Scaling up direct air capture

Not just a possibility but a necessity

June 2022

Summary

Currently, aircraft rely almost exclusively on fossil fuels to be able to fly thereby contributing to climate change. Sustainable aviation fuels (SAFs) offer a viable alternative but currently only account for 0.05% of aviation fuel supply[1]. Therefore, the European Commission (EC) has proposed a SAF mandate known as ReFuelEU. Under this mandate, fuel suppliers will have to supply an increasing share of SAFs at Union airports, from 2025.

SAFs can be advanced biofuels or e-kerosene (otherwise known as synthetic kerosene, or electrofuels). Of these fuels, e-kerosene, made by combining hydrogen and CO_2, provides the most scalable option and should be supported by policy. But to produce e-kerosene, you need CO_2 and it is crucial that we use sustainable carbon feedstocks. To be sustainable, the CO_2 has to come from the atmosphere either via sustainable biomass or via a technology known as Direct Air Capture (DAC)[2]. To demonstrate that in the longer term, only DAC has the potential to sustainably meet the needs of e-kerosene production, Transport & Environment (T&E) commissioned Ricardo to conduct a study to analyse the feedstock availability of fossil and biogenic CO_2 and to compare it with DAC. The objectives were to:

- **Analyse the availability of fossil and biogenic CO_2.** How much fossil and biogenic CO_2 could be supplied if we could make full use of it? How much e-kerosene could be produced with these resources? Three scenarios are considered: the EC's proposal, T&E's preferred SAF deployment targets with continued growth and T&E's preferred targets with demand management measures to reduce energy demand from aviation.
- **Find an equilibrium between fossil, biogenic and DAC CO_2.** When can DAC replace other carbon sources? What is the ideal contribution of the three different sources to the CO_2 supply over time?

The study shows that fossil sources (industry and power) and biomass will not be enough to fulfil the demand for CO_2. Fossil sources are expected to come from industries that will decarbonise and any captured CO_2 will be sent to storage (except for the existing supply from steam methane reforming, see table 12 in the report). Biogenic CO_2 is limited in supply as about half will be sent to storage. To meet demand, the study shows that 281-442 $MtCO_2$ from direct air capture will be required by 2050. DAC will start to supply CO_2 in 2030 and overtake other carbon sources as the main source by 2035-2040

[1] World of Aviation (2021) SAF USAGE SITS AT JUST 0.05% IN EUROPE: EUROCONTROL
[2] See section 3.2.3 of the report for a detailed explanation of the technology.

depending on the scenario. It is thus crucial that we start to support and invest in DAC today. T&E, therefore, recommends:

- An increasing share of DAC carbon mandated as part of ReFuelEU within the synthetic aviation fuel sub-target: 10% of the carbon feedstock in 2030 from DAC, 20% in 2035, 40% in 2040, 80% in 2045 and 100% by 2050.
- Prioritise synthetic aviation fuels, DAC and zero-emission aircraft when funding projects aimed at decarbonising aviation through the Innovation Fund.
- Implement demand management measures such as the modal shift and a kerosene tax to reduce the amounts of DAC required.

1. Sources of CO_2 other than DAC

Fossil CO_2

Currently, the CO_2 supply largely comes from the process of steam methane reforming (SMR) which produces hydrogen as the main product, which is subsequently used primarily for ammonia production, and CO_2 as a by-product. Today, CO_2 is mainly used for the production of urea, enhanced oil recovery and food and beverages (see figure 2 of the report). The study shows that the supply from SMR was 39.8 $MtCO_2$ in 2020 and is projected to increase to 45.6 $MtCO_2$ in 2030. However, from that point on, it is expected that low-carbon hydrogen (either green, from renewables, or blue, from SMR while capturing carbon and sending it to storage) will start to displace grey hydrogen. As a result, the **CO_2 supply from unabated SMR is expected to reach zero by 2050**. And while carbon capture in the industrial sector (e.g. cement and steel) is expected to increase in the coming years, projections in line with the EU's legally binding target of net-zero emissions by 2050 all assume that **CO_2 will be sent to storage**. Currently, all planned industrial and power carbon capture projects aim to store **CO_2** rather than utilise it.

