GOBINA, E., GIWA, A. and BEN-ARON, A. 2022. Unconventional membranes for direct air carbon capture. *Membrane technology* [online], 2022(7). Available from: https://doi.org/10.12968/S0958-2118(22)70077-8

Unconventional membranes for direct air carbon capture.

GOBINA, E., GIWA, A. and BEN-ARON, A.

2022

Unconventional Membranes for Direct Air Carbon Capture

[1]Edward Gobina*, [2]Ayo Giwa and [3]Adam Ben-Aron.

[1] Centre of Excellence for Process Integration and Membrane Technology (CPIMT), School of Engineering, Robert Gordon University, Garthdee Road, ABERDEEN, AB10 7GJ, UK, Tel: +441224262348 (*Corresponding author: e.gobina@rgu.ac.uk)

[2] McAlpha, Inc., 205 - 279 Midpark Way SE, Calgary, ALBERTA T2X 1M2, CANADA, email: a.giwa@mcalpha.com

[3]The Solistra Corporation, 46A Crawford Street, Toronto, ONTARIO M6J 3T6, CANADA. (adam.benaron@solistra.ca)

Introduction

Direct air capture (DAC) technologies extract carbon dioxide (CO2) directly from the atmosphere. The CO2 can be permanently stored in deep geological formations (thereby achieving negative emissions of carbon removal) or it can be used, for example combined with hydrogen (H2) to produce synthetic fuels as shown in Figure 1. The synthetic fuel (e.g., gasoline) can be synthesised by combining CO2 and hydrogen, the CO2 from the air, the hydrogen from water—the H2 is produced by electrolysis —and the CO2 comes from here using our unconventional membrane direct air capture (um-DAC®) technology. Combining these two constituents over a special catalyst gives you hydrocarbons and when stoichiometry is right, a product which has a molecular identity mimicking gasoline, is obtained with the only exception that it comes from water and air rather than from petroleum. Therefore, if combusted CO2 will still be generated but the CO2 that is emitted comes from the atmosphere in the production of the gasoline and therefore you have the carbon circle since the hydrogen is generated using renewable electricity. Therefore, in net terms no CO2 is emitted using the produced from CO2 and H2 from air and water respectively (Figure 1).

