Aviation's CO_2: use it or bury it?

How can aviation end or extend the fossil fuel era

June 2021

Summary

Direct air capture (DAC), a process consisting of capturing CO_2 from ambient air, holds one of the keys to sustainable aviation. Among the ways to use DAC CO_2 to decarbonise aviation, two are being held up as offering competing possibilities: On the one hand, DAC CO_2 combined with carbon capture and storage (DACCS), which means that CO_2 would be collected then buried underground while aviation continues to use fossil kerosene. We call this option, which was proposed inter alia by the UK's Committee on Climate Change, the "*bury it*" option. On the other hand, DAC CO_2 and green hydrogen can be used to produce e-kerosene, a near-zero emission alternative fuel to displace the sector's use of fossil jet fuel. We call this option, the"*use it*" option.

T&E commissioned a study by the Öko-Institut to compare these two scenarios, based on cost and climate benefits. At first, the "*bury it*" scenario may appear more achievable, as the alternative "*use it*" scenario requires additional, and more costly, production processes such as green hydrogen production. However, the report finds that the "*use it*" scenario comes with additional benefits which, if they are taken into account in the cost analysis, mean that e-kerosene can come out cheaper than using fossil kerosene and DACCS. Price, furthermore, is not everything. Indeed, the report explains that the DACCS option might result in carbon lock-in and may make the transition to a non-fossil approach even more expensive at a later stage.

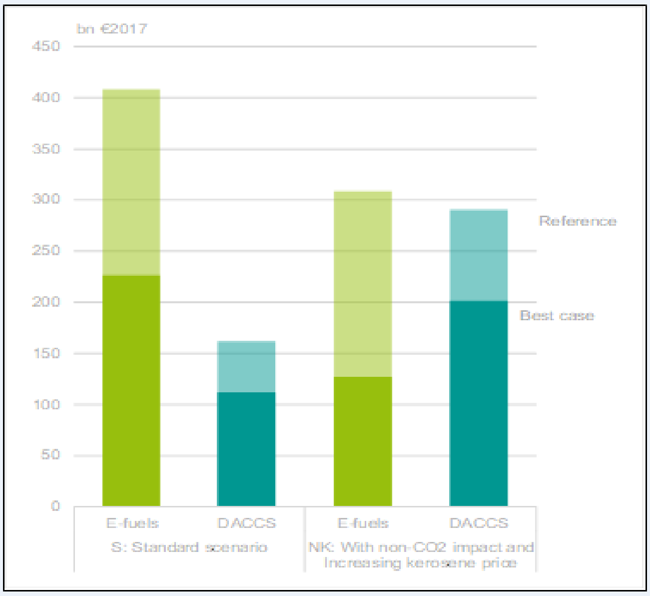
This briefing summarizes that report, provides additional arguments in favour of "use it", and outlines recommendations for policy-makers.

Key findings of the report

- Under standard scenario assumptions, DACCS comes out cheaper than renewable e-kerosene.
- However, that cost advantage may diminish or even disappear between now and 2050 if one takes into account both aviation's non-CO_2 impacts, which are lower with e-kerosene, and moderately increasing fossil kerosene prices.
- Either way, the additional costs per passenger are likely to remain relatively small for both options, below one €cent/pkm until 2050 (less than 5% of the average ticket price).

- After 2050, once aviation is decarbonised, these costs would start to decline, especially if further cost cuts are made to renewable electricity generation, which is the biggest cost factor.

The following chart shows the aggregated total additional costs (2020-2050) of both options in the standard scenarios and in the sensitivity analyses (non-CO_2 impacts, increasing kerosene prices)



T&E recommendations

- The EU should prioritise using CO_2 from DAC to produce e-kerosene rather than bury it underground while continuing to extract fossil fuels. DACCS is indeed a solution which might appear cheaper in the short term, but that is resolutely backward-looking given its dependence on fossil fuels.
- The EU should also set an end date for the combustion of fossil fuels in European aviation of December 31st 2050, at the latest.
- An ambitious industrial strategy is needed to drive the uptake of the technologies on which aviation's decarbonisation relies, such as direct air capture (DAC), which is currently not yet implemented at large scale.
- In the same vein, demand-pull policies are needed to provide more certainty to investors, as raising capital is currently one of the most challenging barriers to scaling up e-kerosene production. These policies should include an ambitious DAC e-kerosene sub-target within the ReFuelEU SAF mandate.

