

DAC and hydrogen electrolysis

The business case for e-fuels

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Carbon dioxide (CO₂) itself is not harmful to humans, up to a certain concentration. But the steady increase in atmospheric CO₂ concentration is causing harm to our environment and threatening human life on our planet in the long term.

CO₂ accumulation in the atmosphere has been through industrial and human activity. CO₂ removal is mainly through biological photosynthesis in plants where the CO₂ is converted to starchy hydrocarbons.

Various mechanical direct air

capture (DAC) processes have been developed to simulate the action of plants and remove CO₂ from the air. A DAC facility rated at one million tonnes of CO₂ capture per year does the equivalent work of 40 million trees. With such enormous potential, it is no surprise that a tremendous amount of development activity has taken place to research, scale up and commercialise these technologies in the past decade.

The theoretical minimum specific energy demand for DAC is 150 kWh/tonne of CO₂, but all real-world

processes operate at a multiple of this value. The challenge is to get as close to this theoretical minimum as possible. Each emerging system has its own advantages, and they are currently at different levels of maturity.

Carbon Engineering

Canadian-based company, Carbon Engineering was founded in 2009. Its four-step DAC process starts with a contactor when air is continuously pulled through a large tower and chemically reacts with a potassium

hydroxide solution to yield potassium carbonate ($\text{CO}_2 + 2\text{KOH} \rightarrow \text{K}_2\text{CO}_3 + \text{H}_2\text{O}$). In the second step, the aqueous potassium carbonate is mixed with calcium hydroxide in a pellet reactor at ambient temperature. This regenerates the potassium hydroxide solution and creates calcium carbonate pellets ($\text{K}_2\text{CO}_3 + \text{Ca}(\text{OH})_2 \rightarrow 2\text{KOH} + \text{CaCO}_3$).

In the next step the calcium carbonate is thermally decomposed in a classical calciner at 900°C. This is like the production of lime or cement and releases carbon dioxide ($\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$). Unlike classical calciners, the CO₂ is not released into the atmosphere, but separated from the process gases. The resultant high purity CO₂ is available for utilisation or sequestration.

The remaining calcium oxide is hydrated in a steam slaker at 300°C ($\text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca}(\text{OH})_2$), and the regenerated calcium hydroxide is fed back into the pellet reactor in step two above.

The specific energy demand varies, depending on the calciner input energy method and operating temperature. The total specific energy is 1,850 kWh/tonne of CO₂ if operated with natural gas only, or alternatively 1,500 kWh/tonne of CO₂ if renewable electricity is used instead of natural gas.

In comparison to some other DAC processes, this is a moderately low specific energy consumption, but the operating temperature is high and the potential to use waste heat is therefore low. Furthermore, water evaporation within the large air contactor could be very high in dry climate zones. This continuous loss of water must be

“CO₂ removal is mainly through biological photosynthesis in plants...”

considered in a full lifecycle analysis.

Carbon Engineering operates a demonstration plant in Canada. A large project in the Permian Basin of Texas has been announced where the captured CO₂ will be used for enhanced oil recovery of depleted crude oil fields. The technology is being commercialised in the US through the name IPOINTFIVE, in recognition of the international climate change target. Oxy Low Carbon Ventures and Rusheen Capital Management have teamed up to deploy the Carbon Engineering DAC equipment at massive scale.

Climeworks

In the first step of the Climeworks process, atmospheric air is blown through a CO₂ collector with the help of a fan. Most CO₂ from the air is captured on an amine-based solid adsorbent in the collector. The CO₂ concentration in the exhaust is significantly reduced.

Once the adsorbent material is saturated, the collector is heated up to between 80°C and 100°C. This releases the CO₂ from the solid sorbent. The high purity CO₂ is collected and can be utilised as a pure gas, further processed to create chemicals such as methanol, or sent for permanent underground storage in a CCS scheme.

CO₂ from DAC can also be used to create methane as an energy gas through methanation with hydrogen. Or syngas (a mixture of hydrogen and carbon monoxide) can be produced when captured CO₂ is combined with methane on a dry methane reformer ($\text{CO}_2 + \text{CH}_4 \rightarrow 2\text{H}_2 + 2\text{CO}$).

Each Climeworks collector can capture up to 50 tonnes of carbon dioxide per year, assuming a capacity factor close to 100%. The actual performance is impacted by several parameters, including the ambient conditions and weather at the installation site.

The specific energy demand is 2,000

4,000

Climeworks is building a 4,000 tonnes per year DAC system in Iceland

kWh/tonne CO₂ of low-grade heat and 650 kWh/tonne CO₂ of electricity. The electrical power is mainly required to operate the fan that draws air across the sorbent material. Despite the heat demand being quite large, an advantage of the process is that it only needs heat at low temperature. If this can be recovered as waste-heat from an adjacent chemical or thermal process, the total primary heat demand can be significantly reduced. Combination with geothermal energy is also highly synergistic.

