THE BIG CO_2 QUESTION - TO STORE OR CONVERT

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Why carbon management, not only carbon capture?

To limit global warming, almost all fossil fuel-based emission scenarios require sizable levels of natural or artificial capture of CO_2. As of now, by 2030, 430 million tonnes of Carbon Capture, Utilisation and Storage (CCUS) projects are expected to be operational, under construction, or in the planning stage (IEA). These projects will become a major source of CO_2. Industrial emitters are seeking socially, financially, and environmentally sustainable solutions for CO_2 usage, other than storage, and that means considering all possible value chains, inclusive of enhanced oil recovery, power-to-liquid, and power-to-gas technologies. For instance, Abu Dhabi's ADNOC plans to develop 10 million tonnes of carbon capture capacity by 2030 and continuously evaluates the best possibilities for utilising this CO_2.

Which green fuel to produce?

Power-to-liquid or gas technologies can convert CO_2, water, and renewable electricity to climate-friendly synthetic feedstocks or liquid energy carriers, whose market prices could compensate for the higher production costs, enabling financial sustainability without subsidies or incentives. While these e-fuels emit CO_2 when burnt, they limit additional accumulation of CO_2 in the atmosphere by re-circulating the captured CO_2, rather than producing new CO_2. These e-fuels include many products, inclusive of e-methane, e-methanol, synthetic liquefied natural gas, liquefied bio-methane, synthetic petrol, compressed bio-methane, oxy-methylene, dimethyl ether and others.

To identify the right synthetic fuel and its targeted use, a filtering process should be considered, for instance

1. **Direct usage of renewable electricity should always be prioritised.** The conversion of renewable energy to e-fuels incurs 50% of electricity losses, with a further 70% energy lost during the combustion of these fuels. In contrast, electric vehicles can utilise the same renewable electricity with almost a 70% efficiency, with only 10% lost during charging and another 20% lost during operation. Electrification, where possible, should be prioritised (for road, rail, and industrial applications), and e-fuels should target hard-to-abate and hard-to-electrify applications (marine, aviation, heavy industries with predominantly process-based emissions).

2. **The technology readiness level (TRL) is a subjective debate.** We should only consider fully commercial technologies for commercial and scaled applications, with a TRL of 9-10. As of today, methanol production from CO_2 and hydrogen is an established technology, with the possibility to produce subsequent products from methanol, such as dimethyl ether or sustainable aviation fuel (SAF).

3. **Agricultural crops diverted to biofuel production have adversely impacted consumer food prices** by locking in considerable agricultural produce (often incentivised by pro-biofuel subsidies and financial incentives). Almost 22% of sugarcane production and 16% of maize production is used for ethanol production. About 15% of vegetable oil production (mostly palm oil, soybean oil, and rapeseed (canola) oil) goes into biodiesel production (OECD/FAO Agricultural Outlook 2022). In the past, this has led to food price spikes in 2007/08, 2010/11, 2012/13, and most recently as a result of the Russia-Ukraine war. The situation will only worsen with reduced availability of fresh water and agricultural land. The solution is to only consider waste products and crop residues as potential feedstocks for biofuels and consider artificial mechanisms for re-converting CO_2 and hydrogen to synthetic fuels.

What is most promising?

Considering the above, the most promising candidate for synthetic fuels today seems to be methanol. Methanol is a precursor to producing formaldehyde and acetic acid, which have many different use cases. In combination with isobutylene, methanol forms an ether (MTBE) which has been used as an additive for unleaded petrol to achieve more efficient burning.

Methanol is also a solution for the marine sector, which, as per the new IMO sulphur regulations, needs to reduce marine fuel sulphur content to 0.1%, and the only options include very low sulphur diesel (MGO), installing scrubbers, or converting ships to LNG. All the former options are hurdled by cost, emissions, or adoption at scale issues. On the other hand, synthetic methanol could replace conventional marine fuel and drastically reduce SOx, particulates, NOx, and CO_2 emissions if produced from renewable sources and captured CO_2.

