

Direct Air Capture (DAC) technology

1. EXECUTIVE SUMMARY

- 1.1. Direct Air Capture (DAC) is a relatively new technology that has been developed in North America and Europe. The chemical process extracts CO₂ directly from the atmosphere. The chemical process has been proven in small-scale trials and has recently succeeded in securing investment from industrial partners in the U.S., where oil producers are planning to capture 1 Mt (1,000,000 tonnes) per year at a levelised cost of \$100 per tonne. DAC plants can be powered with renewable energy, creating significant opportunities to create 'negative emissions' in the Isle of Man carbon account.
- 1.2. The company Carbon Engineering (CE) have developed technology to chemically combine the carbon from the DAC process with hydrogen from electrolysis of water. The resulting compound is a synthetic fuel ('Air to Fuel'), which when burnt, releases ultra-low carbon emissions and is clean-burning. The synthetic fuel is claimed to be able to be produced at a cost of £0.80 per Litre (L), which includes the cost of the DAC process and electrolysis of water.
- 1.3. The Isle of Man currently consumes 55 million L of petrol and diesel per year, producing 162,000 tonnes of CO₂e. A CE DAC facility could capture offset the entire carbon account of the Isle of Man (839,000 tonnes) and produce sufficient synthetic fuel for the transport sector, with a 1Mt facility producing 320,000 L of synthetic fuel per day. The synthetic fuel can also be modified to be used as Jet-2 fuel and in home-heating.
- 1.4. It is recommended that the Isle of Man establishes contact with the DAC industry, particularly those in the industry that can create synthetic fuel as a by-product. The Isle of Man could represent a test-bed opportunity for the industry to trial the technology (with a relatively small and import-dependent liquid fuel industry), particularly since technology to decarbonise HGVs, marine and agricultural industries is not yet available. It will be important to enable DAC with renewable energy as a primary energy source in order to avoid a 'double-counting' exercise in the Isle of Man carbon emissions account.

2. DAC (DIRECT AIR CAPTURE) TECHNOLOGY: OVERVIEW

- 2.1. Over the past decade, direct-air-capture (DAC) technology has attracted increasing amounts of interest, particularly among heavy carbon polluting industries (fossil-fuel energy companies). DAC is a technology that, essentially, presents an artificial sequestration opportunity when considering carbon accounts – which is the opportunity to ‘credit’ the account with CO₂e removal which until recently, has relied upon natural ecosystem processes (photosynthesis).
- 2.2. DAC technology captures CO₂ from atmospheric air and reconstitutes the molecular compounds into a purified form for use (fuel) or for storage. Enterprises such as Carbon Engineering (CE), which has been in operation since 2009, have designed closed-loop systems where the only major inputs are water and energy, and the output is compressed CO₂. The captured, compressed CO₂ then offers a range of opportunities to create products and environmental benefits such a clean-burning liquid fuels which have ultra-low carbon intensity. These fuels could potentially be used in difficult-to-electrify systems of transport (aeroplanes, HGVs) or industries (farming, fishing, IOM steampacket/Shipping) and support the move towards electric vehicles by supplying low-carbon fuel to existing infrastructure and vehicles.
- 2.3. DAC is flexible in the sense that it offers industrial-scale artificial carbon dioxide removal (CDR), can enable production of ultra-low carbon fuels, or a mix of both of these component outputs. CE claim to offer technology that, when paired with the safe and permanent storage of CO₂, can create physical, verifiable ‘negative emissions’ at industrial scale. However, the main question from industry commentators is whether the economics (energy conversion ratio and cost-per-unit removal of CO₂) of the industrial systems offer a compelling business case.
- 2.4. Recent business developments have suggested that the economic scenario is becoming increasingly attractive – CE is planning to double the size of a proposed CO₂ capture plant in Texas which, when built, will be able to remove one million tonnes (1 Mt) of CO₂ from the atmosphere per year (by way of comparison, the net CO₂ account of the Isle of Man is 0.8 Mt per year). The development is in partnership with Oxy Low Carbon Ventures (a subsidiary of US based Occidental Petroleum Corporation), which aims to bury the CO₂ as part of an ‘enhanced oil recovery operation’. CE has also received investment from the Bill Gates Foundation as well as Chevron and BHP.



