DIRECT AIR CAPTURE

Silver bullet or red herring?

Direct air capture technologies have the potential to help achieve net zero. *Simon Crowther* of Frazer-Nash Consultancy*examines the opportunities they offer and the challenges they face.

Numerous studies on the future energy mix highlight the need for carbon removal technologies to meet the Paris Agreement targets. The International Energy Agency (IEA), for example, believes reaching net zero emissions is 'virtually impossible' without carbon capture, use and storage (CCUS), noting that 'stronger investment incentives and climate targets are building new momentum' and that although the technologies are in their infancy, the world of carbon capture is on the 'cusp of a new dawn' (see *Petroleum Review*, July 2021).

Innovations in this field include the development of negative emission technologies (NETs) such as direct air carbon capture (DAC), which removes carbon dioxide (CO_2) from ambient air, acting as an 'artificial tree'. However, while some of the CO_2 captured by a tree can be released into the atmosphere when it dies, all of the CO_2 captured by DAC can be permanently sequestered within geological formations such as saline aquifers or depleted reservoirs, or regenerated for re-use in other processes such as creating plastics, chemicals, refrigerants, fizzy drinks, or as a feedstock for synthetic fuels.

It is also worth noting that while afforestation is a complementary greenhouse gas reduction option, trees can end up competing for land space with food production, potentially resulting in increased global food prices. 'Artificial' trees, aka manufactured DAC systems, have the advantage that they are less limited by location and require less land than other NETs – the biomass required for BECCS (bioenergy with carbon capture and storage) has the same land issue as afforestation. A DAC plant that captures 1mn tCO_2/y is equivalent to the work of approximately 40mn trees requiring approximately 800,000 acres of space, according to a tentree blog. DAC also requires far less water. According to the Innovation for Cool Earth Forum (ICEF), BECCS requires around 600 m^3 of water for each tonne of CO_2 removed (largely due to biomass cultivation) whilst, depending on the concept, the DAC water requirement could be negligible up to a maximum 25 m^3/tCO_2.

Most current DAC projects are focused on the chemical separation of CO_2 from air, as opposed to cryogenic (freezing CO_2 out of the air) or membrane technology (using ionic exchange and reverse osmosis membranes).

Key players

Table 1 lists the main companies currently developing DAC technologies.

Carbon Engineering (CE) is the only liquid solvent-based solution in **Table 1**, enabling a continuous process operating at steady state and reportedly needing less water than other solutions. The regeneration process uses both renewable electricity and natural gas as heat sources. CE is looking to develop a purely electrical calcination process and is currently developing synthesised fuels from CO_2. The company plans to begin construction of a commercial plant in 2022, located in the US Permian Basin, capable of capturing 1mn tCO_2/y. It has also partnered with Storegga to deploy a large-scale site in north-east Scotland by 2026.

Company	Location	Scale	Size (m^2)	Capture Rate (tCO_2/y)	Current cost** ($\$/tCO_2$)	Future predicted cost**($\$/tCO_2$)
Carbon Engineering	British Columbia, Canada	Pilot (fuel production)	5,000	365	600	94–232
Climeworks	Hinwil, Switzerland	Pilot (reuse of CO_2 in a nearby greenhouse)	90	900	600	100
	Hellishi, Iceland (CarbFix project)	Pilot (sequestration linked to a geothermal station)	n/a	50		
	Italy (Store & Go Project)	Demonstration (renewable methane production)	n/a	150		
Global Thermostat	California	Demonstration		1,000	50	15–50

Table 1 Current status of active DAC facilities

**Costs for carbon capture only; excludes compression, transportation, injection and storage costs

*Source: Frazer-Nash Consultancy**

All the CO_2 captured by direct air capture technologies can be permanently sequestered within geological formations such as saline aquifers or depleted reservoirs, or regenerated for re-use in other processes such as creating plastics, chemicals, refrigerants, fizzy drinks, or as a feedstock for synthetic fuels

Source: Shutterstock

Climeworks' solution is modular, enabling scalability and reducing costs. It has a current capacity of 50 tonnes of CO_2 per 'collector' module. Whilst CE's design requires natural gas to power the system (coupled with industrial CCS), Climework's concept is powered by renewable energy and/or low-grade waste heat. Its Icelandic pilot plant is powered by geothermal energy, the Italian demonstrator uses solar power, and the Swiss plant a local incinerator.

Meanwhile, Global Thermostat claims its patented technology can be retrofitted into an existing facility and can be used for both capture from ambient air and flue gas. It has been planning a pilot plant in Alabama to capture 4,000 tCO_2/y, for re-use purposes at a global food and beverage company. This site will use residual low-temperature heat as an energy source.

Other companies entering the DAC market include Infinitree, which is looking to utilise an ion exchange sorbent to generate CO_2 for reuse within greenhouses; whilst Skytree proposes using a humidity swing to regenerate captured CO_2. Skytree's applications include methanol production and scrubbing the air within a car to decrease the power needed for heating and air conditioning.

