QUARTERLY REVIEW #3: DAC & CCUS developments in 2021

December 23, 2021

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This report presents the latest developments in geoengineering technologies, projects and funding programs worldwide in recent months. The report's findings show an increasing interest in capturing CO_2 (carbon dioxide) from ambient air and producing fuels with CO_2 as feedstock. In addition, the report provides further evidence that companies that emit large amounts of climate-damaging gases as part of their business operations, in particular, are exploring and actively promoting ways to remove CO_2. Other companies are using the interest in geoengineering as a business model, despite the fact that the effectiveness of geoengineering technologies has not been proven and despite the risks that each of these technologies entail.

The first part of the review presents new developments, projects and programs in Direct Air Capture (DAC) and Carbon Capture Use and Storage (CCUS).

Direct Air Capture (DAC) capacity in Iceland to increase tenfold by 2024 and other news in the field of DAC & CCUS

Direct Air Capture (DAC) is the process of capturing CO_2 or other greenhouse gases from ambient air using filters. The captured CO_2 is then either used commercially, often for the production of synthetic fuels or for enhanced oil recovery (Carbon Capture Use and Storage – CCUS). Or the captured CO_2 is injected underground for long-term storage (Carbon Capture and Storage – CCS). This section mainly deals with projects and programmes that aim to further develop DAC technology – the approaches range from basic research to scaling. Projects that employ already existing DAC technology to produce consumer goods can be found in the following section on CCUS. The fact that DAC is still undergoing basic research, especially with regard to costs, efficiency and energy consumption, shows that after more than a decade of research with extensive public and private funding, DAC is still in its infancy.

USA

In 2021, the National Energy Technology Laboratory (NETL) organised a kick-off meeting for a DAC project funded by the U.S. Department of Energy (US-DOE) under the funding opportunity announcement *(FOA) DE-FOA-0002188, "Novel Research and Development for the Direct Capture of Carbon Dioxide from the Atmosphere".* Electricore, a consortium from the private sector, public sector and research, aims to combine and optimize a DAC process developed by the Swiss Climeworks AG and a CO_2 capture process developed by Svante (BC, Canada). With this project, Electricore plans to test the optimized DAC system at a site near Palm Spring, California.

The Texan company Co2Rail was founded in 2021 and aims to develop a rail-based DAC system. The DAC modules are to be attached to trains that are used in regular traffic. The energy for the DAC system is generated from the kinetic energy of the braking trains. Solar cells on the roof of the railcars could provide additional energy for DAC. The CO_2 filter does not need a fan because the trains are in motion. The company's goal is to offer a DAC technology that uses little land and less energy compared to already existing DAC technologies.

The Oakland-based company AirCapture aims to develop a modular DAC system to deliver captured CO_2 where it is needed, primarily to avoid transport costs and impurities. The company does not specify which DAC technology will be used in the modular DAC system.

In 2021, the US administration published the funding opportunity announcement (FOA) number DE-FOA-0002481, "Materials and Chemical Sciences Research For Direct Air Capture Of Carbon Dioxide", and in June 2021, the US-DOE announced six grant projects. In August 2021, the US-DOE announced nine additional projects selected for funding. These new projects will conduct basic research into the development and synthesis of novel materials and energy-efficient approaches to capturing CO_2 from ambient air. The institutions conducting these projects include: Oak Ridge National Laboratory (ORNL, Oak Ridge, TN), Northwestern University (Chicago, IL), Case Western Reserve University (Cleveland, OH), North Carolina A&T State University (Greensboro, NC), Washington State University (Pullman, WA), Lawrence Berkeley National Laboratory (LBNL, Berkeley, CA), Oregon State University (Corvallis, OR), University of Illinois Urbana-Champaign (Champaign, IL), Oklahoma State University (Stillwater, OK). In November 2021, the US-DOE announced its "*new goal to remove gigatons of carbon dioxide (CO_2) from the atmosphere and durably store it for less than $100/ton of net CO_2-equivalent*".

The University of Illinois is among the projects selected in the June 2021 round of awards. The University, based in Champaign, Illinois, will develop three preliminary designs for large-scale DAC operations "and work with partners to perfect the designs to permanently store CO_2 at underground facilities in Wyoming, Louisiana and California". The DAC technology will be provided by the Swiss Climeworks AG. The three test sites will be located:

(1) in Southern California, near the Salton Sea. This DAC site will be powered by geothermal energy and the captured CO_2 will be stored in a saline aquifer.

(2) in Louisiana. The trial site will be powered by solar energy and the captured CO_2 will be stored in a saline aquifer.

