agency (IRENA) "[e-methanol] can be used in internal combustion engines, and in hybrid and fuel cell vehicles and vessels. It is a liquid at ambient temperature and pressures, and so is straightforward to store, transport and distribute. It is compatible with existing distribution infrastructure and can be blended with conventional fuels."[7]

Ultimately, e-methanol offers multiple pathways for decarbonization across industries. It can serve as a 1:1 substitute for current methanol use in the industrial chemicals industry. E-methanol can also be a pathway to sustainable aviation fuel (SAF) through MeOH-to-jet processes. Finally, it can serve as an alternative fuel in industrial transport, most notably in international shipping.

6. https://www.iea.org/reports/the-role-of-e-fuels-in-decarbonising-transport
7. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jan/IRENA_Innovation_Renewable_Methanol_2021.pdf

4. The future of the e-methanol market

Forecasts expect the global green methanol market to experience a compound annual growth rate (CAGR) of 3 percent between 2022 – 2027, with a future projected growth rate of up to 53.8 percent[8]. This is in contrast to the current 0.2 million tons of renewable methanol (including both biomethanol and e-methanol) produced annually[9]. So, to achieve this growth, a few key drivers will play a significant role.

Factors such as the need to mitigate climate change, achieve net zero carbon emissions by 2050, and increasing public, political and economic pressures for industries to decarbonize are already driving changes across industrial sectors. Additionally, industries with limited pathways to decarbonize at scale expect e-methanol to play a significant role.

Methanex, the largest producer of methanol worldwide, approximated that the global demand for methanol stood at around 88 million metric tons in 2022. It anticipated that demand would increase by over 14 million metric tons over the next five years.[10] This growth trajectory will be bolstered by a gradual transition towards renewable methanol.

The IRENA holds a similar perspective on e-methanol. In its 2021 forecast, IRENA envisaged a gradual shift towards renewable methanol within methanol production, writing that "looking ahead, the increase in methanol production is expected to see a progressive shift to renewable methanol, with an estimated annual production of 250 million mt of e-methanol and 135 million mt of biomethanol by 2050."[11]

