DAC AND GGR INNOVATION PROGRAMME PROJECT NNB202043 –HEAT-DRIVEN DIRECT AIR CAPTURE POWERED BY NUCLEAR POWER PLANT

PHASE 1 FINAL REPORT

DATE: 21 JANUARY 2022

CONTENTS

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1. INTRODUCTION

In early 2021, Sizewell C (SZC) formed a consortium with University of Nottingham (UoN), Strata Technology, Atkins and Doosan Babcock to participate in the BEIS Direct Air Capture (DAC) and Greenhouse Gas Removal (GGR) innovation competition.

The consortium successfully bid to develop a heat-driven DAC technology for Carbon Dioxide (CO_2) that could in the future be scaled up and integrated with the SZC power plant. This report outlines the key findings and outcomes from Phase 1 of the competition which focussed on research and development, technology and plant design.

2. EXECUTIVE SUMMARY

During Phase 1 of the BEIS DAC & GGR competition, the consortium has successfully completed a research and development project of experimentation and engineering design for a novel heat-driven DAC process. The research has demonstrated that stable air circulation can be achieved by applying a set heat input (which can be provided by a low-carbon source such as nuclear energy) to the process, and that UoN's high performing carbon capture sorbent can achieve an uptake of 80% of its equilibrium capacity with only a 45 second contact time in air.

The experimental phase also identified that the effect of a crosswind moving across the outlet of the air-sorbent contactor has a positive impact on the performance of the system, and during periods of elevated wind speed a significant reduction in the heating requirements of the DAC system could be seen.

The experiments performed using a lab-based pilot plant have enabled the process design for a 100t CO_2/year demonstration plant to be completed. The construction and delivery of this plant in a future phase (if selected) will enable further process development and optimisation to be performed.

3. PROCESS DESCRIPTION

3.1 Overview

The heat-driven DAC process will employ a novel heat-driven solid adsorbent looping system to remove CO_2 from the atmosphere. In the loop, a highly selective solid adsorbent circulates through a heat-driven air-sorbent contactor to directly capture atmospheric carbon dioxide. Recirculation of the solid adsorbent around the carbon capture section of the air-sorbent contact column (adsorber) will ensure that it is near saturated with carbon dioxide before being transferred to the desorber. This transfer will be via a gas-lock, purged with carbon dioxide to minimise the transfer of contaminating permanent gases which will reduce the need for extensive post-capture product clean-up. The heat-driven temperature-swing desorption will occur in a heated desorber and involves using carbon dioxide partially or wholly as the sweeping gas. The regenerated sorbent will be discharged from the desorber, cooled and recirculated back into the adsorber through an arranged loop.

3.2 Chemical and Physical Processes

The CO_2 capture process involves using solid chemical adsorbent materials with moderate surface basicity to react with acidic CO_2 in the air, fully reversibly. The CO_2-adsorped solid sorbent is then regenerated to release the CO_2 with high purity, which can then be compressed for storage or utilisation.

3.3 Materials Consumed

3.3.1 Sorbent

The key material input into the process is the carbon dioxide adsorbent. UoN have previously shown the sorbent as being effective over hundreds of cycles, however further work will need to be conducted within the demonstration plant to quantify sorbent lifespan.

The sorbent consists of a porous support that is functionalised with CO_2-active chemicals for DAC. The support can be purchased in the required quantities for Phase 2 (if selected) from the University's existing suppliers, and the University will then perform the required works in-house.

At the end of the Phase 2 trial, any viable sorbent will be retained by the University for future research and development work in connection with this DAC project. The support material from spent sorbent can be reconditioned to minimise or even eliminate waste production from the process.

3.3.2 Water

A water input to the plant would only be required in the event of a continued dry atmosphere where there may be a risk that the incoming air would not contain the required level of water for contact with the sorbent. However, reviewing weather averages for the demonstration plant area (please see section 6.1) indicates normal ambient humidity of 70-90 % relative humidity (RH)[1], and water is also due to be recovered from the CO_2 product. As such, it is thought the required top up would be minimal (< $10m^3$ per year). This would be sourced from mains water.

3.3.3 Thermal Fluid

A thermal oil heating loop is being used to provide the required heating to the system. Bunding will be in place around the heating unit to minimise risk of release to the environment. Disposal of spent oil will be discussed with the supplier and if possible, it will be sent to a recycling facility.

3.4 Energy and Fuel Requirements

The heating demands are to be met using electrical energy for the demonstrator plant, however at commercial scale the available low carbon heat (and electricity) from SZC could be used to meet process requirements. SZC is proposing to extract up to $400MW_{th}$ of heat from the nuclear power plant once operational. Although a minor modification to the power plant design will be required to implement cogeneration, SZC does not expect any significant change to the replication of the design from Hinkley Point C or its safety case at this stage. Sizewell C will continue to develop its studies and design for cogeneration over the course of phase 2 of the project and, as construction of the power plant progresses, SZC will also explore increasing the proportion of heat extracted from the plant. The heat-driven DAC system operates with only a small amount of electrical energy for process control and motorised mechanical components.