1. Overview

Owing to decades of government inaction (such as the exclusion from climate targets) and special treatment (such as the exemption from fuel taxation), aviation emissions have grown substantially in recent decades, from 1.4% of the total EU emissions in 1990 to 3.7% in 2019. With the Paris Agreement requiring all sectors to bring their emissions to net zero, increased attention is finally turning to the climate impact of flying. Measures are being put forward by governments, campaigners and industry, which include halting airport expansion, carbon pricing, modal shift, reduced flying, aircraft efficiency and, more recently, developing alternative fuels for use in aircraft.

One type of alternative fuel under consideration is e-kerosene, which should be produced by combining hydrogen (from electrolysis powered by additional renewable electricity) with CO_2 captured from the air. This way, the combustion of e-kerosene will be close to CO_2 neutral. E-kerosene being a synthetic form of kerosene, it is therefore "drop-in ready" for existing aircraft, meaning that it can power existing aircraft for any available range. [1]

However the requirement to capture CO_2 from the atmosphere to produce this fuel has led some stakeholders, such as the UK's Committee on Climate Change[2], to suggest that it may be simpler to capture the CO_2 from the continued burning of fossil jet fuel, rather than seek to develop a new fuel, with additional cost and energy input required. This CO_2 would then be permanently stored underground, a technique known as Carbon Capture and Storage (CCS). As the scenario of creating a new fuel involves capturing CO_2 and then using it again as a new fuel, we call this the "use it" option. As the alternative scenario involves storing the CO_2 resulting from continued combustion of fossil kerosene, we refer to this as the "bury it" option.

This study by Öko-Institut compares the two scenarios further, in terms of cost and environmental integrity, and identifies which scenario provides greater environmental integrity.

2. Basis for the scenarios

We requested that the Öko-Institut use T&E's 2018 "Roadmap to Decarbonise European Aviation" as the basis for the analysis. That report found that, even with measures to mitigate demand, such as carbon pricing, aircraft improvements and modal shift, there will still be substantial demand for fuel by the sector until and even after 2050. This residual fuel demand in 2050 is the essential climate problem which needs to be resolved, with the "use it" and "bury it" proposals offering two different ways to resolve it.

[1] Transport & Environment. (2021). FAQ: the what and how of e-kerosene. Retrieved from: https://www.transportenvironment.org/publications/faq-what-and-how-e-kerosene

[2] CCC (2019): Net-zero and the approach to international aviation and shipping emissions, Committee on Climate Change. Retrieved from: https://www.theccc.org.uk/wp-content/uploads/2019/09/Letter-from-Lord-Deben-to-Grant-Shapps-IAS.pdf

	Unit	2020	2030	2040	2050
Traffic	Gpkm	3,751	4,346	4,526	4,853
E-fuel demand	Mt	0.01	1.86	10.54	39.20
Total emissions to be offset by DACCS	$MtCO_2$	0.03	5.73	32.48	120.78
Constant kerosene price	€2017/t	600	600	600	600
Increasing kerosene price	€2017/t	598	770	876	993

Source: T&E (2018), EIA (2019), own calculations and estimates

Table 1: General assumptions applied in the scenarios[3]

3. Common factors for both scenarios: renewable electricity and direct air capture

3.1. Renewable electricity production

Installations for the production of e-kerosene and CCS require considerable amounts of electricity, for the conversion of electricity into hydrogen in the electrolysis process , for the capture of CO_2 from the air and to bury it underground. Furthermore, the expansion of renewable electricity generation is a prerequisite for the technologies to actually reduce GHG emissions in aviation, that is to say that any electricity used in the e-kerosene or CCS process needs to be additional to the increase of renewable electricity which would occur without these strategies. Providing additional renewable electricity at the lowest possible cost is therefore key .

In a scenario relying on onshore wind power generation, assuming 3,000 full load hours per year, the Öko-Institut envisages capital expenditure of 1,260 €/kW_{el} in 2030 and 1,078 €/kW_{el} in 2050 for the reference scenario and 929 €/kW_{el} and 780 €/kW_{el} respectively in 2030 and 2050 for the best case scenario, which involves more optimistic assumptions in terms of technological developments. In a scenario combining both power generation from onshore wind and photovoltaic, the capital expenditure would be around 1,941 €/kW_{el} in 2030 and 1,534 €/kW_{el} in 2050 in the reference case, with 1,537 €/kW_{el} and 1,085 €/kW_{el} respectively in 2030 and 2050 for the best case scenario.

