European Commission

Direct air capture (DAC)

HEADLINES

- IPCC pathways that limit global warming to 1.5°C make use of carbon dioxide removal (CDR) technologies to various extents. Direct Air Capture (DAC) is one of these technologies.
- These technologies will have to be deployed at a scale sufficient to offset non-mitigated CO_2 emissions and further remove CO_2 from the air; for this reason, DAC alone will not be able to address the climate change issue.
- In line with the long term vision of achieving net-zero greenhouse gas emissions by 2050, CDR technologies are expected to support generating negative emissions.
- Cost reductions for DAC are expected by 2025-2030; hence our view is that DAC could roll out beyond that time frame.
- DAC as a part of CDR could make a notable impact on CO_2 removal, once commercially deployed at scale, only around 2050.

Joint Research Centre

THE DEBATE

The idea of capturing carbon dioxide (CO_2) directly from air has been pitched within climate change circles for well over a decade. In 2017, the 'direct air capture' technology, or DAC, was put to test in the real world with the first commercial plant launched in Switzerland (Figure 1). Will DAC be an important tool in our portfolio of technologies to support ongoing efforts to achieve our vision for a climate-neutral economy by mid-century?

Figure 1 Climeworks' commercial DAC plant in Switzerland (Source: http://bit.ly/climeworkspresskit)

THE ARGUMENTS

Capture... anywhere

Enabling the direct extraction of CO_2 from the atmosphere is a main benefit put forward. Land use and hardware distribution are commonly raised issues, but research suggests that DAC units have minimal land requirements compared to other Negative Emissions Technologies (NETs), such as for example Bioenergy with Carbon Capture and Storage (BECCS).[1] On the other hand, a meaningful contribution to CO_2 emissions reduction requires carbon-neutral energy and/or heat to operate DAC. This need may limit the selection of possible locations to those where these resources are available [1].

Requirement for resources

Depending on the separation technology used DAC may need between 0.32 and 4.73 MWh per tonne of CO_2 [2] removed from air, but there is a 'fundamental disagreement on the actual amount of energy required' [3]. For a rough comparison, the capture of 90 % of the CO_2 generated in a natural gas fired power-plant would require 0.38 MWh/t CO_2 [4]. DAC also requires considerable water input[2] – to offset just the non-mitigated CO_2 emissions DAC[3] would require nearly as much water as used in a country the size of Italy.[4]

The price tag

In 2011, the cost of capturing a tonne of CO_2 from air was estimated at around €440 ($600) [5]. On the same year, a study estimated costs even around €1 000 per tonne CO_2. In 2018, cost estimations reduced to between €80 ($94) and €200 ($232) [6].[5] This range reflects differences in design choices which could further reduce costs in the future.

1 As a comparison, land use for BECCS – a highly land intensive technology – ranges from 1 000 to 17 000 m² per tonne of carbon equivalent (C_{eq}) per year, depending on feedstock type. For DAC this figure is larger than 100 m² per tonne of C_{eq} per year [15].

2 To remove 1 t of C_{eq}, DAC (e.g. amines) requires approximately 90 m³ of water [17,18].

3 Assuming current amine technology as in [17].

4 Based on emission reductions required for limiting temperature increase to 1.5°C, as outlined in the European Commission's long-term strategic vision (scenario 1.5TECH) [13] and on water use data from [19] referring to all activities.

5 All values adjusted for inflation and assuming $1=€0.86272 (source: https://www.oanda.com/currency/converter/, accessed October 2018).

Location, location, location

When approaching the lower end of cost, DAC starts to look viable in a climate-neutral world. Yet, the broad cost range indicates the current uncertainty associated with DAC. Amongst others, regionally dependent factors (such as the type and cost of energy needed to power the process, CO_2 volumes and the availability of a CO_2 pipeline network and storage locations) will affect the costs and thus the viability of the process. In Europe, a CO_2 capture cost as low as €80/t ($94) and a natural gas price of €3/GJ (or 3.5 $/GJ) as assumed by Keith et al. [6] are hardly realistic.

What about emissions?

Whereas the biggest chunk of emissions comes from the energy sector, emissions are not only associated with power generation. In this context, DAC can support decarbonisation regardless of the emissions source. To achieve CO_2 emissions reduction, low-cost and low-carbon energy will be required to satisfy the high power demand associated with DAC operation. Still, specific trade-offs will not be avoided – using wind energy to power the DAC process to remove the emissions associated with a typical cement plant would require installing turbines on a land area almost equivalent to the City of Brussels. Pursuing DAC could become worthwhile after carbon capture and storage is applied to any remaining point sources [1].