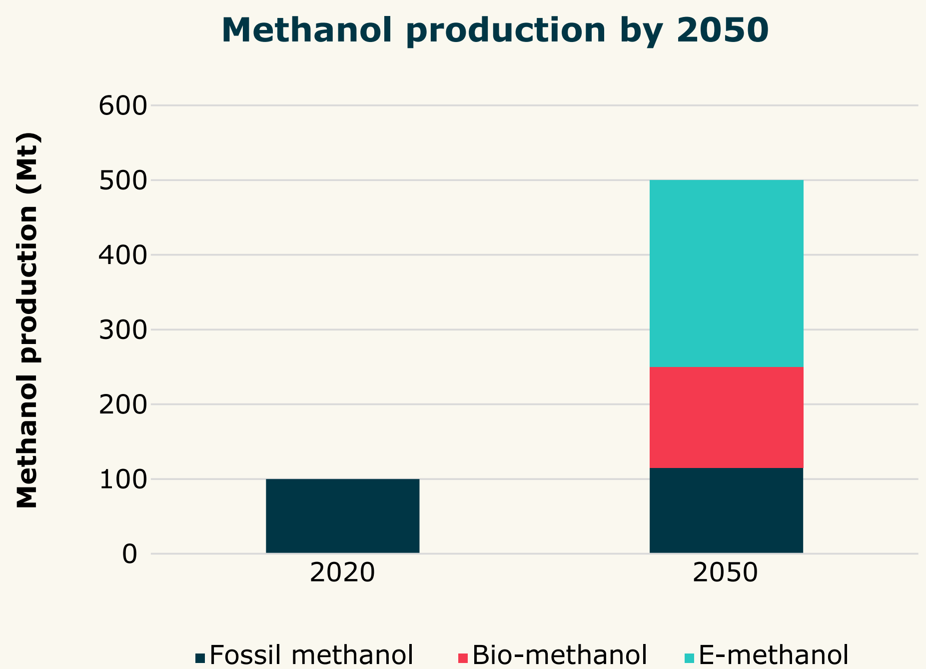


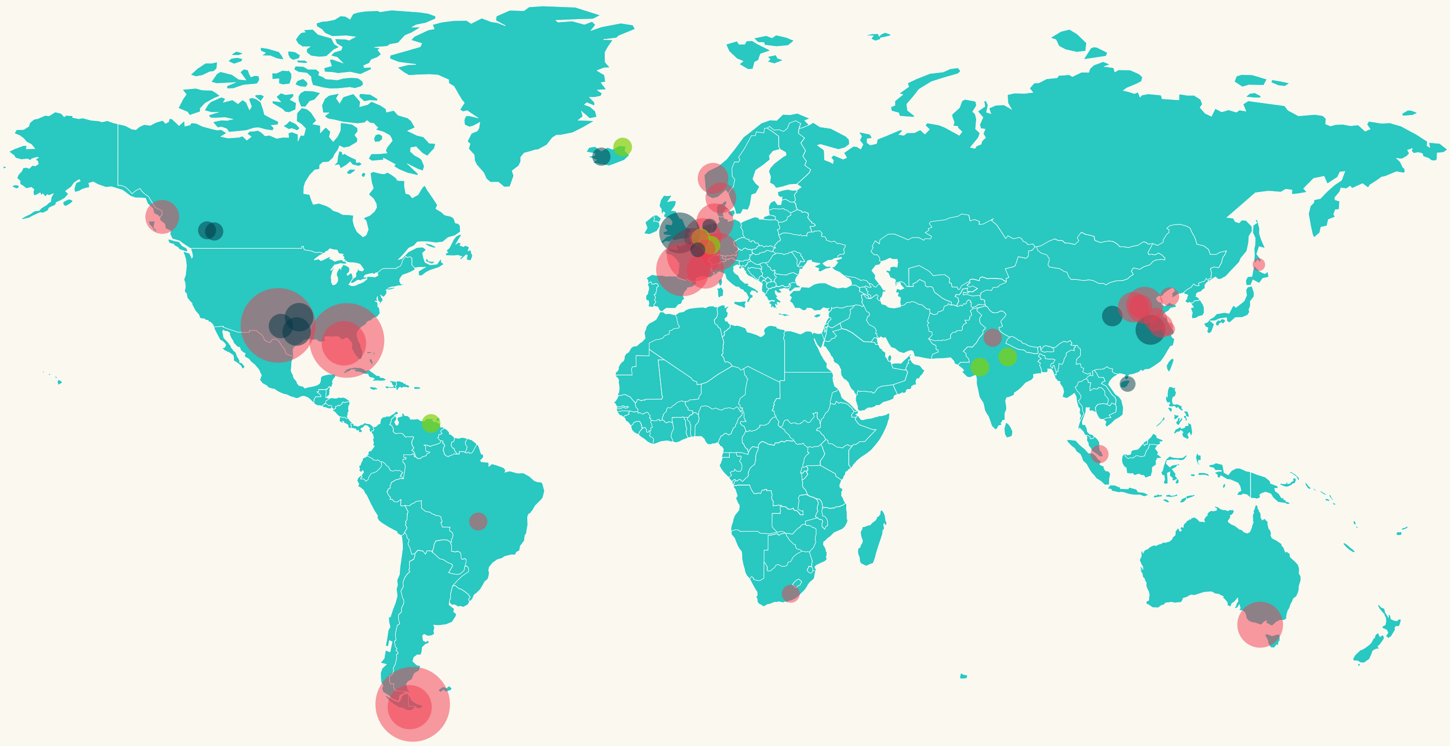
Figure 3: Green e-methanol Production in Detail

8. Green Methanol (marketresearch.com)
9. Innovation Outlook: Renewable Methanol (irena.org)
10. https://www.methanex.com/wp-content/uploads/2023/03/2022-Methanex-Annual-Report.pdf (p.8)
11. https://www.spglobal.com/commodityinsights/en/market-insights/blogs/chemicals/042023-global-initiatives-shaping-the-future-of-green-methanol-production#:~:text=%22Looking%20ahead%2C%20the%20increase%20in,said%20in%20its%202021%20outlook.

