DAC and hydrogen electrolysis

The business case for e-fuels

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Carbon dioxide (CO_2) itself is not harmful to humans, up to a certain concentration. But the steady increase in atmospheric CO_2 concentration is causing harm to our environment and threatening human life on our planet in the long term.

CO_2 accumulation in the atmosphere has been through industrial and human activity. CO_2 removal is mainly through biological photosynthesis in plants where the CO_2 is converted to starchy hydrocarbons.

Various mechanical direct air capture (DAC) processes have been developed to simulate the action of plants and remove CO_2 from the air. A DAC facility rated at one million tonnes of CO_2 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 CO_2, 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 ($CO_2 + 2KOH \rightarrow K_2CO_3 + H_2O$). 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 ($K_2CO_3 + Ca(OH)_2 \rightarrow 2KOH + CaCO_3$).

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 ($CaCO_3 \rightarrow CaO + CO_2$). Unlike classical calciners, the CO_2 is not released into the atmosphere, but separated from the process gases. The resultant high purity CO_2 is available for utilisation or sequestration.

The remaining calcium oxide is hydrated in a steam slaker at 300°C ($CaO + H_2O \rightarrow Ca(OH)_2$), 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 CO_2 if operated with natural gas only, or alternatively 1,500 kWh/tonne of CO_2 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 considered in a full lifecycle analysis.

> "CO_2 removal is mainly through biological photosynthesis in plants..."

Carbon Engineering operates a demonstration plant in Canada. A large project in the Permian Basin of Texas has been announced where the captured CO_2 will be used for enhanced oil recovery of depleted crude oil fields. The technology is being commercialised in the US through the name 1POINTFIVE, 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 CO_2 collector with the help of a fan. Most CO_2 from the air is captured on an amine-based solid adsorbent in the collector. The CO_2 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 CO_2 from the solid sorbent. The high purity CO_2 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.

CO_2 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 CO_2 is combined with methane on a dry methane reformer ($CO_2 + CH_4 \rightarrow 2H_2 + 2\,CO$).

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 kWh/tonne CO_2 of low-grade heat and 650 kWh/tonne CO_2 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.

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

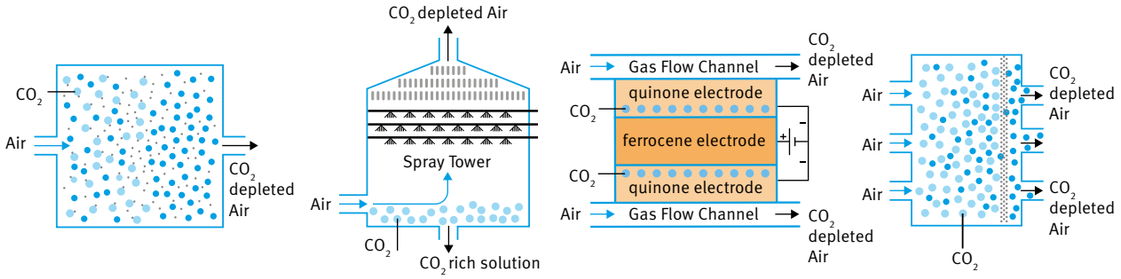
Climeworks has sold and operates more than 14 DAC systems of various sizes worldwide. The largest project, with an annual capture capacity of 4,000 tonnes of CO_2, is under construction in Iceland. The captured CO_2 will be permanently stored underground when the gas is mineralised to carbonates using 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.

CO_2 utilisation and hydrogen from electrolysis for e-fuels

Beside existing industrial gas CO_2 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 CO_2 from DAC in the future. In the simplest case, CO_2 from DAC and hydrogen from an electrolyser are synthesised to methanol ($CO_2 + 3\,H_2 \rightarrow CH_3OH + H_2O$).

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	Verdox	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.