Biogenic CO_2

Today, the biogenic CO_2 largely comes from bioethanol fermentation (0.9 $MtCO_2$ in 2020). The future theoretical biogenic CO_2 supply is significantly higher than that from SMR with 557 Mt in 2025 to 915 Mt in 2050. Sources other than bioethanol fermentation include large-scale solid biomass facilities, biogas upgrading and combustion. The aforementioned figures only include point sources (power plants, industrial installations) as for distributed sources (residential and commercial e.g. fuel combustion in vehicles or domestic properties), capturing the CO_2 is unfeasible. Accounting for where Carbon Capture and Storage (CCS) is viable and taking into account the time to install CCS capacity (see table 35 of the report) reduces the potential to 1 Mt in 2025 to 334 Mt in 2050. If we only consider sustainable biogenic CO_2 (meaning not resulting from problematic production practices and respecting the waste hierarchy[3]), supply would be even less with 0 Mt in 2025 to 26 Mt in 2050. Not all the captured CO_2 will be available for utilisation, as some will be sent to storage. To determine the division between usage and storage, the

[3] See Appendix I of the report for the list of sustainable and unsustainable feedstocks.

European Commission's 1.5TECH scenario[4] was used which assumes 54% of biogenic CO_2 to be stored in 2050, meaning 46% is available for utilisation. This results in a **biogenic supply of 1 MtCO_2 in 2025 to 156 MtCO_2 in 2050.**

2. Demand for CO_2

The study highlights that not all the available CO_2 will be able to be used to produce e-kerosene. There are other competing sectors that will also require sustainable sources of carbon. The other sectors considered in this report include e-fuels (other than e-kerosene), chemicals, materials and horticulture. For e-kerosene, three scenarios were considered to determine the expected demand of CO_2 depending on the ReFuelEU sub-targets for synthetic aviation fuels: the Commission's proposal, T&E's preferred targets and T&E's demand managed forecast[5]. In all three scenarios, the share of zero-emission aircraft (hydrogen and electricity) in aviation's energy requirements is assumed to increase from 1% in 2030 to 20.9% in 2050, which technically reduces the demand for CO_2 for e-kerosene.

The study finds that **the whole market demand for CO_2 increases from 45 Mt in 2025 to 436-597 Mt in 2050 (99-313 for e-kerosene)** depending on the scenario. From the section above, it is clear that neither fossil nor biogenic sources will be enough to meet this demand which outweighs the supply by fossil/biogenic sources by around a factor of three.

In order to meet demand, **DAC will need to provide significant amounts of CO_2, ranging from 5-10 Mt in 2030 to 281-442 Mt in 2050**. Figure 1 below summarises the projected supply and demand for CO_2, clearly showing an increasing gap between supply by SMR and biogenic CO_2 and demand. In order to fill that gap, we will need increasing amounts of direct air capture, especially from 2030 onwards, even with demand management. While biogenic CO_2 could in theory be enough to meet e-kerosene demand in the ReFuelEU continued growth scenario, other sectors will also need to decarbonize and thus a source of sustainable carbon will be needed. It is thus important to look at the total CO_2 demand.

[4] Decarbonization scenario limiting global warming to 1.5 °C from the 'Clean Planet for all communication' with a higher contribution of technology options compared to the 1.5LIFE scenario.
[5] Demand managed forecast means leisure travel capped at 2019 levels and business travel capped at 50% of 2019 levels.