3.2. Direct air capture (DAC)

DAC is associated with a high energy input, which is the result of the low concentration of CO_2 in the ambient air. Other possible sources of higher CO_2 concentrations, such as industrial point sources, would not be carbon neutral given their reliance on fossil feedstocks.

The basic principle of DAC is the adsorption or absorption of CO_2 from air, which is flowing over a sorbent surface, followed by a regeneration process of the sorbent which releases the CO_2 to be collected and purified after leaving the DAC system. The technology is available at small scale today and has not yet been scaled up to industrial capacities.

[3] Öko Institut (2021). E-fuels versus DACCS

In terms of costs, the Öko-Institut bases itself on Climeworks AG's Temperature Swing Adsorption (TSA) low temperature process. Its cost is estimated at 950 €/tCO_2 in 2030 and 571 €/tCO_2 in 2050 under the reference case and 697 €/tCO_2 and 419 €/tCO_2 respectively in 2030 and 2050 under the best case scenario.

4. "Use it" scenario analysed

4.1. Description and production process

The "use it" scenario assumes that the residual fossil jet fuel demand over the period 2021/2050 is progressively replaced with e-kerosene, beginning with 0.01Mt in 2020. The Öko-Institut makes a number of assumptions in developing the cost estimate for e-kerosene, including the type of electrolyser used.

The Fischer-Tropsch synthesis is the production process identified by the Öko-Institut which has the advantage of using existing refining capacity (with adjustments), thereby reducing one concern around e-kerosene, i.e. that it would require the construction of additional refining capacity.

The study confirms the energy-intensive nature of e-kerosene production, finding that only 50% of the energy that is used in the production process ultimately ends up available for aviation in the form of e-kerosene. This is similar to T&E's earlier work which highlights that synthetic fuel is a solution only for those sectors, such as aviation, where more efficient decarbonisation solutions (such as direct electrification) are not viable in the foreseeable future[4].

4.2. Costs

In terms of production costs, the report provides a reference and a best case scenario for new plants. In the reference case, with a baseline cost around 3,000€/toe in 2020, increasing demand and production capacities would lead to a decreasing cost for new plants of 2,300 €/toe in 2030 and 1,575 €/toe in 2050. As for the best case, after starting at around 2,300 €/toe in 2020, the production costs would decrease to 1,580 and 1,000 €/toe, respectively in 2030 and 2050.

The report finds that the main cost drive for e-kerosene production is the cost of the electricity supply for the fuel production. Therefore, low renewable electricity cost and efficiency improvements for the process of e-kerosene production are key for decreasing fuel cost.

[4] Transport & Environment. (2020). Electrofuels? Yes, we can… If we're efficient. Retrieved from: https://www.transportenvironment.org/sites/te/files/publications/2020_12_Briefing_feasibility_study_renewables_decarbonisation.pdf

5. “Bury it” scenario analysed

5.1. Description and storage process

The “bury it” scenario is an alternative scenario to the e-kerosene scenario and assumes that emission reductions which would have been achieved through the use of e-kerosene, are instead achieved using Carbon Capture and Storage (CCS). The demand for CCS is charted over the same period as the e-kerosene scenario, therefore beginning with 0.03Mt CO_2 in 2020 (i.e. the e-kerosene demand of 0.01Mt, multiplied by a CO_2 emissions factor of 3.15).

CCS requires substantial additional renewable energy and energy-intensive technology to capture CO_2. These attributes are similar to e-kerosene, which also requires these inputs in its production process. The CCS scenario departs from the e-kerosene scenario in requiring storage for the CO_2 captured. The study details a number of different storage options (pp 14-15). CCS in depleted oil and gas fields should have sufficient storage capacity, although it is impossible to offer a precise figure given the many physical, engineering, environmental and regulatory factors in play.

However, CCS comes with some significant potential hazards. For example, leakage would be detrimental to the efficiency of CCS from an environmental and sanitary point of view. That being said, recent research predicts that about 70% of stored CO_2 would still be retained after 10,000 years, thus corresponding to a negligible annual leakage rate of 0.003%. In addition to technological pathways such as installing three layers of seals, monitoring plays an important role in leakage mitigation and will thus constitute a long-term cost factor, without fully preventing the small leakage described above. The combination between these sanitary and environmental risk factors means that public acceptability would also be a major variable, if not barrier, in the uptake of CCS.