3.5 Environmental Impact

As detailed in Section 6.1, the demonstration plant is anticipated to be sited around the 3.2 GW Sizewell C station which is currently being developed in Suffolk (and will be a major infrastructure and construction project in the UK).

Due to the nature of the site selected for the demonstration unit, there would be very limited impact on natural assets (and relevant planning and other consents for the heat-driven DAC development will be obtained), as well as the consideration that the research and development work carried out on this plant could provide a

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[1] Sizewell Climate Weather Averages, World Weather Online, https://www.worldweatheronline.com/sizewell-weather-averages/suffolk/gb.aspx

pathway to a scaled and integrated DAC plant linked to Sizewell C which has potential to remove in excess of 1 MT CO_2/annum by utilising heat from cogeneration from Sizewell C.

With regards to this unique heat-driven DAC process, the key environmental risk that has been identified and mitigated within the demonstration plant is the potential for sorbent particles to be fluidised and carried out of the top of the column. To minimise this risk, a specially designed vessel section has been positioned above the sorbent/air contacting bed to prevent the particles moving onwards with the air. There is also a provision for particle monitoring to be performed and, in the unlikely event that this sensor indicates that particles are being carried over, the plant can be stopped, and a sorbent replacement shall be initiated.

4. EXPERIMENTAL PROGRAMME AND RESULTS

Built upon the research at UoN, the project aims to design and demonstrate a novel heat-driven direct air capture system, which is expected to offer major cost reductions and reduced electrical energy demand compared to the existing DAC technologies, by making effective use of low-cost low-carbon heat from a nuclear power plant or any other harvestable low or zero-carbon energy at above ambient temperatures including industrial waste heat or geothermal sources. To define and optimise the key parameters of both the process and sorbent materials at sensible scales for the design of the demonstrator plant, a heat-driven DAC pilot facility has been constructed and a range of pilot tests have been successfully carried out under various conditions at UoN, supported by both process modelling and characterisations. Due to an unexpected -yet welcome- important development, additional pilot tests have also been conducted to examine and quantify the effect of crosswind on air circulation within the DAC system at different wind velocities; the extraordinary results obtained demonstrate that depending on local or geographic conditions, natural wind could deliver further major cost reductions to the heat-driven DAC system. In brief, while a wide range of key data sets and process parameters have been generated to aid the demonstrator design, the pilot tests coupled with the results of the process modelling also further confirm the practical and techno-economic feasibility of the heat-driven DAC system for major cost reductions. The following sections present a summary of the major results and findings.

4.1 Experimental Programme

4.1.1 Pilot plant design and construction


Figure 1 laboratory-based heat-driven pilot DAC system

A pilot facility for the heat-driven direct air capture system has been successfully designed, constructed and commissioned, as shown in Fig.1. The pilot DAC facility consists mainly of a heat-driven air-sorbent contactor section with a heating chamber to allow heat input at different levels. Thermocouples were installed at different heights to monitor the temperature profile of the heat-induced air flows. Differential pressure transducers and anemometers were also installed to measure the air flow velocity and pressure drops under different operation conditions.

4.1.2 Air flow velocity versus heat input

Using the pilot heat-driven DAC system, the characteristics of resultant air flows as a function of heat input have been established and key process parameters have been derived to aid the engineering design of the DAC demonstration plant. The pilot tests have demonstrated that large volume heat-induced air flows with high velocities can be readily facilitated and effectively regulated with high operational flexibility. No appreciable variations of air velocity were found for the whole effective length of the sorbent-air contactor. Reynolds number calculations indicate that the air flow is fully turbulent at all levels of heat input levels examined, suggesting that efficient air-sorbent contact and mixing can be achieved to ensure high efficiency of CO_2 capture. The pilot tests also confirms that the heat-induced air flow heat pressures appear to remain generally stable even under the dynamic conditions examined at all levels of heat input.

4.1.3 Effect of sorbent-air contactor configuration

The air flow through the heat-driven sorbent-air contactor (adsorber) can be potentially affected by the internal structural arrangement and levels of sorbent loading in the adsorber, due to the accordingly reduced flow areas. However, the pilot tests under various conditions show that a 40% reduction in air flow path through the adsorber as a result of sorbent loading and/or internal structural arrangement has negligible effect on air flow (Fig. 2). Nevertheless, a reduction in air flow path at such an extremely high level is never anticipated in practical operations.

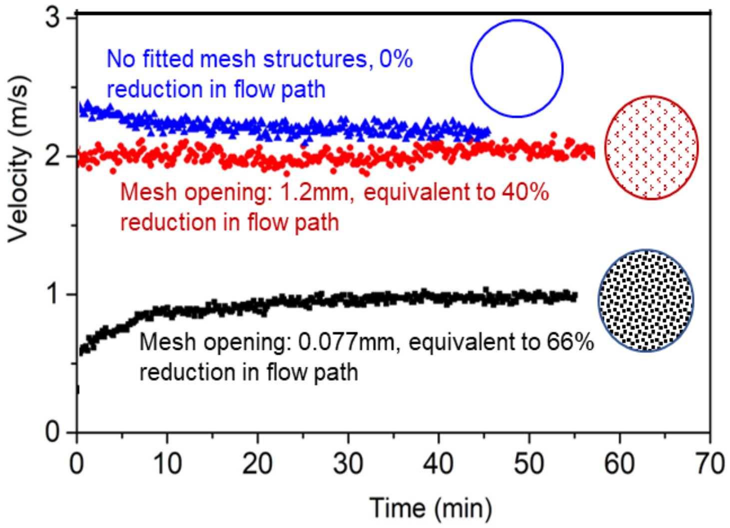

Figure 2 Effect of gas flow area on air flow velocity in the sorbent-air contactor