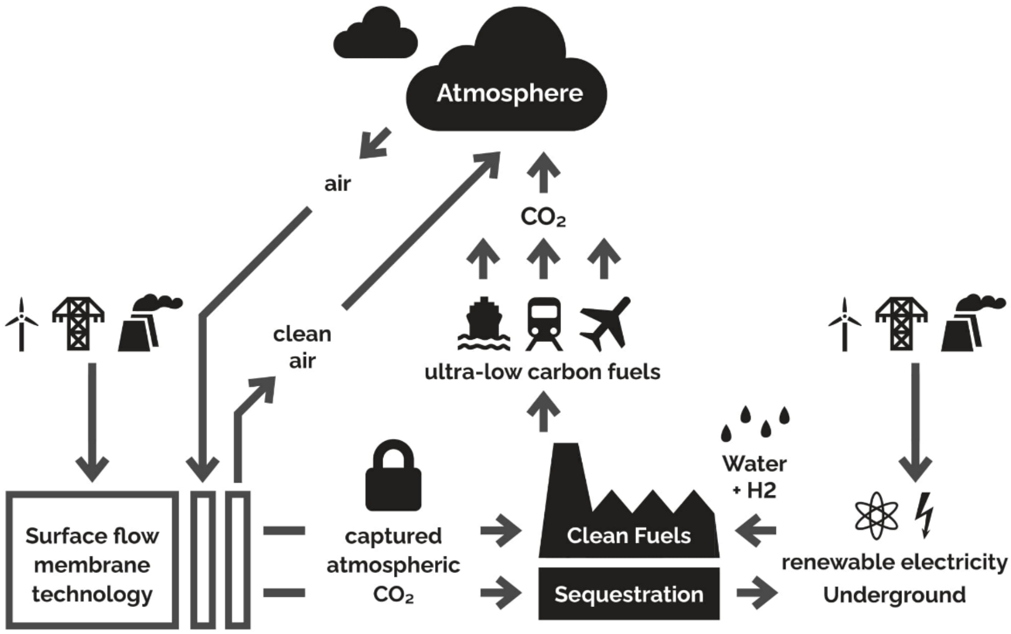

Figure 1: Direct Air Capture with Renewable Energy Integration and Utilisation

Figure 1: um-DAC® with Renewable Energy Integration and Utilisation

Direct Air Capture (DAC) Plants

There are currently at least 20 direct air capture (DAC) plants operating globally, capturing over 0.01 million tons CO2 per year, and at least one 1 million tons CO2 per year capture plant is in advanced development in the United States of America. Swiss climate tech company Climeworks announced on 28 June 2022 that it has broken ground on its biggest DAC plant yet. The new plant named Mammoth, will significantly scale up the company's operations in Hellisheiði, Iceland where Climeworks built Orca, which was the largest DAC plant in the world when it began operations in September 2021. Orca has the capacity to capture up to 4,000 tons of CO2 per year, for storage in basalt formations, which roughly equates to how much climate pollution 790 passenger cars release into the atmosphere annually. In comparison, Mammoth can capture about nine times as much CO2 as Orca. In the Net Zero Emissions scenario, by 2050, DAC is scaled up to capture more than 85 million tons CO2 per year by 2030 and then ~980 million tons CO2 per year by 2050. This level of DAC deployment will require a huge refinement of the technology through several more large-scale demonstrations and reduction in capture costs.

Direct Air Capture (DAC) Technologies

Today, two technology approaches are being used to capture CO_2 directly from the air: liquid and solid DAC (Figure 2). Both these technologies are semi-batch processes due to the need for regeneration to release of the captured CO_2.

Liquid DAC Systems

Liquid systems pass air through chemical solutions (e.g., a hydroxide solution), which removes the CO_2. The system reintegrates the chemicals back into the process by applying high-temperature heat while returning the rest of the air to the environment.

Solid DAC Systems

Solid DAC technology on the other hand makes use of solid sorbent filters that chemically bind with CO_2. When the filters are heated and placed under a vacuum, they release the concentrated CO_2, which is then captured for storage or use.

Unconventional Membrane DAC (um-DAC®) Systems

Our unconventional membrane DAC (um-DAC®) systems could be considered as solid DAC, however there is a major difference with the traditional solid DAC systems (Figure 2). In our um-DAC® process the air is forced through the membrane where CO_2 and water vapour are selectively removed by permeation thus creating a clean air stream in the retentate. For our system to be able to perform this task, the membranes are porous (mean pore size ~6,000 nano meters) and utilise the same base material as those used in a car's catalytic converter. The main difference being that our systems have straight-through pores. In these pores large enough for viscous flow to occur, a CO_2-affinity solid is deposited on the pore walls which allow the CO_2 to attach itself and flow from the feed side to the permeate side because of a slight imposed pressure gradient. Because the bond between the affinity material and the CO_2 is only a week bond it detaches itself from the material at lower pressure in the permeate. The water vapour plays a key role as it condenses in the pores resulting in capillary condensation. The combination of high flux due to viscous flow, surface flow due to affinity to CO_2 and capillary condensation of water vapour creates a unique combination that results in high CO_2 flux and selectivity. Another key factor is that CO_2 forms a bond with water vapour and therefore

‘’dragged’’ along with the CO2 creating a surface flow mechanism in the pores while preventing oxygen (O2) and nitrogen (N2) to go through the membrane. This means that unlike the traditional DAC system our um-DAC® is a continuous process that does not need any heat for regenerations, water or disposal issues and can ideally be located anywhere including in decommissioned offshore platforms where they can take advantage of already existing infrastructure to reinject the captured CO2 into depleted oil and gas reservoirs or saline aquifers for a more permanent storage (Figure 3)