(3) in Wyoming. The DAC site will be powered by wind energy. The captured CO_2 will be stored in a depleted fossil gas reservoir.

The project partners include: Climeworks AG, Kiewit Power Engineers, Lawrence Livermore National Laboratory, Gulf Coast Sequestration, North Shore Energy, Sunpower, Ormat, and Sentinel Peak. In August 2021, the University was granted another research project under the same US-DOE funding announcement, this time titled "Reversible Electrochemical Capture/Release of Carbon Dioxide Mediated by Electrostatically-Enhanced Charge Transfer".

In 2021, the U.S. government agency 'Advanced Research Projects Agency–Energy' (ARPA-E) provided funding to the following DAC projects:

- Founded in 1961, Creare is a private engineering service company. In 2021, Creare received funding to demonstrate a new DAC technology. The new technology aims to reduce the cost of CO_2 removal from ambient air through a new contactor material. The contactor is designed for passive, wind-driven DAC systems.
- The Georgia Tech Research Corporation (GTRC) is part of the public Georgia Institute of Technology. The ARPA-E funded project aims to develop a scalable, modular DAC device and is designed as a passive, wind-driven DAC device.
- The University of Michigan, in collaboration with the University of Massachusetts Amherst, has received ARPA-E funding to develop a technology that captures CO_2 from the atmosphere using an electrochemical approach. The project concept involves a pH swing cycle in which conditions alternate between basic and acidic to capture or release CO_2. This new DAC approach aims to reduce the costs and improve the efficiency of DAC.

Iceland

In September 2021, the Swiss DAC company Climeworks AG commissioned its new DAC plant 'Orca' near the Icelandic power plant Hellisheidi. The power plant is located in the Hengill geothermal area, about 25 km east of Reykjavík. Climeworks' new DAC plant on Iceland has a CO_2 capture capacity of up to 4,000 tonnes per year. The captured CO_2 is injected underground using a process developed by the Icelandic company Carbfix: In this process, CO_2 is first dissolved in water through a water scrubbing process – a physical process in which the gas is brought into contact with water under pressure. The dissolved gas is then injected into basaltic formations at 400 to 800 m depth, with the objective of storing the gas in mineral form in the bedrock. Following the commissioning of Orca, Climeworks is already considering increasing the DAC capacity at Hellisheidi tenfold in about three years.

Carbfix initiated the Coda Terminal – a CO_2 transport and mineral storage hub to be built in Straumsvík Bay, southwest of Reykjavik. The hub aims to inject captured CO_2 into basaltic formations near Straumsvík using the Carbfix method. The CO_2 will be captured by DAC in Iceland or arrive by ship from industrial plants in northern Europe.

In July 2021, Elkem announced plans to test the Carbfix method at its Grundartangi ferrosilicon plant north of Reykjavik. In October 2021, Rio Tinto partnered with Carbfix to launch a CO_2 capture project at its ISAL aluminium smelter in Straumsvík, southwest of Reykjavik.

The combination of Climeworks' DAC technology and Carbfix' injection method involves high consumption of scarce resources and high costs:

- Climeworks' DAC process needs ~2,000 kWh of thermal energy and ~650 kWh of electricity to capture one tonne of CO_2;
- According to a press report, the Carbfix process requires 25 tonnes of water for one tonne of CO_2;
- The cost of building Orca, including development and storage, are estimated at 10 to 15 million USD

Norway

The Norwegian company Nordic Electrofuel AS (formerly Nordic Blue Crude AS) plans to produce carbon-based synthetic fuels and other fossil substitutes, such as synthetic kerosene, diesel and gasoline. For production, the company needs water, CO_2 and energy. The CO_2 was to be provided by Climeworks' DAC technology. In November 2021, Nordic Electrofuel AS announced that the required CO_2 will be captured at a neighbouring smelter for cost reasons. In total, the company plans to commission ten commercial production facilities in Norway, starting with the "E-Fuel 1" plant at the Heroya Industrial Park in Porsgrunn, which is scheduled to come on stream in 2022 (with a two-year delay), however, construction work has not yet begun.

In 2021, Climeworks and the Northern Lights CCS project, a partnership between Equinor, Shell and Total, agreed to explore the realisation of a CO_2 capture project in Norway. A joint project would combine Climeworks' direct air capture technology with the injection of liquefied CO_2 into a former natural gas reservoir below the seabed in the North Sea.

The Netherlands

The Dutch company Carbyon is a spin-off of the Dutch TNO and a developer of DAC technology. Carbyon's DAC concept is based on a thin film of CO_2 sorbents. The thin film is a porous membrane coated with amine and/or bicarbonate. The company's main goals include reducing DAC costs, energy consumption and land footprint. The company is currently looking for investors and for partners to further develop and pilot the technology.