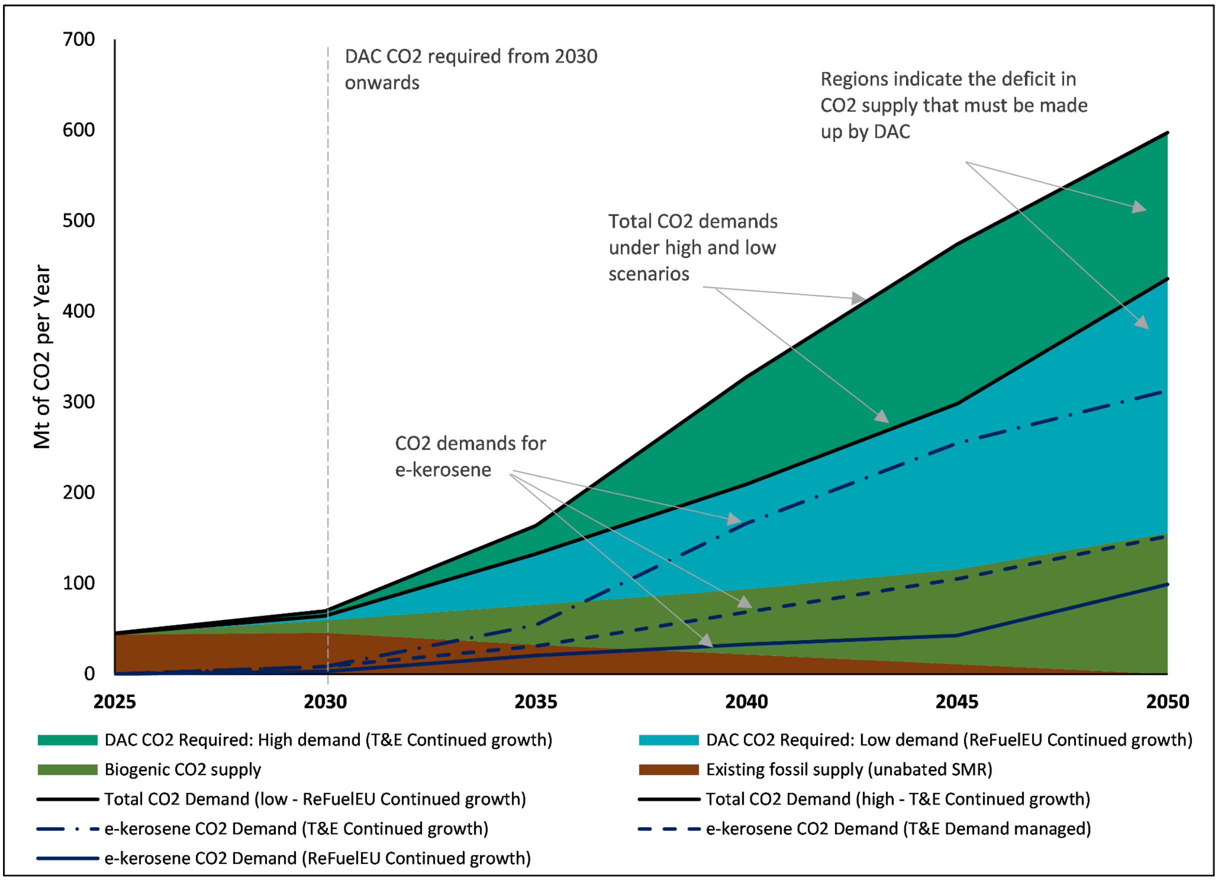

Figure 1. Summarising figure by Ricardo of CO2 demand and supply from 2025-2050.

3. Scaling up DAC

According to a recent article by the Energy Monitor, the current EU27+UK DAC capacity for utilisation is 0,000266 $MtCO_2$[6]. While CO_2 could theoretically be transported from Norway and Switzerland, the study shows that quantities would still fall short of the required 5-10 Mt in 2030. According to expert views gathered by Shayegh et al (2021)[7], if we continue with current policies, DAC capacity would not be sufficient to meet even the lower range of needed supply (as shown in Table 14 of the study). However, according to those same experts, **with policies consistent with limiting global warming to 2 °C, it is possible to meet and even exceed demand**.

The study finds that the annual growth rates for DAC capacity required are significant, especially in the early years, with 37-59% for 2025-2030. On average (2025-2050), the annual growth rate required is 25-28%. However, if we were to delay the increase in capacity, these numbers would increase. With a delay of 10 years, for example, the required growth rate would almost double, making reaching our goals more difficult. It is clear that **in order to give ourselves the best chance of meeting the targets, we need to start creating more DAC capacity now.**

[6] Energy Monitor (2022): The birth of the carbon removal market
[7] Shayegh et al (2021): Future Prospects of Direct Air Capture Technologies: Insights From an Expert Elicitation Survey

Such high growth rates for breakthrough technologies are not unprecedented. Offshore wind had a similar growth rate compared to what is required for DAC (Figure 2). While we should be careful in comparing different technologies, it shows that with the right incentives and regulations, these solutions can come to fruition rapidly.