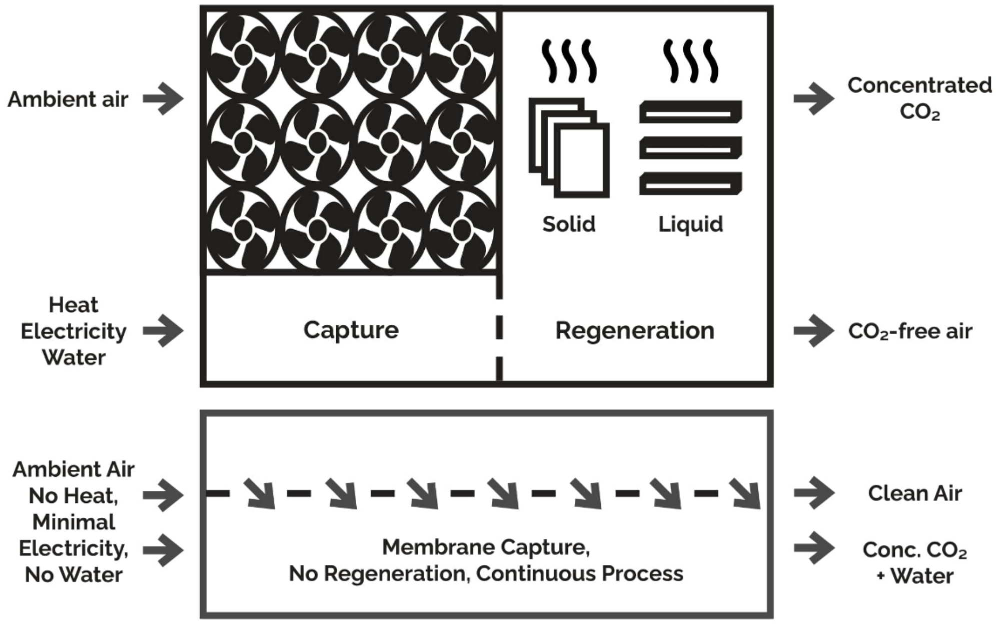

Figure 2: A comparison Of Our um-DAC® With Traditional DAC Systems

Large-Scale Opportunities

Most large-scale opportunities to reuse the captured CO2 would result in its rerelease into the atmosphere (Figure 1). These include when synthetic fuel is burned. This would not create negative emissions but still generate climate benefits if the fuel is produced using renewable hydrogen and if the synthetic fuels replace conventional fossil fuels. In a transition leading to net zero emissions the CO2 used to produce synthetic fuels would increasingly need to be captured from sustainable sources such as bioenergy sources or directly from the atmosphere to circumvent delayed emissions from fossil-derived CO_2 when the fuel is burned. If our um-DAC® were built alongside offshore wind turbines, they would provide an immediate source of clean energy from excess wind power and could pipe captured carbon dioxide directly to storage beneath the sea floor below as described in Figure 3, thereby reducing the need for extensive pipeline systems.

Advantages of um-DAC®

The IPCC recommendation is for achieving the 1.5 °C scenario, which means other approaches too are being proposed. In this context, compared to thin film membrane systems using polymeric membranes identified as having several advantages compared to the conventional sorbent-based DAC process. It is modular and therefore can be densely packed for example on an offshore platform and take advantage of utilising offshore wind energy. Also, our approach is unique since it produces high CO_2 flux at low pressure differentials. In addition, our approach does not require special chemicals or sorbents for CO_2 capture meaning it can be made autonomous. Like other membranes our approach is scalable and can be installed in almost anywhere for widespread and ambient DAC. This uniqueness of um-DAC® provides opportunities to capture legacy CO_2 and in applications that have never been considered in the past. For example, the CO_2 concentration in the beer and bread production and open plan offices where CO_2 concentration often exceeds more than 1000 ppm without proper ventilation since an average human being emits ~1 kg CO_2 per day. In these environments um-DAC® becomes relatively efficient since the driving force of CO_2 is greater than ambient conditions. With reduced energy utilisation, modularity, absence of frequent regenerations and specific chemicals makes our um-DAC system a truly distributed and scalable process.