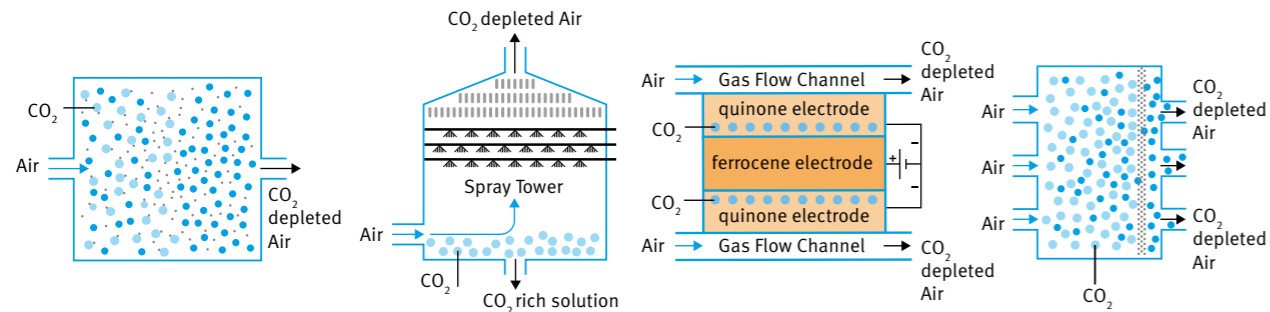
Climeworks has sold and operates more than 14 DAC systems of various sizes worldwide. The largest project, with an annual capture capacity of 4,000 tonnes of CO₂, is under construction in Iceland. The captured CO₂ will be permanently stored underground when the gas is mineralised to carbonates using the innovative Carbfix process. Heat and power for the system will be supplied from a geothermal power plant to ensure a negative carbon footprint for the overall scheme.

CO₂ utilisation and hydrogen from electrolysis for e-fuels

Beside existing industrial gas CO₂ utilisation cases such as pH control in wastewater, beverage dispense and accelerated growing conditions in greenhouses, the production of e-fuels can be a major application of CO₂ from DAC in the future. In the simplest case, CO₂ from DAC and hydrogen from an electrolyser are synthesised to methanol ($\text{CO}_2 + 3\text{H}_2 \rightarrow \text{CH}_3\text{OH} + \text{H}_2\text{O}$).

Methanol acts as a hydrogen carrier and remains liquid under ambient pressure and temperature. Thus, the ▶

Figure 1. DAC Technologies for Direct Air Capture of Carbon Dioxide



| | Climeworks | Carbon Engineering | Verdax | Carbyon |
|---------------------------|---|--|---|--|
| System type | Solid sorbent | Liquid absorbant | Solid sorbent | Solid sorbent |
| Technology | Amine-functionalised | Potassium hydroxide solution/calcium carbonation | Quinone-carbon nanotube composite | Thin film coated amine- and/or bicarbonate-based porous membrane |
| Regeneration | Temperature/vacuum | Temperature | Electro-swing | Temperature |
| Specific energy demand | Heat: 2,000 kWh/t _{CO2} Electricity: 650 kWh/t _{CO2} | NG: 2,777 kWh/t _{CO2} or Electricity: 1,500 kWh/t _{CO2} | Electricity (only cell, w/o BoP in particular ventilation): 568 kWh /t _{CO2} | TBD |
| Operating temperature | 80-100°C | 900°C | Ambient | 60-85°C |
| Technology maturity level | Commercial | Pilot | Laboratory | Theoretical |

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► storage and transport of methanol is generally easier and cheaper than cryogenic or pressurised distribution of hydrogen. Methanol synthesis has an energy efficiency of about 80%. This is much better than generating cryogenic liquid hydrogen, which consumes about 30% of the lower heating value (LHV) of hydrogen. Conversion to methanol is only slightly less energy efficient than using high-pressure compressed hydrogen for storage or distribution. For high pressure hydrogen compression, the energy

losses are between 10-15% of the LHV of hydrogen.

The exhaust heat of the methanol synthesis at circa 200°C, and the exhaust heat from electrolysis to produce the required hydrogen at circa 80°C, can both be used in the processes of low-temperature DAC. This smart heat integration would be beneficial for the overall e-fuel production process efficiency.

In considering the merits of any renewable fuel value chain, neither efficiency nor specific heat demand

alone will determine the viability of the process. The total costs associated with production, distribution and utilisation will be the governing factor to consider the optimum value chain. [gw](#)

ABOUT THE AUTHOR

Stephen B. Harrison is Managing Director of sbh4 consulting. Harrison has over 30 years' experience of the industrial and specialty gases business.

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