Renewable methanol projects

Renewable MeOH estimated annual production by 2050:

- 135 million mt bio-MeOH
- 250 million mt e-MeOH



Sized by mt/year

• Existing • Upcoming • To be confirmed

Growing number of renewable MeOH projects w/ progressive shift to e-MeOH	Capacity to rise over next 5 years thanks to R&D & increased government support: from 5-10 kTPA to +50-250 kTPA	Sale of production for renewable MeOH facilities ramping up

Figure 4[12]: Renewable methanol project expansion

12. Renewable Methanol, METHANOL INSTITUTE: 2023. METHANOL INSTITUTE
Image: "Global initiatives shaping the future of green methanol production", Kamna Kapoor & Stergios Zacharakis, S&P Global Commodity Insights: April 20th, 2023.
Global initiatives shaping the future of green methanol production

5. Case study: shipping

One of the key industries looking to implement e-methanol as a decarbonization solution is international shipping. It is an industry at the foundation of global commerce and responsible for thousands of large cargo vessels around the world. Around 80-90 percent of globally traded goods are transported on these ships.[13]

Traditionally, residual refined crude oil powers the engines on these vessels. They include fuels such as heavy fuel oil, marine gas oil (MGO), and marine diesel oil (MDO). This reliance on fossil-based fuels results in the release of approximately 940 million tons of CO_2 emissions from well-to-wake, contributing to about three percent of the world's total greenhouse gas emissions.[14]

According to the Methanol Institutes 2023 report, shipowners are beginning to recognize the massive potential methanol has as a shipping fuel alternative. It provides them with a low pollution, lower carbon fuel which is closest to matching market needs. This means "a lower upfront CAPEX cost, whereas choosing LNG as a fuel attracts a considerable premium, largely due to the expensive cryogenic fuel tanks and gas handling systems."[15]

The International Maritime Organization (IMO) has committed to reducing shipping emissions by at least 70 percent by 2040[16]. It has also committed to moving towards measuring emissions on a well-to-wake lifecycle basis. This means it is pushing the shipping industry towards lower carbon fuel alternatives. Most important, it is advocating for low caron fuels that are available now.

13. https://unctad.org/publication/review-maritime-transport-2021#:~:text=Maritime%20transport%20is%20the%20 backbone,higher%20for%20most%20developing%20countries.
14. https://www.imo.org/en/ourwork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx
15. METHANOL INSTITUTE_2023-Milestones-Yearly-Publication_FINAL (1).pdf (p.20)
16. https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx

"With IMO's 40 percent CO_2 reduction target of 2030 fast approaching, shipping does not have the luxury of waiting for as yet unavailable fuel technologies to reach technical readiness, regulatory approval and availability," the Methanol Institute reports that lower carbon, "methanol is available now – for existing vessels as well as newbuilds and as shipowners are demonstrating, the increasing trend towards lower carbon and renewable formats will only accelerate its adoption."[17]

To meet regulatory demand, the production of methanol fueled ships is on the rise, with companies such as A.P. Moller-Maersk, CMA CGM and Xpress Feeders leading vessel orders.[18] While demand is projected to continue increasing over the coming decades, there is still a significant disparity between this growth and the available supply of renewable methanol.