5.3. Cost of CCS

The overall costs of CCS are difficult to quantify because there are many items beyond the pure costs of injection of CO_2 into a subsurface reservoir, such as CO_2 capture, transportation, drying and compression. However, the Öko-Institut made some cost predictions for storage both in Europe and in the Middle East and North Africa (MENA) region, where renewable electricity feedstocks are potentially more widely available (pp. 18-20).

6. Costs of e-kerosene and DACCS compared (standard scenario)

Due to economies of scale and technological learning, the costs for avoiding one tonne of CO_2 decline between 2020 and 2050 for both the e-kerosene and DACCS options, between -63% and -75% for the former, and -58% and -68% for the latter, depending on whether the reference or best case scenario is used. Despite a quicker decline in cost for e-kerosene, the specific costs to avoid one tonne of CO_2 are under all assumptions lower with DACCS than with e-kerosene.

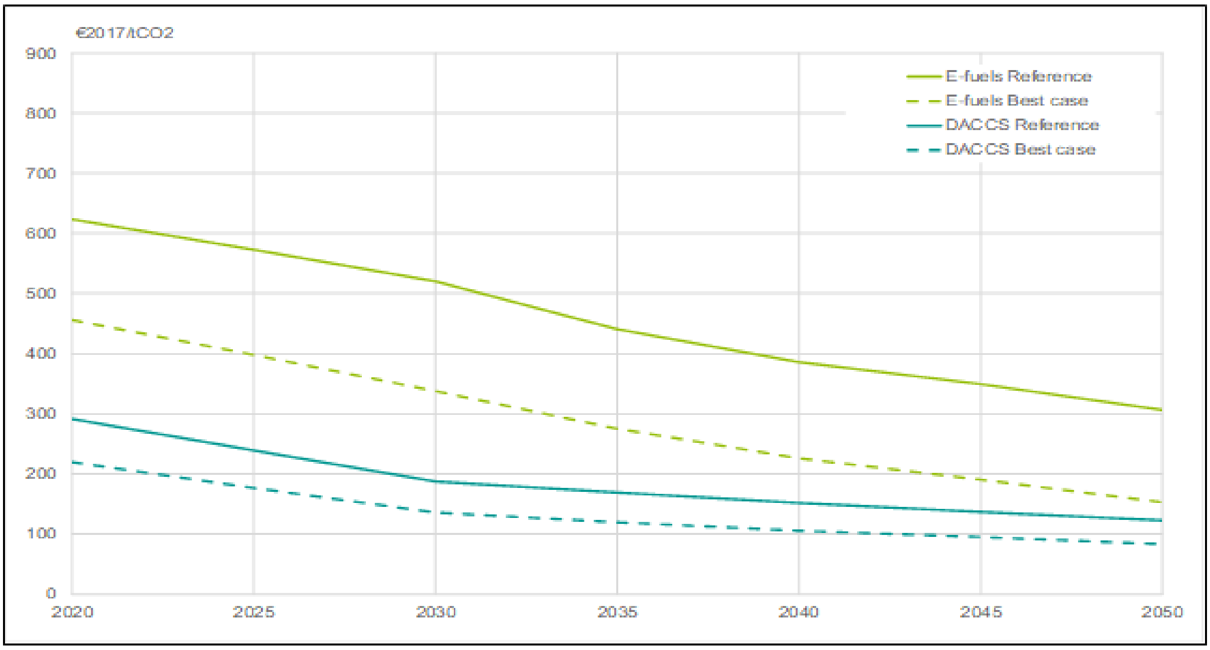


Figure 1: Additional cost per tonne of CO_2 avoided in the standard scenarios[5]

The report then goes on to determine the impact of e-kerosene and DACCS on ticket prices. The report assumes an average ticket price of 0,22 €/pkm throughout the period from 2020 to 2050, adjusted only to reflect the increase in carbon price. In this case too, DACCS appears to be the cheapest route, with a cost between 0.002 and 0.003 €/pkm in 2050 as opposed to between 0.004 and 0.009 €/pkm for the e-kerosene option. Despite declining costs for avoiding one tonne of CO_2, the uptake of e-kerosene demand and the increasing amount of CO_2 to be captured and stored to meet aviation's decarbonisation targets are much faster than the cost decrease.

7. Sensitivity analysis

The aforementioned costs have so far ignored two very important factors: non-CO_2 effects and the increase in kerosene prices. The Öko-Institut therefore conducted a sensitivity analysis based on these two parameters, which provide a very different picture with regards to the comparison between the e-kerosene and DACCS options.