4.1.4 Crosswind effect and potential further cost reductions for the heat-driven DAC system

During the operation of the newly constructed pilot heat-driven DAC plant, an interesting phenomenon occurred. The air flow measured was always higher than the air flow theoretically predicted whenever the centrally controlled building ventilation system was turned on and this inspired us to examine the role of crosswind. Fig. 3 shows the effect of crosswind on the air flow velocity in the heat-driven air-sorbent contactor at different simulated wind speed varying from 34 to 55 miles/hour (15 to 24 m/s), which represents the medium/high wind speeds in the UK. Under the tested conditions, the air flow velocity was found to increase by 55% at a crosswind speed of 55 miles/hour and by ~20% at a wind speed of 34 miles/hour, respectively. This means that the energy requirement of the heat-driven DAC system can potentially be further significantly reduced with the aid of natural wind, subject to local or geographic conditions.

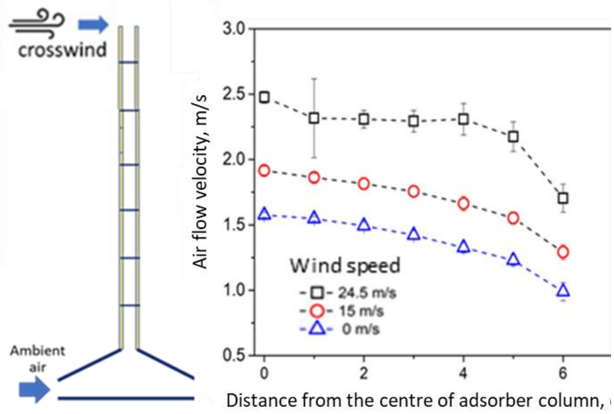

Figure 3 Effect of crosswind on heat-induced air flow in the adsorber at a heat input level of 0.4 kW_{th}

4.1.5 Optimisation, characterisation and scale-up production of sorbent materials

Two different types of sorbent materials were used for direct air CO_2 capture with the pilot DAC system. Both types of sorbent materials were tested to show rarely seen high capacities with fast adsorption kinetics and desirable adsorption/desorption performance, compared to reported capture materials [2] [3].

To determine the suitable operational conditions at the lab-based pilot scale, the terminal velocity (u_t) of the selected sorbent material was first evaluated based on the physical properties of both the air and the capture material. The terminal velocity of a solid particle represents the maximum updraft air velocity that should not be exceeded to avoid carry-over. Fig. 4 shows the terminal velocity for the sorbent materials with particle size between 0.1-0.9 mm and density between 0.7-1.58 g/cm^3. The terminal velocity could be easily obtained based on the density and particle size of a sorbent material.

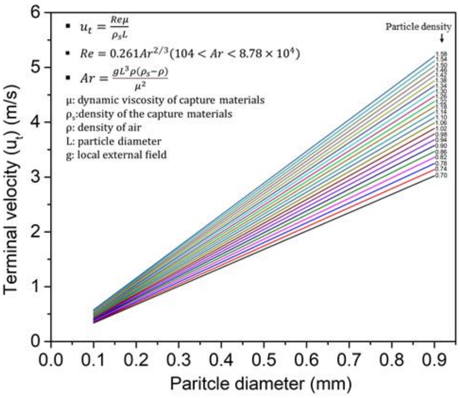

Figure 4 Terminal velocity as a function of the density and particle size of sorbent materials

4.1.6 Operation of the heat-driven pilot DAC plant with selected sorbent materials

All pilot tests were conducted with the ambient air at an ambient air temperature of about 20 °C. The CO_2 concentration of the indoor ambient air was measured at 440 ppm, and an integrated ABB's Magnos28 analyser was used to continuously monitor the outlet CO_2 concentration. The sorbent material was manually fed into the heat-driven adsorber at different feeding rates, as shown in Fig. 5(a). Under the test conditions examined, the residence time of the sorbent used was estimated at approximately 5 seconds. The pilot operation tests show that the air CO_2 removal rate increases linearly with the sorbent feeding rate. As shown in Fig. 5(b), the superior CO_2 removal performance has been achieved with exceedingly fast adsorption rate in an extremely short residence/contact time estimated at just 5 seconds. At the relatively low sorbent feeding rate of just 4.2 kg. m^{-2}. min^{-1}, the CO_2 removal rate reached an exceedingly high level of 61%, with the CO_2 concentration in the air reduced from its original 440 ppm down to 177 ppm. Clearly, a significantly higher removal rate can be achieved by either increasing the sorbent feeding rate and/or the contact time between the sorbent material and air. Continuous cycles of adsorption-desorption pilot tests were also carried out with the pilot DAC plant, which confirms the superior performance and operational stability of both the sorbent materials and the heat-driven DAC system, as shown in Fig. 5(c).