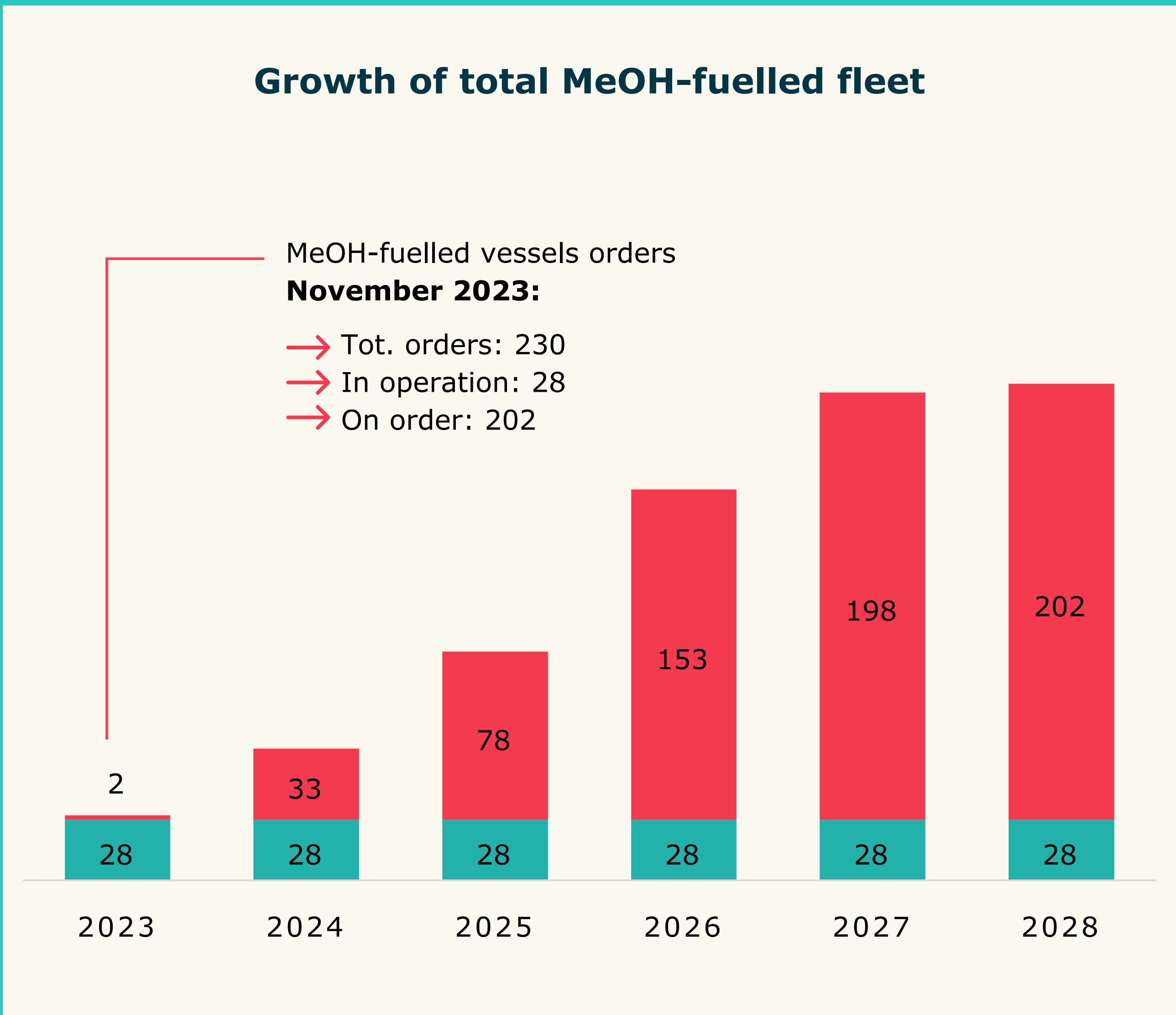


Figure 5: Projected growth in methanol-fuelled vessels[19]

17. METHANOL INSTITUTE_2023-Milestones-Yearly-Publication_FINAL (1).pdf (Page 21)
18. Shippers bet on green methanol to cut emissions, supply lags | Reuters
19. Alternative Fuels Insight (dnv.com)

6. Costs driving e-methanol production

The high-level cost assessment of producing e-methanol is defined by three key drivers: a capital expenditure highly dependent on the cost of key technologies, operating expenditure dependent on the cost of renewable electricity, and finally the feedstock cost of biogenic CO_2.