7.1. Aviation's non-CO_2 climate impact

A recent study authored by the European Union Aviation Safety Agency on behalf of the European Commission concluded that aviation's non-CO_2 impact on climate change is two times greater than that of CO_2 alone[6]. These impacts are linked to several factors including contrails and NO_x emissions.

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[5] Öko-Institut (2021). E-fuels versus DACCS

[6] European Commission. (2020). Updated analysis of the non-CO2 effects of aviation. Retrieved from: https://ec.europa.eu/clima/news/updated-analysis-non-co2-effects-aviation_en

With regards to non-CO_2 effects, e-kerosene is a better option than DACCS. Indeed, whilst the latter maintains the status quo given its continued reliance on fossil fuels, the former presents a potentially important non-CO_2 positive impact. Given its lower level of aromatics, e-kerosene is projected to lead to less contrail production[7], which therefore means that its non-CO_2 impact would be smaller than that of fossil kerosene. The Öko-Institut report assumes that the use of e-kerosene can reduce the total climate impact of aviation by some 60%, but this requires further study to clarify.

If we include the positive impact of using e-kerosene on non-CO_2 emissions, more CO_2 needs to be captured and stored under the DACCS option to ensure the same effect for the global atmosphere (2.1 $GtCO_2$ instead of 1.1 $GtCO_2$). Based on these assumptions, the Öko-Institut conducted a sensitivity analysis taking into account non-CO_2 impacts, which shows that the total cost of the two considered options would actually be similar in 2050 under the reference scenario, with the best case scenario still giving a 38% cost advantage to DACCS.

7.2. Increasing kerosene prices

In a second sensitivity analysis, the report considers the impact of rising kerosene prices on the overall costs of e-kerosene and DACCS. Making predictions on kerosene prices is a difficult endeavor, but while some argue that prices could go down amidst lower demand, it is still assumed by many projections that prices could increase in the coming decades, until 2050.

Under the assumption that kerosene prices would increase to 993 €/t in 2050, the total additional cost for the e-kerosene option declines because of the incurred avoided expenditure. Whilst for the reference scenario, the DACCS option remains more cost-effective than the e-kerosene option (-33%), in the best case scenario, the latter may become cheaper than the former from 2045 onwards.

7.3. Impact of both sensitivity analysis combined

The report then combines both the impacts of non-CO_2 effects and of rising kerosene prices to run an overall sensitivity analysis against the standard scenario outlined in section 5.

The differences are quite striking: under the aforementioned assumptions, DACCS no longer has a cost edge on e-kerosene and the total additional cost of both options appears somewhat similar under the reference scenario. Under the best case scenario, from 2035 onwards, the e-kerosene route ends up significantly cheaper than using DACCS.

The following table shows the total additional cost to avoid the remaining CO_2 in the scenarios with non-CO_2 impacts and increasing kerosene prices.