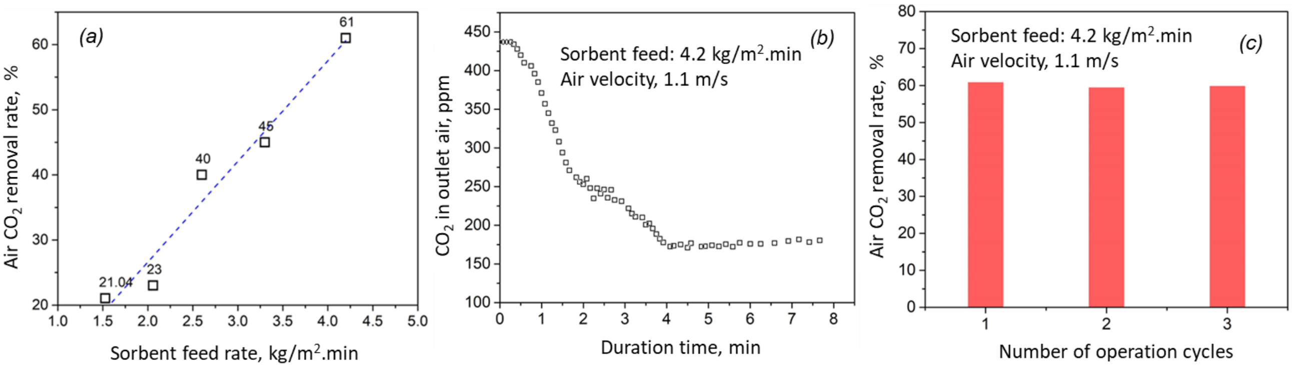

Figure 5 Continuous pilot testing of a selected sorbent material for DAC: (a) Outlet CO_2 concentration; (b) relationship between sorbent feeding rate and capture efficiency; (c) cyclic performance of selected sorbent material.

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[2] H. Azarabadi and K. S. Lackner. A sorbent-focused techno-economic analysis of direct air capture. Applied Energy, 250 (2019) 959-975.

[3] J. A. Wurzbacher et al. Heat and mass transfer of temperature-vacuum swing desorption for CO_2 capture from air. Chem. Eng. Journal, 283 (2016) 1329-1338.

4.2 Sorbent Characterisation

Various characterisation tools have been used to characterise the sorbent materials prepared at different scales and those from the pilot tests, such as thermal gravimetric analysis, BET measurements, and small and pilot testing facilities. The characterisation results have helped optimise and prepare the sorbent materials.

4.3 Process Modelling

4.3.1 Modelling of the pilot heat-driven DAC system

To assist the demonstrator design, models simulating the heat-driven air and particle movement within the adsorber column have been developed and validated in general, based on the pilot experimental data and using the engineering simulation software of ANSYS FLUENT (V2021 R2). Figs. 6 and 7 show some of the modelling results. The modelling indicates that stable and consistent heat-induced air flow velocity can be enabled and effectively regulated with the level of heat input, and the predicted flow air velocity agrees generally well with the experimentally measured.

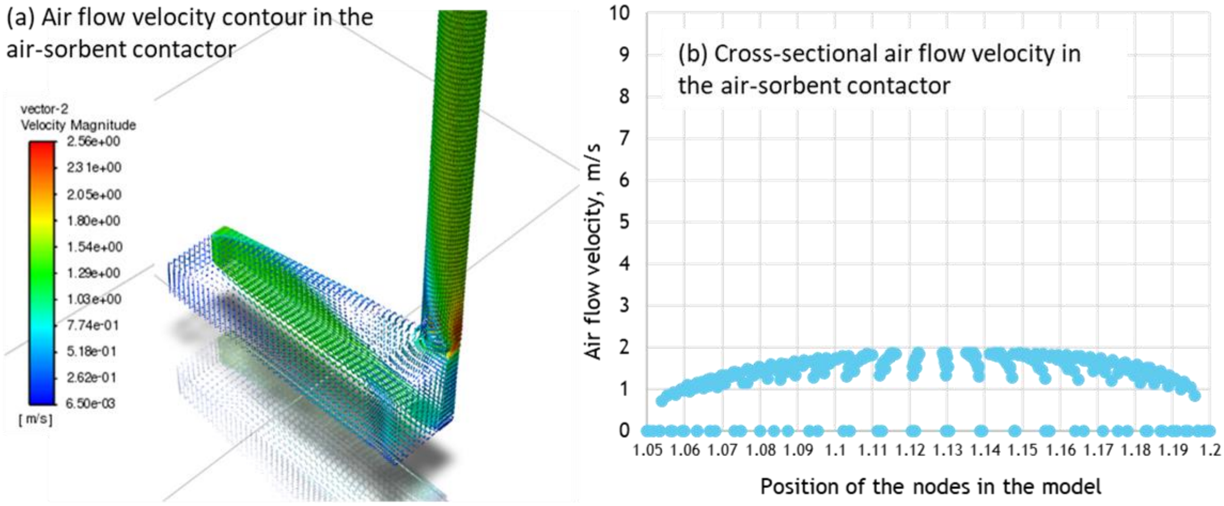

Figure 6 Modelling of air flow characteristics in the lab-based heat-driven pilot DAC plant