Dublin-based Carbon Collect is working to commercialise the passive direct air capture technology developed by Arizona State University's Dr Klaus Lackner. Its mechanical tree, unlike the three companies in **Table 1**, will let wind direct ambient air towards the sorbent (no fans are proposed). Once the sorbent tiles are saturated with CO_2, the mechanical trees are lowered and CO_2 is released from the sorbent. The pilot farm is due to be made up of 24 mechanical trees each capable of capturing 33 tCO_2/y. Carbon Collect's long-term plan is to deploy large-scale farms globally comprising of 120,000 trees, capturing up to 4mn tCO_2/y per farm, and the company believes it can bring the cost of capture well below \$100/tCO_2.

All the companies in **Table 1** are aiming for active megatonne capacity DAC plants (capturing 1mn tCO_2/y) with a 30-year lifetime, at a cost of about \$100/tCO_2 within the next 10–15 years. As of July 2021, no plants of this scale were in operation.

Future deployment

A PESTLE (political, economic, sociological, technological, legal and environmental) analysis highlights some of the challenges DAC needs to overcome before the technology can be deployed at scale.

Political: Government policy will be a key enabler or blocker to the success of DAC. Funding is likely to be staggered as the technology matures (with increased subsidies as concepts go from research to active deployment). Policy levers available to government include subsidising research and development, providing tax incentives to advancing DAC, taxing carbon/carbon pricing, carbon credits, and/or adapting regulation/standards to support low carbon fuels and re-use of CO_2.

In the UK, the Department for Business, Energy & Industrial Strategy (BEIS) has committed £70mn of funding for Stage 1 of its innovation programme, with further funded stages planned to achieve commercial scale demonstrations in the mid-2020s. UK Research and Innovation is also funding £31.5mn for greenhouse gas reduction demonstrators. In the US, Rhodium Group has recommended that the Department of Energy spend \$240mn/y during the next decade on DAC R&D.

Economic: The cost of DAC systems is not currently seen as viable without incentives. CO_2 in air is much more dilute than in flue gas (300 times greater compared to a coal-fired power plant, according to the National Academies of Sciences, Engineering and Medicine). The more dilute a stream is, the harder it is to separate, the more energy it requires to separate, which in turn makes it more expensive.

Social: As with any new infrastructure, public acceptance is not guaranteed. However, DAC facilities can be situated almost anywhere, meaning they do not need to be near population centres or industrial sources.

Technical: Other greenhouse gas reduction options provide benefits in addition to removal of CO_2, DAC does not. Due to the energy intensity of the current technology, DAC must be powered by low carbon sources to be classified as a NET.

Legal: There is a risk in prioritising the deployment of DAC at scale at the expense of other developments. If these technologies were unable to deliver the desired reduction in CO_2, the Paris Agreement targets might not be met.

Environmental: There are minute location and seasonal variations in the concentration of CO_2 found in air that may affect the quantity of CO_2 captured by a plant. This appears to be an area that could benefit from further research. However, from a cost and practicality perspective, the logical locations for a DAC facility would either be close to a geological storage site, near to a process requiring the use of CO_2 (eg a food and beverage facility), or near to an accessible low-cost heat source.

Looking ahead

Focusing on energy efficiency, developing renewables/nuclear power, and investing in 'traditional' CCUS remain the most viable options in reducing global warming. However, with the development of CCUS infrastructure, DAC plants could feed into transportation and storage infrastructure. If the global carbon budget is exceeded, NETs such as DAC become a necessity.

In the UK, the aim of the government's net zero cluster approach is for areas to exist that either produce no CO_2 or offset the CO_2 that is produced by NETs. The current technologies being developed to capture carbon at source are aiming for efficiencies of approximately 95% – could DAC be used to capture the residual 5% and enable net zero to be achieved within a cluster? This is already being considered by Pale Blue Dot Energy (part of the Storegga Group), which is working with CE to develop a commercial-scale DAC plant potentially linked to the Acorn project's planned cluster in the north-east of Scotland. Alternatively, could DAC be employed in more rural areas where the concentration of industrial CO_2 sources is more sparse and traditional CCS is not an option? As the UK looks to become a global leader in renewables, could DAC be used flexibly within the wider energy system (eg using surplus clean energy for desorption when demand is lower)?

The main driver in whether DAC will be a noteworthy contributor in the greenhouse gas reduction arena will be cost. It is for investors to judge whether this technology will be commercially viable in the future, based on their assessment of technology cost reduction and market conditions. Ultimately, DAC could be a piece of the puzzle in enabling the energy transition. ●

*This article is based on a White Paper, *Direct air capture: silver bullet or red herring?*, published by Frazer-Nash Consultancy in November 2020.