[7] *Ibid.*

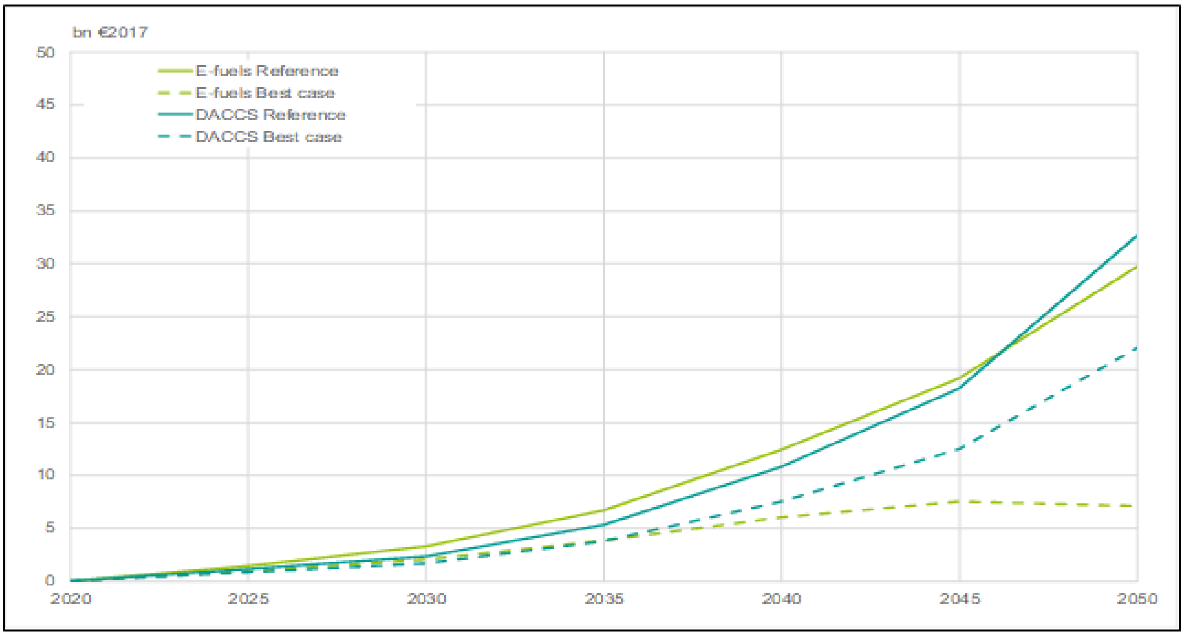

Figure 2: Total additional cost to avoid the remaining CO_2 in the scenarios with non-CO_2 impacts and increasing kerosene prices (NK)[8]

8. Concluding remarks and recommendations

This report estimated and compared the total costs of both options while considering direct and upstream emissions and environmental risks of both the DACCS and e-kerosene options. On the one hand, the analysis showed that under the standard scenario assumptions, DACCS comes out marginally cheaper than e-kerosene. However, that cost advantage may diminish or even disappear between now and 2050 if one takes into account both aviation's non-CO_2 impacts, which are projected to be lower with e-kerosene, and moderately increasing fossil kerosene prices.

Cost, however, is not everything. Indeed, the report explains that the main issue with the DACCS option is that it will not result in the defossilisation of European aviation. On the contrary, it might result in carbon lock-in, with the negative environmental & social impacts of oil extraction, and may make the transition to a post-fossil approach at a later stage even more expensive due to the persisting fossil-based capital stock and infrastructure. Regulators are therefore asked to choose not just between two cost scenarios, but two climate, energy, costs and environmental scenarios more broadly.

The "use it" scenario provides additional benefits on all three of these counts. Regarding climate policy, it's a less risky approach as it provides a clearer path to ending the extraction and combustion of fossil fuels. As the study authors acknowledge, this would be more consistent with the precautionary principle approach to policy.

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[8] Öko Institut (2021). E-fuels versus DACCS

For energy policy, it allows for a more consistent approach towards oil companies: their production of fossil fuel is no longer required for aviation in Europe post-2050. This is important as aviation is often held out as a 'last demand' for oil. Ending that demand will provide clarity for all actors in the energy sector, including investors. For environmental policy, it permits the ending of oil exploration and extraction, which is noted for its considerable negative environmental impact, as exemplified by oil spills such as the Deepwater Horizon catastrophe.

The "bury it" scenario is the mirror opposite of this scenario: continued extraction and combustion of fossil fuel, continued search for, and use and monitoring of, sites for storage. The Öko-Institut concludes that, given that the difference between the e-kerosene and the DACCS option ranges in 2050 between 1.0% and 2.5% of the ticket price, it should be considered that embarking on the e-kerosene option might be more consistent with the precautionary principle as the basic rule of environmental policy.

Given the relatively minor, and at times non-existent or even inverse, price difference between the two scenarios, **for T&E it is clear that regulators should begin the development of e-kerosene for aviation, as well better price emissions and fossil fuels, so that we can turn the tap off on oil demand in Europe by 2050. Those who are proponents of DACCS should otherwise prove that the world has more to gain in continuing fossil fuel extraction beyond 2050.**

Recommendations:

- The EU should prioritise using CO_2 from DAC to produce e-kerosene rather than bury it underground. DACCS is indeed a solution which might appear cheaper in the short term, but that is resolutely backward-looking given its dependence on fossil fuels.
- They should also set an end date for the combustion of fossil fuels in European aviation of December 31st 2050 at the latest.
- An ambitious industrial strategy is needed to drive the uptake of the technologies on which aviation's decarbonisation relies, such as direct air capture (DAC), which is currently not yet implemented at large scale.
- In the same vein, demand-pull policies are needed to provide more certainty to investors, as raising capital is currently one of the most challenging barriers to scaling up e-kerosene production. These policies should include an ambitious e-kerosene sub-target within the ReFuelEU SAF mandate.

Further information

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