Fig. 7 presents the key modelling results for the particle movements of a selected sorbent material in the air flow through the adsorber. A finite difference numerical method (FDM), which is used to solve the Navier-Stokes equation that defines the air movement in a vertical adsorber column, is integrated with a Discrete Element Method (DEM) to model the sorbent particle movement in the air updraft. The DEM sub-model describes numerically the momentum exchanges between the continuous gas flow and solid particles in granular flow. It can be seen that the trajectory of particles movement (defined by the position and residence time in the adsorber) is governed by air velocity and the particle size/density of a sorbent material. At an air velocity of 1.4 m/sec, the particle movement modelling reveals that no uplift or carryover of the sorbent particles occurs in for the sorbent material with particle size in the range of 500~800μm. For comparison, at a higher velocity of 2.4 m/sec, however, multiple particle movement trajectories could occur, with smaller particles (e.g. <200 μm) being uplifted or even carried over, some being held standstill and with only the largest being able to drop down to the collector. In general, the modelling results for different conditions examined are in good agreement with the observations in the pilot tests. The modelling has formed a sound basis for the demonstrator plant's engineering system modelling to serve the design and operation of future full-scale DAC plants.

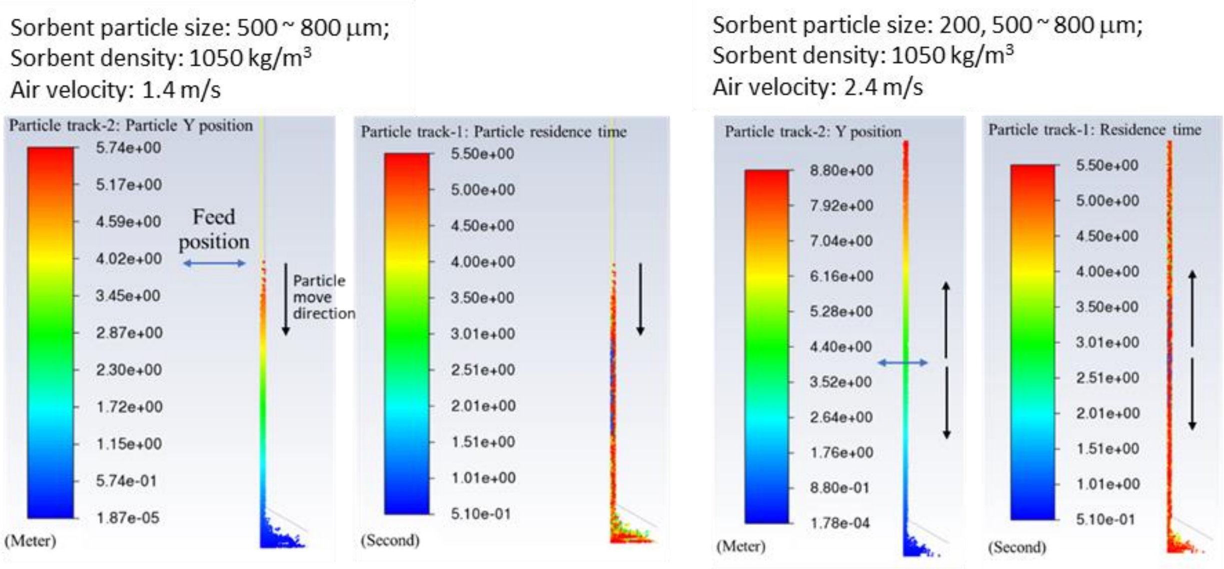

Figure 7 Movement of sorbent particles in the air flow within the adsorber of heat-driven pilot DAC plant

4.4 Experimental Summary

A heat-driven direct air capture pilot facility has been successfully designed, constructed, and commissioned for testing. All research tasks, including the pilot testing of heat-induced air flow characteristics and the fabrication, characterisation and testing of the capture materials, have been carried out with great success for key parameters required for the design of the demonstrator. The wide range of process tests and characterisations also has further demonstrated both the superior capability of the DAC technology for high-capacity CO_2 removal with good operational flexibility and potential major cost reductions as well as the exceedingly high CO_2 adsorption capacity and fast adsorption rate of the sorbent materials. As an unexpected but very welcome development, the use of crosswind could help further reduce the energy requirement of the heat-driven direct air capture, thanks to the strong promotive effect of crosswind.

CFD-based models have been developed and successfully evaluated for the modelling of the heat-driven air flow characteristics and particle movements within the DAC system, which have formed the sound basis for the process & system modelling of the demonstrator required for full-scale commercial plant design, process control and operation.

