UNLOCKING THE DECARBONIZATION POTENTIAL OF SYNTHETIC FUELS: A ROBUST ASSESSMENT OF THE KEY COST REDUCTION LEVERS

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Overview

Reaching net-zero greenhouse gas (GHG) emissions by 2050 requires a fundamental transformation of society, from the current fossil fuel-centric model to an efficient, highly renewable, and electrified energy system, with clean hydrogen complementing electrification where it is costly or difficult to electrify (Zeyringer et al., 2018; Babacan et al., 2020; DeAngelo et al., 2021; Shirizadeh and Quirion, 2022; Shirizadeh et al., 2023a). However, the low energy density of hydrogen and electricity makes them less suitable fuel options for aviation and maritime shipping for most applications (IRENA, 2021; Clean Air Task Force, 2024). Therefore, decarbonizing these sectors will rely on low-carbon fuels like biofuels and synthetic fuels. Intense cross-sectoral competition for limited biological feedstock, as well as limited availability of sustainable bioenergy feedstock, are expected to hinder large-scale biofuel adoption (Sustainable Shipping Initiative, 2021), positioning synthetic fuels (e.g., ammonia, methanol, and synthetic kerosene) centrally for decarbonizing aviation and maritime shipping in the long run. Their adoption, however, will largely depend on their economic performance.

Synthetic fuels are currently much more expensive than their fossil counterparts, and their future costs involve significant uncertainties (IEA, 2023). Nevertheless, they hold the key to decarbonizing aviation and shipping, requiring a thorough analysis of different cost components and their impact on synthetic fuels' overall costs. This analysis would highlight key cost reduction levers and the areas to focus on for creating affordable future synthetic fuel markets. Moreover, it would provide critical insights into the arbitrage among different fuel options, leading to low-regret investment strategies. This paper focuses on the development of future synthetic fuels markets, the key cost components of these fuels, and the necessary actions to reduce their production costs to unlock their decarbonization potential effectively.

Methods

This study combines two modeling approaches. First, demand was estimated using a mixed top-down and bottom-up methodology. Second, an optimization model was developed to assess the cost and origin of synthetic fuels and the input hydrogen in each geography for each year and their trade. Hydrogen demand estimation follows the methodology described in Shirizadeh et al. (2023b): we identify each sector's electrification potential yearly, based on sectoral characteristics and existing outlooks (IEA, 2022a; IRENA, 2022; and DNV, 2022). We then identify the demand that can be met by hydrogen, synthetic fuels, and bioenergies as the demand that cannot be met by electricity. Following trends in hydrogen development and the latest public announcements and outlooks, the demand values have been revised downwards compared to Shirizadeh et al. (2023b). Assuming gradual integration of more efficient airplanes and vessels and implementing operational efficiency measures in vehicle utilization, using ICCT's "Transformation" scenario (ICCT, 2022) and IMO's EEDI regulation requirements (IMO, 2024), future energy demand levels for aviation and shipping have been identified. Assuming almost 40% of synthetic fuels in aviation and 70% in shipping, the demand for hydrogen-based synthetic fuels in these sectors reaches 75 MtH2eq and 154 MtH2eq by 2030 and 2050, respectively.

Following a detailed literature review (notably based on IEA, 2022b; IEA-GHG, 2021; and TNO, 2019), high-confidence biogenic and direct air capture-based (DAC) CO_2 potentials and cost spectrums were identified. While biogenic CO_2 availability is limited to regions with significant biomass potentials, DAC-based CO_2 can be produced virtually everywhere. The average cost of DAC is estimated to fall from around US\$500/tCO_2 in 2030 to slightly above US\$300/tCO_2 by 2050. The demand values and different cost elements, including calculated CO_2 costs, are then fed into a global clean hydrogen and its derivatives supply and trade optimization model (HyPE). A detailed description of the HyPE model and the baseline input data used can be found in Deloitte (2023) and Shirizadeh et al. (2023b). The updated cost and hydrogen and synthetic fuels demand data can be found in Appendix 1 of Deloitte (2024a).