Figure 1. Artists' impression of CE Direct Air Capture and Air to Fuels™ plant, which will capture 1 MT of CO₂ per year.

2.5. Other DAC developments have been commercially scaled by firms such as Climeworks in Switzerland and Global Thermostat in Alabama. Climeworks use a design with low energy requirements, using residual heat from a local waste incineration plant. Their development, which was the first industrial scale DAC facility, began operation in 2017 in Zurich and is capable of capturing 900t (0.0009 Mt) per year, at a cost of \$600 per tonne. The CO₂ is used to increase vegetable yields in a nearby greenhouse (Tollefson, 2018). Global Thermostat, by comparison, has operations that remove up to 50,000 t (0.05 Mt) for \$120 per tonne and has recently partnered with ExxonMobil with the intention to produce DAC-to-fuel technology.

3. HOW DOES THE DAC CHEMICAL PROCESS WORK?

3.1. DAC systems have four major unit operations that create a chemical loop. The system continuously captures CO₂ from atmospheric air and delivers a purified compressed stream of CO₂, using water and energy as inputs.

- Step 1: Air contractor. The process starts with a 'wet scrubbing' air contactor which uses a strong hydroxide solution to capture CO₂ and convert it into carbonate. This occurs within a structure modelled on industrial cooling tower design.
- Step 2: Pellet reactor. The second step converts the carbonate solution into small pellets of calcium carbonate. This calcium carbonate, once dried, is then processed in the third step.
- Step 3: Calciner. A circulating fluid bed calciner heats the calcium carbonate pellets to decomposition temperature, breaking them apart to release the CO₂ as a gas and leave behind solid lime (calcium oxide).

- Step 4: Slaker. The calcium oxide is hydrated and then returned to the pellet reactor to regenerate the hydroxide capture solution, closing the chemical loop.
- 3.2. In the CE industrial baseline design, the calciner is heated by oxy-fired natural gas (which would be available via the gas interconnector). The calciner therefore contains CO₂ originally captured from air, CO₂ from natural gas consumption and water vapour. The CO₂ emissions from combustion of natural gas are delivered alongside the atmospheric CO₂ as the plant output. CE has also designed DAC configurations capable of reducing or completely eliminating the use of natural gas, instead relying on clean electricity as the sole energy input (available, hypothetically, from an offshore wind farm).

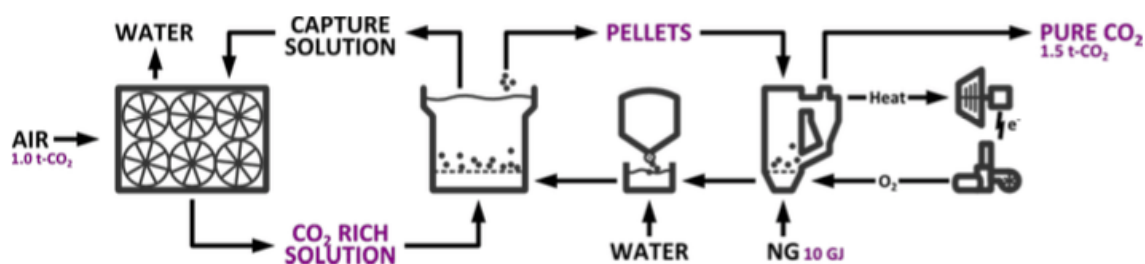


Figure 2. A diagrammatic illustration of the chemical process.