5. ENGINEERING DESIGN

The demonstration plant consists of two continually circulating loops, the first being the air/sorbent contacting loop and the second being the CO_2 removal loop. Fig. 8 shows the basic layout of the demonstrator plant designed; the plant framework has been designed to give suitable access to equipment for operation as well as foreseeable maintenance activities. A lifting beam will be positioned above the top floor of the plant framework to enable lifting of fresh sorbent from ground level to the floor at which the sorbent will be loaded into the process.

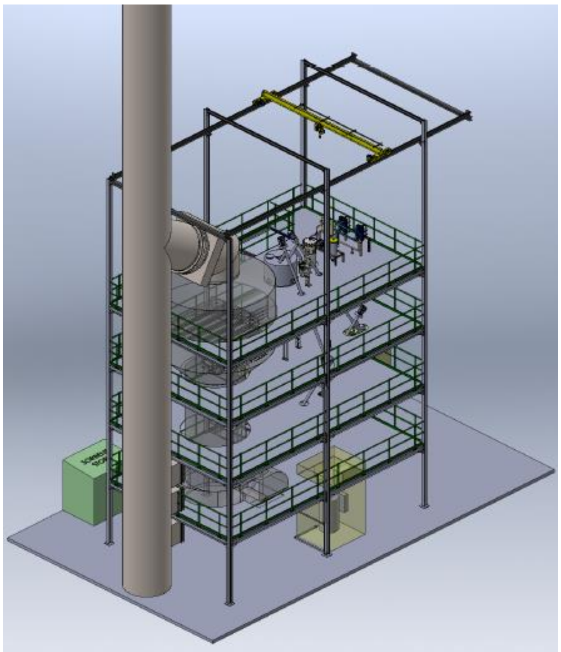

Figure 8 Heat-driven DAC Plant Conceptual Model

The dimensions of the air contacting loop have been selected to provide a practical balance between achieving a reasonable overall system pressure drop and a heating requirement that is practical for installation within the available project budget. The diameter was selected to give similar air velocities to those which were observed within the pilot DAC plant. It is to be manufactured from Carbon Steel with both an internal and external coating to prevent rusting.

Environmental wind speed and direction will be measured externally at the same height as the CO_2-lean air exits the plant. This would be done using a cup anemometer and electric weather vane, and the data can be used to help quantify the impact of ambient wind speed on air velocity within the adsorbent/air contacting loop.

The experimental data obtained by the UoN indicates that the sorbent can achieve approximately 80% of the carbon dioxide equilibrium capacity with a 45-second residence time and the number of passes through the air/sorbent contactor has been selected in order to achieve this. A bespoke sorbent distribution system is to be mounted within the adsorbent/air mixing vessel and will be made fully accessible such that it can be inspected or adjusted during the course of operation.

The sorbent will be mechanically conveyed and metered throughout both circulating loops. Initial trial work undertaken during phase 1 has indicated the sorbent is compatible with several widely used methods of bulk material conveying.

The CO_2 removal vessel, also known as the desorber, has been based on the design used successfully within a previous pilot plant delivered by Strata to the UoN. UoN's experiments have indicated that a desorber temperature of $\leq 100\ ^{o}C$ would be optimal for the sorbent, and a residence time of 15 minutes would enable suitable removal of captured carbon dioxide.

6. DEMONSTRATION PLANT PROJECT

6.1 Site Selection

The consortium estimates that a plot of c.12m x 20m will be required to construct and test the DAC demonstrator plant in phase 2 of the GGR competition (if selected). It is estimated that the plot will be required approximately one year after phase 2 of the competition is kicked off and it is intended that the plot will be located within an area in or around the proposed wider Sizewell estate.

The consortium will work closely with SZC's land and planning departments to coordinate and obtain planning approvals (that will be separate from the ongoing planning application for the SZC nuclear power plant), in time for the required use of the plot.

The key advantage of siting the demonstration plant in or around the wider Sizewell C estate is that the environmental conditions that the adsorber column is exposed to will be representative of the potential commercial scale plant for integration with Sizewell C, subject to any necessary permissions and other consents being secured at the appropriate time.

Both the demonstration plant location, and the potential commercial scale site are coastal locations. The coastal air may contain trace quantities of sea salt, which consist mainly of NaCl and mixed (Na, Mg, K, and Ca) sulphates[4], and the air-borne sea salt particles may travel more than 50 miles inland[5]. The sea salt species are not chemically reactive with the CO_2 sorbents, so they are not expected to generate any major impact. However, excessive physical deposition of the salt particles, which have diameters typically in the range of 0.05~10μm[6], may have some potential effect on the sorbent materials due to the reduced surface accessibility. Nevertheless, UoN's 14 days' continuous pilot tests with similar sorbents did not show any sorbent degradations associated with ambient air-borne particles, though the local ambient air at Nottingham may have lower levels of sea salt particles but higher quantities of terrestrial particles. The potential effect of air-borne sea salt particles in the coastal area will be examined and form part of the characterisation programme in Phase 2.

6.2 Phase 2 Responsibilities

6.2.1 Sizewell C

Sizewell C will continue to be the lead organisation for the consortium and manage the consortium's relationship with BEIS. Sizewell C will also provide the heat parameters and specifications for future compatibility with an operational Sizewell C plant. Sizewell C will also provide support for the planning and other consents required in respect of the demonstration plant.