Over 90 methanol plants operate worldwide with a combined annual production capacity of 110 million metric tonnes, inclusive of China's captive coal-to-olefin/coal-to-propylene sector, which has its own captive methanol production exclusively for olefin production. Naturally, there is active consideration for using renewable hydrogen and captured CO_2 to create syngas for olefin production as well.

Methanol synthesis is similar to catalytic methanation, where CO_2 is catalytically combined with green hydrogen to generate methanol. The reaction is exothermic, and gas-phase single-step hydrogenation of CO_2 to methanol operates in the temperature range of 230-280 degrees and at high pressures (60-80 bar). Economic evaluations of carbon capture and utilisation processes producing methanol, conducted by Nyari et al. and Yousaf et al., resulted in methanol net production costs of 1.8-2.1 USD/kg methanol and 0.7-1.1 USD/kg methanol respectively. Given current methanol prices of 0.3 USD/kg, the cost competitiveness of synthetic methanol requires either a green premium or carbon tax on conventional fuels.

What could make synthetic methanol plants happen?

The answer is multi-faceted. Firstly, the capacity factor of synthetic methanol plants should be high (in the range of 8,000 hours). This will require in-house captive renewable power generation capacity supplemented by grid power and clean energy certificates. Secondly, variable OPEX accounts for 70% of the cost of large methanol plants, and cheap renewable power, green hydrogen, or carbon capture can substantially reduce the cost of synthetic methanol. A lower WACC expectation, free land, and proximity to ports or end-users could further reduce costs.

The conversion of methanol to sustainable aviation fuel (SAF) presents the possibility of allowing green synthetic fuels to be sold at even higher prices or premiums. The aviation industry produces roughly 3% of global CO_2 emissions. The International Civil Aviation Organisation (ICAO) established the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) in 2016, intending to cap net carbon emissions of international flights at the 2020 level by 2027, and by 50% by 2050 relative to 2005 levels. Airlines could invest in emission reduction via offsetting in other sectors or reduce emissions directly through energy efficiency in the design or operations of their fleet or with the use of SAF. However, as of last year, SAF only accounted for 0.2 per cent of aviation fuel use, given its uncompetitive price (conventional aviation fuel sold at 2.9 USD per gallon vs SAF at 6.7 USD per gallon in the US, 2023). Given fuel is a third of an airline's operating costs, shifting to SAF will require a considerable green premium on ticketing.

Is converting methanol to SAF feasible?

Power-to-Liquid (PtL) routes with Fischer–Tropsch (FT) and methanol-to-jet (MtJ) fuel synthesis are SAF production pathways if CO_2 and hydrogen are available. Both MtJ and FT routes show different advantages and disadvantages, but the main technical and economic results indicate that the routes are similarly suitable for the synthesis of SAF. As per process analysis performed by V. Eyberg and S. Fendt, the Levelised Cost of Production (LCOP) of the optimal Fischer Tropsch and Methanol-to-Jet configurations are nearly equal at about 0.91 USD/kWh, which is around nine times the average costs of fossil jet fuel in 2022.

What could process integration offer?

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The GCC region is characterised by low-cost renewable resources, ample land availability, an increasing supply of captured CO_2, substantial variation in summer and winter power demand, flexible reverse osmosis-based desalination capacity, water storage, and good port and transportation infrastructure. In this respect, oil, gas, electricity, and water sectors could integrate and co-optimise their processes to produce synthetic fuels. This process integration will enable substantial cost savings and produce new sources of revenue from oxygen, methanol, ammonia, SAF, or others. Given that green hydrogen production from cheap renewable electricity and desalinated water is critical here, the role of electricity and water authorities is extremely important. However, most electricity and water authorities in the region are regulated monopolies, and their role is constrained to providing electricity and water only. A different sector-operating model could unlock substantial cost savings, which could enable the GCC region to continue its energy leadership in conventional fuels to green synthetic fuels as well.

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