Place and space

The number of DAC plants to be built per year is limited primarily from a cost perspective. To achieve major CO_2 emissions reduction and toward net-zero, it will need to be coupled with CO_2 transport and storage. Direct air capture is modular and developers claim it could be scaled up rapidly. Yet, it is uncertain whether DAC can be scaled up quickly enough and sufficiently to make an impact on CO_2 levels in the atmosphere in the medium term [5,7].

Going in cycles

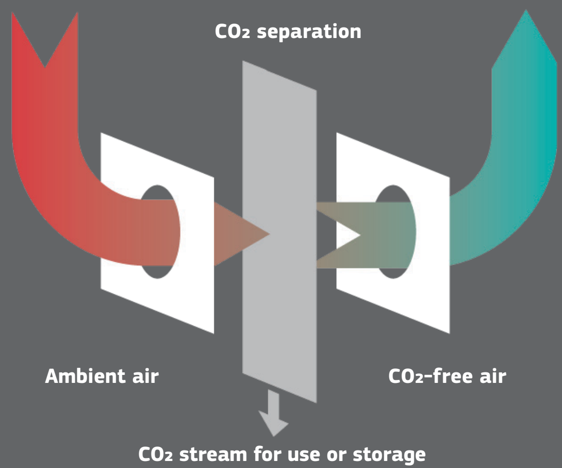
As the planet moves towards a circular economy, DAC could go hand in hand with opportunities to utilize the captured CO_2. These include, for example, longer term approaches to CO_2 storage such as mineral carbonation or short term ones like fuel synthesis [8]. In industries without proximity to other CO_2 sources, DAC could cut down CO_2 transport costs even if these are minimal compared to the costs of CO_2 capture (~70-80 % of the total [9]). DAC enhances the argument for processes using the captured CO_2 to have a climate change mitigation potential by creating a closed carbon loop. Nevertheless, it will need to be powered with clean energy and the captured CO_2 to be permanently stored. The Scientific Advice Mechanism High Level Group (SAM HLG), considered DAC for short-lived, CO_2-based products such as fuels, capturing of CO_2 from the air [10]. In this case, DAC would be necessary to achieve carbon neutrality provided that it is powered with renewable energy. However, the European Academies' Science Advisory Council (EASAC) concludes that maximising mitigation with carbon capture and permanently storing CO_2 will reduce the future need to remove CO_2 from the atmosphere [11].

MARKET AND PROSPECTS

Seven leading commercial DAC system developers [12] and many companies are already demonstrating the technology on both sides of the Atlantic. Their business models include generating a revenue from the captured CO_2 for use in industries such as oil and gas, fuel production, materials, food and beverages but also in carbon markets. Climeworks for example, is offering CO_2 removal credits in an effort to boost funding and expand its carbon capture technology. As such, the perspective business case of DAC companies ultimately depends on the price of the CO_2 traded;[6] DAC cost should drop by at least an order of magnitude with respect to its value today for this scheme to become lucrative. n Europe, Climeworks is the only one running a commercial plant in Zurich, Switzerland, and a pilot plant in Iceland. Climeworks' commercial plant is selling its CO_2 to greenhouses while the Iceland pilot plant is the only one which, after capturing an annual 50 tonnes of CO_2, buries it in basalt rock. Climeworks, which operates a plant currently at a cost of €440, hopes to get this down to €90 per tonne CO_2 by 2025 or 2030.[7] With carbon markets being the main funding instrument, DAC cost, even on the low end, would break even to the projected European Emission Allowance (EUA) cost after 2045 [13].

HOW DOES IT WORK?

In a continuous cycle, ambient air is drawn into the DAC plant and the CO_2 within the air is bound in the processes. The concentrated CO_2 collected is then routed for use or permanent storage and CO_2-free air is released back into the atmosphere. The exact process depends on the technology but a rough representation of the CO_2 flows involved is given below (adapted from https://mag.ebmpapst.com).



RESEARCH AND INNOVATION

The EU is already funding DAC through the Horizon 2020 research project STORE&GO.[8] In July 2018, another Direct Air Capture plant was launched in Troia, Apulia (Italy), within this project. Importantly, this project will also assess the economic and business aspects and market-uptake potential of the technology.

Research is ongoing to tackle issues common to conventional carbon capture such as high energy requirements, low efficiencies and high

6 Typically agreed through private negotiations between parties but examples of known prices go as low as EUR 3 per metric tonne of bulk CO_2 and EUR 26 incorporating pipelines [16].
7 http://www.climeworks.com/carbon-brief-the-swiss-company-hoping-to-capture-1-of-global-co2-emissions-by-2025/
8 https://www.storeandgo.info/

cost. However, the challenge associated with the permanent storage of CO_2 remains an issue [14]. Available storage capacity or public perception among other issues underline that these elements will require serious consideration.