4. AIR-TO-FUELS™ TECHNOLOGY

- 4.1. CE's Air-to-fuels™ technology recycles the atmospheric CO₂ captured by the above process into liquid fuel, displacing crude oil. The process uses the captured CO₂ from the DAC process and green electricity to electrolyze water and generate hydrogen. The CO₂ and hydrogen are thermos-catalytically reacted to produce syngas, and reacted again to produce hydrocarbons.
- 4.2. The technology can harness low-carbon energy (such as offshore wind) and material inputs of water and air to generate fuels that are compatible with present infrastructure and vehicles. The solution complements the transition to electric vehicles by offering ultra-low carbon fuel options for long-haul transport (HGVs) as well as marine and air travel, which currently require the high energy density of liquid fuels. Air-to-fuels™ claims to offer a way to deliver liquid fuels, while avoiding the infrastructure turn-over of hydrogen fuel cells and the land-use problems associated with biofuels.
- 4.3. The fuel can be blended with traditional fossil fuels to allow progressive emissions reductions, with no blending limit. CE state on their website that they are actively seeking strategic partners to build full-scale commercial Air-to-fuel™ facilities and customers interested in supply agreements for the ultra-low carbon fuel. The Isle of Man, with a commitment to decarbonise emissions from transport (a sector that currently requires 505 GWh from 50 million L of road fuel per year, emitting approximately 162,000 t CO₂e) as well as the low tax environment for corporations and a defined liquid-fuels requirement (among a range of fleets and industries), may

be an interesting partnership proposition for the Canadian based CE or other DAC firms; they could provide a technologically based solution to facilitate the first transition to carbon-neutrality for an entire jurisdiction.



Figure 3. Air-to-fuel™ product.

5. (VERY SIMPLE) ECONOMIC APPRAISAL

- 5.1. A detailed economic analysis of DAC technology, published in the peer-reviewed journal *Joule* (Keith, *et al.*, 2018), was written by researchers at CE in Calgary, Canada. That trial plant provided the basis for the economic analysis, which includes cost estimates from commercial vendors of all of the major components. Using the cost estimates cited in Keith *et al.*, (2019), a CE facility of the scale required to remove the entire Isle of Man carbon account (0.839 Mt per year) in a process designed to optimise CO₂ provision for fuel synthesis (Table 2d in Keith *et al.*, 2019).¹

¹ Variant "D" in Table 2 is optimized to provide CO₂ for fuel synthesis. CE is developing air-to-fuel systems in which the hydrogen required as feedstock for the fuel synthesis step is produced by electrolysis, which can be created through renewable energy, as opposed to cracking methane (natural gas), thereby making the process carbon neutral. In this configuration, the oxygen from electrolysis is sufficient to supply the DAC plant, so in this application CE drop the ASU from the DAC process. The fuel synthesis system requires a CO₂ supply pressure of ~3 MPa, reducing the cost and complexity of the CO₂ compression and clean up. CE is developing methods to integrate the DAC and fuel synthesis, but for simplicity of analysis, they show the inputs for a plant that receives O₂ and produces atmospheric pressure CO₂.

Capital cost:	£412.5 m
O&M cost²:	£ 15.5 m
Levelised cost³ per tonne CO₂ removed:	£ 105.02
Net impact on CO₂e account:	-0.839 Mt
Total cost per annum:	£ 88.1 m

- 5.2. The CE claim that their process is now able to capture carbon for a levelised cost of £105 per tonne (depending on the cost of inputs, including energy) means that offsetting the entire Isle of Man carbon account (0.8 Mt), would therefore cost **£88.1 million** per annum.
- 5.3. The Air-to-fuels™ process claims to be able to produce ultra-low-carbon liquid fuels for a levelised cost of less than \$1.00 per L (**£0.80 per L**) once scaled up, which is cost competitive with biodiesels (again based on the price of energy input). By comparison, the price of petrol and diesel (before duty and VAT) is £0.69 and £0.74 respectively. However, Isle of Man produced air-to-fuel™ liquid hydrocarbon products may not be subject to the same levels of UK MHRC HCO duty rates as conventional hydrocarbons, potentially creating a competitive ultra-low-carbon fuel available for domestic consumption, storage and export. As far as can be determined at this point, synthetic fuels were not considered in the UK HMRC duty regulations and aviation fuel currently pays no duty.
- 5.4. A full scale DAC plant, which captures 1 Mt of carbon, is expected to have the resources to produce 320,000 L of air-to-fuels™ liquid per day, or 116.8 million L per year. A DAC facility capturing 0.839 Mt (Isle of Man net emissions 2018) would produce 98 million L, with a levelised cost (including the entire process of DAC and A2F) of £0.80 (£78.4 million). The process can use carbon-free renewable power such as wind and can accommodate the intermittent nature of this power source to continuously produce high value transportation fuels (carbonengineering.com). The fuel is claimed to burn cleaner than conventional petroleum fuel, with lower sulphur and particulates as well as GHG emissions (figure 4).