6.2.2 Strata Technology

Strata Technology will be responsible for the detailed design, build, installation and commissioning of the demonstration plant. Strata Technology will also be responsible for providing engineering support during the operation of the plant.

6.2.3 University of Nottingham

The University of Nottingham will be responsible for the development, manufacture and characterisation of the sorbent for the demonstration plant, and the production of the required quantity for testing. Once the demonstration plant is in operation, they will be responsible for collecting and analysing the process data. The University will also be performing system engineering modelling, which will be validated using the demonstration plant data.

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[4] M. Posfai et al. Compositional variations of sea-salt-mode aerosol particles from the North Atlantic. J. Geophysical Research, 100 (1995) 23063-23074.

[5] J. Poma. Studies show salt air affects metals more than 50 miles inland, https://pomametals.com/salt-air-inland-distance-for-metal/

[6] R. F. Lovett. Quantitative measurement of airborne sea-salt in the North Atlantic. Tellus, 30(1978) 358-364.

6.2.4 Atkins and Doosan Babcock

Atkins and Doosan Babcock will be working to advise on the scalability of the demonstration plant design as well as reviewing the output data from the demonstration plant once in operation to enable a feasibility study for a commercial scale plant. To ensure there is a continued focus on scalability in phase 2, Atkins and Doosan Babcock will review key design deliverables prior to plant construction. Areas of particular interest will be expected levels of performance, footprint and cost of the plant.

6.3 Project Cost

Based on the consortium's current estimates, the phase 2 demonstration plant is expected to cost c. £3m. This cost includes further design work, materials, construction, site installation, commissioning and operation labour, consumables, energy as well as a feasibility study for a commercial scale plant.

7. COMMERCIALISATION

The data generated from the demonstration plant in Phase 2 will be used by the consortium scaling partners (Atkins and Doosan Babcock) to produce a commercial feasibility report. The output of this report, particularly the techno-economic assessment, could be used to drive further commercialisation and initiate conversations with investors/parties interested in offsetting their emissions using the DAC technology. The Phase 2 operational data will also allow the consortium to define the feasible temperature envelope of the heat source required to drive the process. This will allow the consortium to define and approach a wider commercial network of potential industries that the DAC technology could work with / be integrated with, in addition to the nuclear industry.

7.1 Next Stage of Development

As part of the route map to scaling the DAC technology to be able to capture 50k tonnes by 2030, we are exploring opportunities to make use of heat sources from other nuclear plants in the UK between 2025 and 2030. Heat from nuclear plants in this timeframe would enable the consortium to progressively scale up and optimise the technology from the 2025 demonstrator plant capable of capturing 100 tonnes CO_2/year (if our bid is successful), to one that captures 50,000 tonnes CO_2/year by 2030, before further scaling up to a plant that is capable of capturing CO_2 on a Megatonne scale and can be integrated with an operational Sizewell C power plant in the 2030s.

Once significant data has been generated from the demonstration plant, giving further confidence in the technology's commercial potential, the consortium will evaluate potential funding mechanisms for the 50,000 tonnes CO2/year scale plant.

Scaling up to a 50,000 tonne CO_2/year plant would require processing huge volumes of air for capture and ultimately larger equipment. The design and operational information from the demonstration plant in Phase 2 would be used to inform the process design activities for scale up. A key focus of the scaling project would be determining the trade-off between increasing the throughput of individual units and increasing the number of units used for processing. The major steps will include the concept design of commercial scale plant & process/system modelling; front end engineering design (FEED); engineering, procurement and construction (EPC); and commissioning and operation.

7.2 Dependencies

For the DAC technology to scale up to 50,000 tonnes CO_2/year by 2030, we are exploring opportunities to make use of heat sources from other nuclear plants in the UK between 2025 and 2030, which would enable the consortium to meet the 50,000 tonnes CO_2/year by 2030 objective (before further scaling up to a plant linked to SZC that is capable of capturing CO_2 on a Megatonne scale). An alternative nuclear (or other) plant needs to be identified with a heat source that could drive the process, as Sizewell C would not be in place by this time, but of course SZC will be capable of driving carbon capture solutions at a Megatonne scale when operational in the 2030s.

In addition, the commercial viability of the process is dependent on the government's policy with regards to the commercial framework for transport, utilisation or storage of captured CO_2.

8. CONSENTS AND LICENSES

The consortium will seek planning permission for the positioning of the demonstration scale plant on the identified site. The Sizewell C team have significant experience in the submission and completion of the planning application process, and would look to progress this as soon as would be feasible during Phase 2 (if selected).

9. CO_2 REMOVAL COST

The high cost associated with Direct Air Capture is a major barrier to the development of a significant UK market. This project aims to address this cost barrier by making use of future low-cost, low-carbon heat available from a nuclear power plant to meet both the major energy demands of the process and BEIS' target of removing CO_2 on a Megatonne ($MtCO_2e$) scale at a cost of less than £200 per tonne CO_2e removed.