Ireland

The Dublin-based company Carbon Collect Ltd. (formerly Silicon Kingdom Holdings Ltd.) aims to market and "plant" mechanical carbon capture trees. The DAC technology was developed by Klaus Lackner and his team at the Centre for Negative Carbon Emissions (CNCE) at Arizona State University. Carbon Collect Ltd. has acquired the rights to commercialize the technology. In June 2021, the company received funding under the US-DOE funding opportunity announcement (FOA) number DE-FOA-0002481, "Materials and Chemical Sciences Research For Direct Air Capture Of Carbon Dioxide". Carbon Collect Ltd. plans to use this funding to develop initial designs for three commercial DAC plants that will capture 0.3 million tonnes of CO_2 annually. The names of potential project partners and the exact locations for the three DAC plants have not yet been disclosed. The two company founders and other members of the company management have worked for oil companies such as BP in the past.

Australia

Melbourne-based company Southern Green Gas aims to commercialise DAC technology and process captured CO_2 into synfuel. The DAC technology is based on small modules. The exact technological DAC approach employed by the company is not yet publicly known.

Outlook

In 2019, researchers at the University of Michigan published the following results:

- "*even a high-efficiency, low-cost version of DAC that's ready to be scaled up would still cost much more than speeding up the switch to renewables.*"
- "*DAC is inherently more expensive than if we started an immediate transition to renewable energy on a larger scale.*"

The costs of DAC are still very high. The high energy consumption of DAC also remains a problem, as well as the fact that safe and long-term CO_2 storage cannot be guaranteed.

The Hari Oni project breaks ground in Chile and other developments in Carbon Capture Use and Storage (CCUS)

CCUS is about the idea that captured CO_2 from industrial processes or directly from ambient air can be used as a feedstock for manufacturing products. The captured CO_2 is to be "stored" in the products. Currently, the most common use of captured CO_2 is enhanced oil recovery and the production of synthetic fuels – especially because the number and size of synfuel projects is increasing. However, the fuels are consumed within a short time, so the "stored" carbon is released back into the atmosphere. Furthermore, both the capture of CO_2 and the production of the fuels are energy-intensive – both can lead to additional CO_2 emissions.

Chile

The groundbreaking ceremony for the Hari Oni project took place in September 2021. The project was announced in late 2020 by AME, Siemens Energy, Porsche AG, ENAP and Enel and plans to manufacture Highly Innovative Fuels (HIF). The aim of the companies is to produce synthetic fuels from captured CO_2, water and energy. The CO_2 is to be captured directly from the air using wind energy – hence the choice of a site north of Punta Arenas, in the windy province of Magallanes in Chile, as the project location. Energy is also needed to split water into oxygen and hydrogen. The captured CO_2 is then combined with the hydrogen to produce synthetic methanol, which serves as a feedstock for further processing into fuels.

Canada

In October 2021, Huron Clean Energy announced a commercial synfuel production facility in British Columbia. The plant will be built in partnership with Upper Nicola Band, Oxy Low Carbon Ventures and Carbon Engineering. The facility aims to produce transportation fuel such as gasoline, diesel and aviation fuel based on CO_2 captured from ambient air. The DAC technology will be supplied by Carbon Engineering. The plant is to be built 25 kilometres from Merritt, in British Columbia. Construction is scheduled to begin in 2023 and the plant is expected to be operational in 2026. A FEED study is currently underway.

In November 2021, Air Canada and Carbon Engineering announced a Memorandum of Understanding to explore commercial opportunities for DAC-based aviation fuels.

USA

In November 2021, Velocys entered into a contract with Southwest Airlines for the purchase of an expected 830 million litres of synthetic aviation fuel. Delivery is scheduled to begin in 2026 and extend over a period of 15 years. Velocys' Bayou Fuels plant is still in the planning phase. It is expected to be built in Natchez, Mississippi. The planned facility will use woody biomass for the plant and heat it to produce carbon and hydrogen in gaseous

form. This synthetic gas will be purified and converted into fuels, such as diesel for trucks and aviation fuel, using the Fischer-Tropsch process developed by Velocys. The individual production steps are very energy-intensive.

In September 2021, the US-DOE provided funding to LanzaTech to build and operate a pre-pilot plant to produce CO_2-based aviation fuel using renewable energy. For this project, LanzaTech is collaborating with Argonne National Laboratory (ANL), LanzaJet Inc. and the Pacific Northwest National Lab. The technology to convert ethanol into aviation fuel was developed by LanzaTech's subsidiary LanzaJet in the USA and is known as the LanzaJet® process.