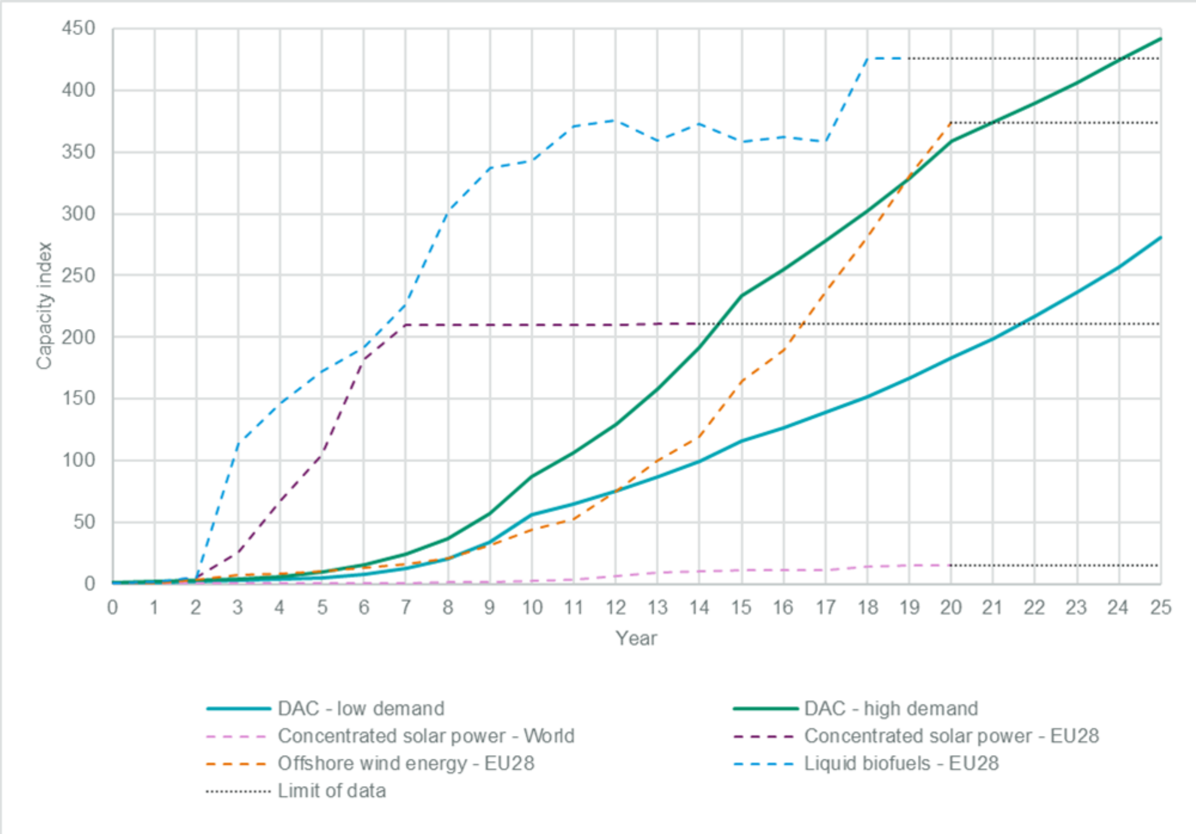

Figure 2. Indexed capacity growth for various technologies and required DAC to meet targets[8].

4. Reducing costs and energy requirements

Increasing DAC capacity as early as possible will also reduce costs in the long term. According to Climeworks, one of three pioneering companies developing DAC[9], the current cost of DAC CO_2 is 445-535 €/tCO_2. In time, the cost of capturing carbon dioxide from ambient air is expected to decrease to **139-240 EUR/tCO_2 in 2050** depending on the learning rate[10] and demand. This is in line with expert assessments (in Table 21 of the study) of 130-217 EUR/tCO_2. However, the latter is assuming policies consistent with limiting global warming to 2 °C, further emphasising the need for more ambitious climate policies

[8] Year 0 represents various start years. For DAC, this is 2025. For the remaining technologies, year 0 is the first year any significant capacity exists. For offshore wind and CSP (world), some capacity existed in 2000. For CSP in EU-27+UK, there was no existing capacity until 2006. Year 0 for liquid biofuels is 2001.
[9] The other two being Carbon Engineering and Global Thermostat.
[10] Learning rates are expressed as the percentage fall in cost for every doubling in capacity.

including to support DAC[11]. **Policy support will especially be needed to make DAC competitive with other sources**, which are expected to remain cheaper for the foreseeable future.