According to the IPCC, 'avoiding overshoot and reliance on future large-scale deployment of carbon dioxide removal (CDR) can only be achieved if global CO_2 emissions start to decline well before 2030' [15]. This is a clear message that timely action is needed for meeting our decarbonisation ambitions. If not, CDR technologies will be an urgent solution. However, DAC is only one of the CDR technologies that can be considered. Given the technology's early stage of development and limited existing demonstrations, DAC's potential impact can be positioned in the longer term. Compatibly with the EU's long-term strategic vision for a prosperous, modern, competitive and climate neutral economy [16], we view that DAC could be impactful in compensating for non-mitigated CO_2 emissions in the long run. DAC is an interesting technology if viewed as a tool that could potentially fill gaps of current technologies and not as a stand-alone solution.

REFERENCES

1 European Academies' Science Advisory Council, *Negative emission technologies What role in meeting Paris Agreement targets?*, 2018, ISBN: 978-3-8047-3841-6.

2 S. Brandani, *Carbon dioxide capture from air: a simple analysis*, Energy Environ., 2012, 23, 319–328, doi:10.1260/0958-305X.23.2-3.319.

3 R.S. Haszeldine, S. Flude, G. Johnson, V. Scott, *Negative emissions technologies and carbon capture and storage to achieve the Paris Agreement commitments*, Phil. Trans. R. Soc. A, 2018, 376, 20160447, doi: 10.1098/rsta.2016.0447.

4 J. Mletzko, S. Ehlers, A. Kather, *Comparison of Natural Gas Combined Cycle Power Plants with Post Combustion and Oxyfuel Technology at Different CO_2 Capture Rates*, Energy Procedia, 2016, 86, 2–11, doi: 10.1016/j.egypro.2016.01.001.

5 R. Socolow et al., *Direct Air Capture of CO_2 with Chemicals: A Technology Assessment for the APS Panel on Public Affairs*, 2011, url: https://www.aps.org/policy/reports/assessments/upload/dac2011.pdf.

6 D. W. Keith, G. Holmes, D. St. Angelo, K. Heidel, *A Process for Capturing CO_2 from the Atmosphere*, Joule, 2018, 2, 1573–1594, doi: 10.1016/j.joule.2018.05.006.

7 National Research Council, *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration*, 2015, Washington, DC: The National Academies Press, doi:10.17226/18805.

8 J. Wilcox, P. C. Psarras, S. Liguori, *Assessment of reasonable opportunities for direct air capture*, Environ. Res. Lett., 2017, 12, 065001, doi:10.1088/1748-9326/aa6de5.

9 D.Y.C. Leung, G. Caramanna, M.M. Maroto-Valer, *An overview of current status of carbon dioxide capture and storage technologies*, Renew. Sustain. Energy Rev. 2014, 39, 426-443, doi:10.1016/j.rser.2014.07.093.

10 European Commission – Directorate-General for Research and Innovation, *Novel Carbon Capture and Utilisation Technologies*, 2018, Luxembourg: Publications Office of the European Union, doi:10.2777/01532.

11 European Academies' Science Advisory Council, *Forest bioenergy, carbon capture and storage, and carbon dioxide removal: an update*, 2019, url: https://easac.eu/fileadmin/PDF_s/reports_statements/Negative_Carbon/EASAC_Commentary_Forest_Bioenergy_Feb_2019_FINAL.pdf.

12 M. Fasihi O. Efimova C. Breyer, *Techno-economic assessment of CO_2 direct air capture plants*, J. Clean. Prod. 2019, 224, 957-980, doi:10.1016/j.jclepro.2019.03.086.

13 H.P. Witzke et al., *EU Reference Scenario 2016 - Energy, transport and GHG emissions Trends to 2050*, 2016, Luxembourg: Publications Office of the European Union, doi:10.2833/001137.

14 M. Bui et al., *Carbon capture and storage (CCS): the way forward*, Energy Environ. Sci., 2018, 11, 1062–1176, doi: 10.1039/C7EE02342A.

15 The Intergovernmental Panel on Climate Change, *Special report: Global Warming of 1.5 °C*, 2018, Geneva (Switzerland): World Meteorological Organization, url: www.ipcc.ch/sr15.

16 European Commission, *A Clean Planet for all: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy*, 2018, COM (2018) 773 final.

17 P. Smith et al., *Biophysical and economic limits to negative CO_2 emissions*, Nat. Clim. Chang., 2016, 6, 42–50, doi: 10.1038/nclimate2870.

18 D. Sandalow, J. Friedmann, C. McCormick, S. McCoy, *ICEF2018 Roadmap: Direct Air Capture of Carbon Dioxide*, url: https://www.icef-forum.org/pdf2018/roadmap/ICEF2018_DAC_Roadmap_20181210.pdf

19 Eurostat, Water statistics 2017, url: https://ec.europa.eu/eurostat/statistics-explained/index.php/Water_statistics#Water_uses [accessed 8 May 2019].

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