Results

The modeling results show that the costs of producing synthetic kerosene, methanol, and ammonia vary from US$45/GJ to US$130/GJ, US$33/GJ to US$101/GJ, and US$33/GJ to US$71/GJ, respectively, in the short run (2030). By 2050, production costs fall significantly, varying between US$32/GJ and US$78/GJ for synthetic kerosene, US$25/GJ and US$61/GJ for methanol, and US$23/GJ and US$44/GJ for ammonia. This significant variation mainly stems from the geographical variability of renewable endowments, impacting the production cost of clean hydrogen. The cost of climate-neutral CO_2 is another essential element, representing almost half of the production cost of methanol and synthetic fuels in regions with high renewable endowments if produced via direct air capture. However, availability of biogenic CO_2, notably as a byproduct of bioenergy processing, can reduce the CO_2 component to below 10% of methanol and synthetic kerosene production costs. Therefore, the cost competitiveness of synthetic kerosene and methanol is tied to biomass resources availability, which significantly varies globally. In contrast, conversion costs are relatively stable worldwide and always represent only a small part of synthetic fuels' overall production costs: around US$11/GJ, US$6/GJ, and US$8/GJ for synthetic kerosene, methanol, and ammonia, respectively, in 2030 and US$6.5/GJ, US$4/GJ, and US$5/GJ in 2050.

As hydrogen is highly capital-intensive and it represents bulk of synthetic fuel production costs, synthetic fuels' production cost is highly sensitive to financing conditions, internalized through the weighted average cost of capital (WACC). The riskier a project, the more difficult its financing conditions, and the higher its WACC. Ironically, the countries with the best renewable endowments often have the highest WACC levels. For instance, with no de-risking, financing costs can represent 60% of the cost of producing solar PV-based renewable hydrogen in Namibia (US$4.2/kg$H_2$ out of US$7.1/kg$H_2$). De-risking measures, such as different guarantee mechanisms, can reduce the WACC of such a project from 14.4% to 6.4%, bringing the overall renewable hydrogen production cost down to US$4.5/kg$H_2$, dividing the financing costs by 2.5 (Deloitte, 2024b). This would reduce the cost of producing ammonia from US$81/GJ to US$55/GJ and methanol (assuming using biogenic CO_2) from US$80/GJ to US$54/GJ. Therefore, de-risking investments is a highly effective lever to reduce the cost of synthetic fuels. As transport costs represent a small part of the landed cost of synthetic fuels, de-risking synthetic fuel production projects in the global south with abundant renewable energies can further reduce the costs associated with synthetic fuels’ value chain.

Despite the expected long-term cost reductions, synthetic fuels will likely remain more expensive than fossil fuels. Our modeling results show they are two to ten times more costly than fossil fuels in 2050. A progressive support mechanism taxing CO_2 emissions of fossil fuels and using the tax revenues for subsidizing synthetic fuels can reduce this cost difference significantly, and in a few cases, breakeven points can be reached as early as 2035 for maritime shipping and 2045 for aviation. Nevertheless, using a carbon tax in line with IEA’s Net-Zero pathway (progressive increase reaching US$250/t$CO_2$ in 2050, IEA, 2023), in such a zero-sum policy support scheme, due to limited availability of low-cost CO_2 feedstock and inter-sectoral competition for both clean hydrogen and sustainable CO_2, an important share of synthetic fuels supply (notably synthetic kerosene and methanol) will remain more expensive than conventional fossil fuels, even in the long run. Though it is worth mentioning that fuel cost does not necessarily represent an important part of a shipped good's final cost. For example, shipping 1kg of rice from Thailand to the United States costs around 3.5 US cents, representing less than 1% of its retail price of US$4/kg. Using DAC-based methanol (the most expected synthetic fuel for shipping in our analysis) would only add 0.5% to its final retail price. For aviation, while fuel cost represents an important part of air travel cost and a shift to synthetic fuels can lead to significant increases in travel fares (up to 50% increase for a flight from London to New York), it is expected to add gradually to the current mix, not exceeding 40% of the final aviation fuel mix even in the long run.

Conclusions

Our findings demonstrate that synthetic fuels are significantly more expensive than their fossil counterparts. While there are notable uncertainties regarding technology development and clean hydrogen and climate-neutral CO_2 costs, synthetic fuels will likely remain more expensive than fossil fuels in the foreseeable future. This necessitates policy schemes beyond subsidies and taxes, such as incorporation mandates and emission quotas, to kickstart and sustain their uptake.

In addition to renewable endowments, the availability of biogenic CO_2 is crucial to produce low-cost carbon-based synthetic fuels like methanol and kerosene. Thus, synthetic fuels' production costs vary significantly across different geographies (up to 3x in 2030 and over 2x in 2050). However, their transport over long distances entails limited additional costs. This calls for the development of truly global synthetic fuel markets, with facilitated trade and investments. On the one hand, it would provide regions with limited renewable and biogenic CO_2 potentials with affordable synthetic fuels. On the other, it can generate revenues for regions with high renewable endowments. Therefore, beyond regional and national policies, a globally harmonized regulatory framework, including harmonized certification and standards, is crucial for synthetic fuels' uptake.

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