One way to reduce costs is by developing DAC, electrolysers and Fischer-Tropsch (FT) plants in proximity to each other. This can negate or at least reduce transport costs and emissions. Co-location may also help in reducing energy requirements in the case of solid sorbent DAC which can use waste heat to regenerate the sorbent[12]. DAC with solid sorbents already has the benefit of having much lower energy requirements compared to DAC with liquid solvents. This is because it requires a lower temperature (80-130 °C) to regenerate the sorbent compared to DAC with liquid solvents (900°C). Using exclusively solid sorbents would reduce energy and land requirements by 69% compared to exclusively using liquid solvents (taking into account both power and heat). However, the lifetime of solid sorbents is significantly shorter (0.5-1 year) compared to liquid solvents (20-30 years) meaning it requires more chemicals. It is also several times more expensive. Both methods have their advantages and drawbacks (table 11 of the report). Selecting either of them will require consideration of all those factors[13].

Another solution is demand management. Less fuel demand means less CO_2 required and thus less DAC. The Ricardo study shows that **our demand management scenario can halve the CO_2-demand for e-kerosene in 2050** compared to our continued growth scenario. Total energy and land requirements[14] are reduced by 27% under the demand management scenario. Measures in other sectors can further help to reduce CO_2-demand (and thus energy and land requirements) such as recycling plastics and construction materials.

And while the European Commission's proposal requires the least amount of DAC, it means that aviation would still rely on fossil fuels for 37% of their fuel demand in 2050 while 35% would potentially come from biofuels. This is incompatible with the goal of climate neutrality by 2050 and the reliance on biofuels entails risks as some are not sustainable while others are limited in quantity.

5. Conclusion

It is clear that DAC will be essential if aviation is to decarbonise with the sector alone demanding 99-313 $MtCO_2$ by 2050. When including other sectors' demand as well, this increases to 436-597 $MtCO_2$. There are simply insufficient amounts of biomass (156 Mt in 2050, 26 Mt if only considering sustainable biomass) to provide all that carbon for e-fuels. And point sources (industry and power sector) are expected to decarbonise and thus send all their remaining carbon to storage. Similarly, the existing supply of steam methane reforming is expected to decrease to zero by 2050 with the transition to low-carbon and green hydrogen. Therefore, it is up to DAC to provide the remaining 281-442 $MtCO_2$. Given the current low DAC capacity for utilisation in the EU (0.000266 $MtCO_2$), we need to massively scale up DAC in Europe now as the later we start, the faster we will have to build

[11] Shayegh et al (2021): Future Prospects of Direct Air Capture Technologies: Insights From an Expert Elicitation Survey
[12] Sorbents: CO_2 is adsorbed onto solids. Solvents: CO_2 is absorbed into a liquid.
[13] T&E (2021): What role for Direct Air Capture (DAC) in e-kerosene
[14] Taking into account the whole market demand for CO_2, not just e-kerosene.

DAC in order to meet our goals and the bigger the pressure. In order to achieve quicker deployment of DAC, T&E would make the following policy recommendations:

1. A share of DAC should be mandated as part of ReFuelEU within the synthetic aviation fuel sub-target: 10% of the carbon feedstock in 2030 should come from DAC, 20% in 2035, 40% in 2040, 80% in 2045 and 100% by 2050. This will send a strong signal to the market that DAC is the only sustainable source of carbon feedstock for e-fuels.
2. Prioritise DAC and zero-emission aircraft when funding projects aimed at decarbonising aviation through the Innovation Fund. Significant investments are needed and true climate-neutral technologies should be prioritised.
3. Implement demand management measures, such as shifting to cleaner modes of transport, and limiting unnecessary air travel for business, in order to reduce the required amounts of DAC making it easier to reach our climate goals.

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Further information

Reinout Debergh
Aviation policy analyst
Transport & Environment
reinout.debergh@transportenvironment.org