SZC's modelling illustrates that as the consortium's DAC technology becomes more economical by utilising heat from a nuclear power plant (which according to a recent study by Columbia University is the cheapest form of low-carbon heat[7]), the technology could transform the cost-optimal net zero pathway for the power sector and the wider economy, by offering this low-carbon heat-based at scale carbon capture solution.

For the power sector, lower-cost DAC technologies linked to nuclear power plants can drive/accelerate our pathway to net-zero. In the wider economy, there is further opportunity to offset carbon emissions from difficult-to-decarbonise sectors (such as heavy transportation) until cleaner transportation and industrial technologies become more economical. Heat powered technologies are currently difficult to decarbonise economically, and one of SZC's aims is to be able to provide low-cost, low-carbon heat to other sectors as well as become a net-negative emission energy generator.

10. SOCIAL VALUE

Norfolk and Suffolk's east coast energy cluster is one of the few places in the UK where expertise and operations in oil, gas, nuclear, renewables, solar and microgeneration exist in close proximity[8]. The Economic Strategy for Norfolk and Suffolk, published in 2017, sets out the ambition to drive the region's position as a leading centre for the UK's clean energy sector, capitalising on the strength and diversity of the energy sector and its supply chain and skills base.[9] However, the area also exhibits some of the most significant issues in the UK relating to social mobility and deprivation, with Suffolk becoming relatively more deprived in comparison to other areas in England since 2010, moving from 114 (out of 149) in 2010 to 99 (out of 151) in 2019.[10] As Sizewell C is proposed to be developed in Suffolk, the project has already been involved in various discussions with stakeholders on

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[7] S. J. Friedmann, Zhiyuan Fan, and Ke Tang. Low-carbon Heat Solutions for Heavy Industry: Sources, Options, and Costs Today. Centre on Global Energy Policy, Columbia University SIPA, 1255 Amsterdam Ave, New York NY 10027, October 2019.

[8] Norfolk and Suffolk Economic Strategy (November 2017), New Anglia LEP, https://newanglia.co.uk/wp-content/uploads/2020/03/New-Anglia_Norfolk-Suffolk-Unlimited_Economic-Strategy-Brochure-1-1.pdf

[9] *Ibid*.

[10] 2019 index of multiple deprivation published by the Ministry of Housing, Communities & Local Government, https://www.gov.uk/government/statistics/english-indices-of-deprivation-2019

creating social value locally, regionally and nationally – an innovative pathfinder project such as the DAC technology developed here offers a further opportunity to build upon SZC's existing learnings and involvement, and serve as a further accelerator for social value creation.

The construction of a Direct Air Capture facility shares many of the same skills requirements and inputs as a Nuclear New Build Project. These include welders, pipe fitters and more specialist roles such as thermal installers. For instance, a DAC facility linked to SZC can utilise partnerships between SZC and local colleges to train future DAC plant operatives not only for SZC but also for other UK DAC plants. Memorandums of Understanding have been signed between SZC and key colleges and universities in the region to ensure that we maximise skills opportunities for local people and learners. Local training capabilities can be tailored to include DAC as part of the syllabus. For example, the *Design Engineer Construct!* two-year course at local high school Alde Valley Academy and the *Step up to clean energy* course could include a module on DAC.

In addition to working with academic institutions, the consortium will also look to create social value leveraging SZC's work with third sector organisations in the region – for instance SZC is working with *Women in Construction* (alongside the DWP) to promote careers for women and has reached dozens of women on universal credit in the Lowestoft area. This could help ensure DAC in the UK supports employment for hard-to-reach groups.

SZC is working heavily on creating regional opportunities and has committed to an employment and skills investment. A DAC plant linked to an operational SZC would add to the legacy created by SZC and through the creation of long-lasting benefits that SZC can leave in the region after SZC's construction phase.

Finally, by replacing fossil-fuel power, the SZC plant will avoid around nine million tonnes of carbon emissions each year.[11] DAC powered by heat from a nuclear power plant would create a carbon net negative energy source helping support the UK's Net Zero target, slow-down climate change and thereby positively impacting the population's overall well-being.

Further, during the Phase 2 project (if our bid is successful), UoN will be using three research associates to support their activities. Gaining knowledge and skills on this novel carbon capture technology will ensure that the UK's scientific community continues to pioneer in low-carbon technologies.

During the Phase 2 project, the consortium intends to use UK suppliers for as much of the procured materials as is possible. To date, UK based companies are being considered for supply of the adsorber column, bespoke vessels, the heating and cooling packages, rotary valves, screw conveyors and framework. It is currently estimated that c.80% of the procurement budget for the project will be spent with UK entities.

In operation of the plant, it is anticipated that two operators would be required: one experienced plant operator and one apprentice. SZC has committed to supporting apprentices during the construction of the SZC plant. There will be opportunity to leverage this apprenticeship scheme to perform a dedicated rotation at the DAC plant to be involved with the project / maximise the opportunity for exposure of the UK energy skills pipeline to DAC technology.

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[11] Compared to a gas-fired power station, https://www.edfenergy.com/energy/nuclear-new-build-projects/sizewell-c