Policy and CO2 Accounting Frameworks

In the meantime, we must ensure that policy and CO_2 accounting frameworks recognise negative emissions because in the near term, large-scale demonstration of DAC technologies will require targeted government support, including through grants, tax credits and public procurement of CO_2 removal. Our um-DAC® technology deployment may also benefit from initiatives and pledges from the corporate sector to become carbon-negative through the voluntary market. Longer-term m-DAC deployment opportunities will be closely linked to robust CO_2 pricing mechanisms and accounting frameworks that recognise and value the negative emissions associated with storing CO_2 captured from the atmosphere. Therefore, offshore um-DAC® is very important. However, our um-DAC® technology has been backed with a six-figure award to further develop this technology by the Net Zero Technology Centre (NZTC). The grant will be used to test cheaper and more affordable membrane materials, optimise CO_2 perm-selectivity (obtained during air mixture separation since ideal selectivity from single gas permeation measurements would not clarify the assessment of membranes for DAC), process and application stability/durability of the membrane system against the typical, matured but incredibly expensive and energy-intensive alternatives such as adsorption, absorption and cryogenic distillation, process cost analysis since DAC conditions are significantly different for those operating in typical CO_2 capture, and process cost reduction to make the um-DAC® process economically viable.

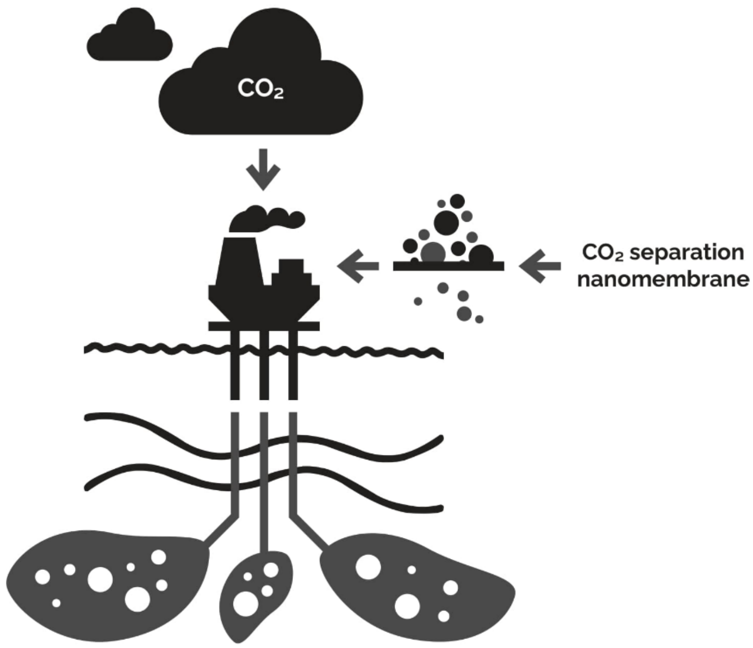

Figure 3: Marinization of um-DAC Systems

Figure 3: Marinization of um-DAC® Systems

Conclusion

Our um-DAC may seem now as a mere potential. The Centre for Process Integration and Membrane Technology at RGU is leading an investigation into the marinization of the um-DAC® technology and how renewable H_2

will be generated from the sea. It will study the seawater electrolysis systems and hydrogen transport by repurposed pipeline, as well as the capture of CO2 from the atmosphere, nitrogen production by membrane air separation, flue gas conversion to green chemicals and green ammonia production at sea. In addition, it will conduct a comparative analysis of the technologies, with a focus on conceptual design, scale, technological maturity, integration conditions, and estimated costs. We will identify the requirements in terms of the political, legal, social, policy, energy regulations and industrial-marine safety guidelines, to establish an offshore integration of um-DAC with green hydrogen and ammonia production, storage, and logistics chain. Finally, we will conceptually validate the solution on a laboratory scale and integrate it into an Internet of Things platform that, based on intelligent monitoring and optimisation will facilitate the operation, maintenance, and management in an offshore platform cluster.

Acknowledgements

The Authors acknowledge matched funding from the Net Zero Technology Centre and McAlpha, Inc., for this research.