Switzerland

Synhelion, a spin-off of the ETH Zürich, aims to produce liquid hydrocarbon fuels, compatible with the current global fuel infrastructure. The production process requires large amounts of solar energy. This is probably why Synhelion recently acquired the German solar company Heliokon GmbH. As of November 2021, Synhelion has raised approximately € 15 million, with backers including Swiss KMU Partners, Orchilla, SMS Concast, CEMEX Ventures, AMAG, and private investors. In October 2021, it was announced that the German Federal Ministry for Economic Affairs and Energy (BMWi) will fund a synfuel-demonstration project based in Germany, in which Synhelion is involved, with € 3.92 million.

Germany

In 2021, Synhelion signed an agreement with Wood, an international consulting and engineering firm. The two partners announced plans to bring Synhelion's hydrocarbon fuels to market by 2023. The partners intend to design and install a plant that will later be commissioned at the solar tower of the German Aerospace Centre in Jülich, Germany. The new plant aims to demonstrate Synhelion's technology for producing synthesis gas on an industrial scale. The resulting synthesis gas mixture can then be processed into hydrocarbons such as paraffin or methanol using the energy-intensive Fischer-Tropsch synthesis process. The German Federal Ministry for Economic Affairs and Energy (BMWi) provided funding for the project in October 2021, which will be used to build the plant in Jülich. The planned plant is expected to produce about 0.01 million litres of synfuel annually by 2023. By 2023, Synhelion plans to commission its own industrial plant in Germany, which would initially produce around 10,000 litres of synfuel per year. Synhelion's production target for 2030 is 875 million litres of synfuel per year.

The German Sunfire GmbH was founded in 2008 and developed a process for the production of syngas. In its 2021 financing round, the company received € 109 million. The backers include: Audi, Carbon Direct Capital Management, HydrogenOne Capital, Idinvest Partners, INVEN Capital, Lightrock, Planet First Partners, Sunfire Entrepreneurs Club, Total Energy Ventures, and existing shareholders.

UK

The Green Fuels, Green Skies (GFGS) competition aims to support companies that pioneer new technologies to convert household rubbish, waste wood and excess electricity into sustainable aviation fuel. Among the winning proposals are the following projects:

- **Project AtmosFUEL**: The companies Carbon Engineering and LanzaTech aim to build a commercial jet-fuel plant. The feasibility project is expected to produce more than 100 million litres of jet fuel annually. The project will use Carbon Engineering's DAC technology in combination with LanzaTech's CCUS technology. The LanzaTech process converts CO_2 into ethanol; the conversion is done by microbes feeding on the CO_2 and producing ethanol. The ethanol is then converted into fuel using the LanzaJet® process.
- **Project Dragon**: In July 2021, LanzaTech announced plans to produce CO_2 -based aviation fuel in Port Talbot, South Wales. The aim of the project is to carry out a Front-End Engineering Design (FEED) study for the proposed aviation fuel plant at Port Talbot. The plant is expected to produce more than 100 million litres of aviation fuel/ kerosene per year. The CO_2 will be provided by one of the local steel mills.
- **Project Speedbird**: This feasibility project is a partnership between British Airways, LanzaJet and Nova Pangaea Technologies. The project plans to study the optimal design for a facility that produces more than 100 million litres of fuel per year using UK woody residues. The plant will integrate Nova Pangaea's REFNOVA® process, a process for converting biomass carbon into chemicals such as ethanol. LanzaTech's LanzaJet® process will convert the ethanol into fuels such as paraffin or diesel.
- **Velocys – Altalto Plant**: Velocys announced plans to open a waste-to-jet fuel plant near Immingham, North East Lincolnshire, UK. The project will be carried out in partnership with British Airways. The proposed plant

will use municipal solid waste and heat it to produce carbon and hydrogen in gaseous form. This syngas will be purified and converted into jet fuel and naphtha using a Fischer-Tropsch process developed by Velocys.

Sweden

In November 2021, Vattenfall, SAS, Shell and LanzaTech signed a Memorandum of Understanding and announced plans to produce CO_2-based aviation fuel near Forsmark on Sweden's east coast. LanzaTech has developed a CCUS process that captures CO_2 from exhaust gases and converts it into ethanol. In the USA, LanzaTech is developing a process for the production of CO_2-based aviation fuel, the LanzaJet® process. In a first step, the project partners plan to conduct an in-depth analysis of the project and, in a second step, to commission a production plant for synthetic aviation fuel using the LanzaJet process between 2026 and 2027. Vattenfall's combined heat and power plant in Uppsala would provide about 0.2 million tonnes of CO_2 for the production process.