These first two drivers rely heavily on achieving economies of scale in the long term and government incentives in the short term. In the case of renewable energy, the cost of production has already been driven down significantly. However, access to cheap renewable energy still varies region to region. Because of this, the localized cost of renewable electricity is a decisive factor when scouting for e-methanol plant locations.

For key technologies such as electrolyzers, the IEA forecasts a 60 percent decrease in the capital expenditure of electrolysis technology by 2030, and government incentives such as Title 17 Clean Energy Financing[20] and the IRA's 45V hydrogen tax credit can be used to support projects reliant on this technology in the short term.[21]

The third driver, the feedstock cost of biogenic CO_2, is once again highly dependent on the source, with prices ranging anywhere from $20-$400 USD.[22] It is for this reason that production processes that already produce a steady supply of highly concentrated and low-cost biogenic CO_2 are regarded as natural partners in creating e-methanol, and this is especially relevant in the case of ethanol production.

20. https://www.energy.gov/lpo/title-17-clean-energy-financing
21. https://www.iea.org/policies/16255-inflation-reduction-act-2022-sec-13104-extension-and-modification-of-credit-for-carbon-oxide-sequestration
22. Based on Topsoe analysis of EU3: France, Spain, Germany – identified in BM Market Report as having highest MeOH potential

7. The landscape of tax incentives for e-fuel production in the US

The applicability of incentive structures that exist for building up e-fuel production is of course dependent on a number of variables, such as the specific nature of the project type, chosen feedstock, the local community, state-level incentives etc.

The following illustrates different examples of available tax credits based on the high-level variables relevant to e-methanol production in the United States:

7.1 Incentives for CO_2 usage and sequestration

CCUS Tax Credit (26 USC §45Q) – An ethanol plant capturing CO_2 and ensuring its permanent geological storage while meeting bonus credit construction labor requirements = $85 / ton tax credit.

An ethanol plant capturing CO_2 and delivering it for intended usage in projects, such as e-fuels production, operations while meeting bonus credit construction labor requirements = $60 / ton tax credit.

7.2 Investment and production tax credits

An ethanol plant can elect to treat carbon capture and USE* equipment installed as a 26 USC §48C qualifying advanced energy project credit and follow all bonus credit construction labor requirements to become eligible for a 30 percent investment tax credit.

It is important to note that a facility claiming the investment tax credit (capex) cannot additionally claim the production tax credits (45Q, 45Z, etc.) and would not be able to collect the 26 USC production tax credit for CO_2 captured and stored by that equipment or the 26 USC §45Z production tax credit for lower carbon fuels production.

*The use equipment would be the e-fuels production process.

7.3 Incentives for lower carbon hydrogen production

Clean hydrogen production tax credit (26 USC §45V) – A taxpayer can construct a hydrogen production plant with a carbon intensity of below 4 kg CO_2e / kg H_2.

Assuming all bonus credit construction requirements are followed, the taxpayer would be eligible for a production tax credit on each kg of hydrogen produced and sold or used in the ordinary course of business or trade. The amount would vary from $0.60 to $3.00 depending on the actual carbon intensity.

7.4 Renewable energy tax credits

Clean electricity production tax credit (26 USC §45Y) – A resource that generates lower carbon electricity that meets the carbon intensity thresholds established by the Secretary or Revenue for a taxable year will be eligible for a $0.015 / kWh production tax credit (assuming they meet all bonus credit construction labor requirements).

8. The case for pairing ethanol and e-methanol production

The ethanol industry is uniquely situated to become a key partner and potential supplier of e-methanol. This is due to its ready access to cheap biogenic CO_2, the possibility to convert this CO_2 onsite without the need for additional pipeline infrastructure, and its pre-existing familiarity with distilling and transporting alcohols.