² Non-energy O&M expressed as fixed per unit of capacity with variable costs including cost of make-up streams included and converted equivalent fixed costs using 90% utilization.

³ Calculations assume CRF (capital recovery factor) of 1.5%. Natural Gas at \$3.5/GJ and a 90% utilization. Electricity at £48 /MWhr (which is above the levelised cost of electricity from offshore wind).



Figure 4. A visual demonstration comparing the combustion of conventional diesel (left) and air-to-fuels™ liquid (right).

- 5.5. The current estimate for road-fuel use in the Isle of Man is 50 million litres per year. The surplus fuel production could be exported to the UK, where demand for low-carbon liquid fuels is high, or trialled within marine and aviation transport as well as use within domestic heating (kerosene). Exporting surplus fuel would have the benefit to the Isle of Man carbon account as being shown as 'negative emissions' on the domestic carbon account as the fuel would be burnt (and carbon released) in the UK (though overall, national carbon accounting aside, the net balance would be near-zero). Full consideration should be given to avoid 'double-counting' in national carbon accounts.
- 5.6. Given the average price of liquid hydrocarbon on the forecourt in the UK today (£1.30 per L), 98 million L of air-to-fuels™ production equates to a potential revenue generation of £127.5 million per year if sold at the same average price of diesel/petrol.
- 5.7. Additional benefits to the Island include energy independence in the form of being completely independent of having to import liquid fuels. Furthermore, there would be no requirement to transition to electric vehicles in the near future. However, it is important to note that road-fuel duty currently generates £30 million for the IOM Government. The greatest benefit, though, could be the potential for the Isle of Man to be the first jurisdiction in the world to achieve CO₂ net-neutrality with the installation of a single technology. A full systems efficiency analysis would help determine the economic appropriateness of this technology. Importantly, adopting a synthetic fuel surface-transport solution may isolate the Isle of Man in the context of a global industrial shift toward electrification of transport.

6. TIMELINE

- 6.1. Today, CE is running a commercial validation project to test the last remaining integration risks at larger scale and sell synthetic fuels to commercial customers. CE will use data from the DAC and AIR TO FUELS™ pilots, as well as the commercial validation effort, to complete the engineering design for the subsequent full scale commercial AIR TO FUELS™ facilities that CE aims to deploy.
- 6.2. In 2021, following commercial validation, CE will move to deploy the first full scale, commercial AIR TO FUELS™ facilities that directly synthesize liquid fuels, and supply them to end users within existing transportation fuels infrastructure and markets. CE envisions building individual facilities with a capacity of 2000 barrels per day, and deploying first projects in leading markets such as British Columbia and California where existing Low Carbon Fuel Standards favour clean fuels such as CE's.
- 6.3. This technology, if proven to be viable, could be operational by the mid-2020s and deliver carbon neutrality for the Isle of Man when powered at full capacity. The scale of development will dictate the capacity to capture CO₂, which will be balanced against economic feasibility and business case, but could (in theory) deliver a net-negative carbon account for the Isle of Man.

7. RECOMMENDATIONS

- 7.1. Further research into the technical and economic implications of adopting such a technology.
- 7.2. Evaluate the risk of being a near 'first-adopter' of the technology.
- 7.3. Investigate competitiveness within the DAC industry.
- 7.4. Investigate opportunities for commercial trials in the Isle of Man through partnering with industry leading DAC developers.
- 7.5. Engage with existing Isle of Man petroleum importers (EVF / MPL).
- 7.6. Further economic analysis of DAC and A2F technology using renewables and electrolysis of water as primary inputs.
- 7.7. Assess 'expression of interest' for Isle of Man DAC facility.

8. REFERENCES

Keith, D. W., Holmes, G., Angelo, D. S. & Heidel, K., 2018. A process for capturing CO₂ from the atmosphere. *Joule*, 2(8), pp. 1573-1594.