8.1 Converting biogenic CO_2 into an additional revenue stream

The fermentation process within ethanol production yields 99.9 percent pure CO_2[23], with 1KG of ethanol produced giving 1KG of biogenic CO_2 . While the ethanol industry already supplies CO_2 as a feedstock to a variety of off takers, (supplying roughly 270,000 MT of CO_2[24] annually to enhanced oil recovery in Kansas and Texas alone[25]), there exists further opportunities for ethanol producers to expand their revenue base while simultaneously meeting growing policy and market expectations for lower carbon fuels.

By leveraging the IRA's 45Q tax credit, which provides $60/ton of CO_2 captured for usage, along with additional government incentives dedicated directly to the production of lower carbon fuels, ethanol producers in the US are, according to research published in 2017, positioned to "financially capture the added environmental value inherent in producing fuels with a lower carbon footprint."[26]

8.2 Onsite production independent of CO_2 pipeline infrastructure

A significant issue that concerns e-methanol producers is the matter of CO_2 acquisition and transportation. If an e-methanol plant site is not already connected to a CO_2 pipeline, it needs to be transported in. This can create complex logistical and cost challenges. Additionally, the CO_2 emissions that result from this transportation can negatively reflect in the life-cycle assessment of the e-methanol produced. Depending on the region in question, this can determine whether it is classified as a lower carbon fuel.

In the case of ethanol producers that choose to expand into e-methanol production with a small to medium sized plant, onsite access to biogenic CO_2 avoids this issue altogether. By collecting the biogenic CO_2 directly from the ethanol process, ethanol producers avoid the need to purchase it elsewhere. As a result, ethanol producers can enter the growing e-methanol market with a competitive advantage.

23. Capturing and Utilizing CO2 from ethanol white paper
24. https://www.capturemap.no/the-biogenic-co2-breakdown/#:~:text=As%20a%20rule%20of%20thumb,70%25%20biogenic%20CO2.
25. Capturing and Utilizing CO2 from ethanol white paper
26. https://betterenergy.org/wp-content/uploads/2017/12/Capturing-and-Utilizing-CO2-from-Ethanol.pdf

Figure 6[28]: Illustration combining Worley's standardized approach to lower carbon hydrogen production, with Topsoe's scalable, modular e-methanol technology.

8.3 Built-In offtake infrastructure and expertise

Finally, ethanol producers are uniquely positioned to understand, plan and execute the transportation of alcohols. The majority of ethanol producers in the US already leverage rail transportation to connect their products with their respective off takers, in fact according to the U.S. Department of Agriculture, 90% of ethanol is transported by rail or by road[27].

The transportation of methanol would be a 1:1 addition. This expertise once again puts ethanol producers at a comparative advantage to other players in the e-methanol space, with a built-in access to infrastructure that others need to actively search for.

27. https://afdc.energy.gov/fuels/ethanol_production.html#:~:text=According%20to%20the%20U.S.%20Department,approximately%20 30%2C000%20gallons%20of%20ethanol.
28. 10.Eelco20191021IEARenewable-methanol.pdf (windows.net)

9. Conclusion

In the ever-evolving energy landscape, identifying synergies between compatible industries not only establishes exciting new business opportunities, it is a deeply important accelerant in the effort to decarbonize the world's energy systems. This makes it vital to identify these synergies and build the necessary collaborations needed to enable them.

This paper has shown that there is immense opportunity in pairing e-methanol production with ethanol producers in the US. By accessing the ample onsite supply of biogenic CO_2 and leveraging the pre-existing expertise and infrastructure required to produce and transport alcohols, ethanol producers have a unique head start in entering a market that is set to grow exponentially over the coming decades.

E-methanol will act as a key driver in decarbonizing the hard-to-electrify sectors, and may be one of the leading e-fuels used in reducing carbon emissions in industries such as international shipping. The energy landscape has already laid the groundwork for ever-increasing demand in e-fuel production. Now it is time to see which players within the energy industry will take advantage of available synergies, seize these opportunities, and lead this new wave of production.

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