Process Synthesis and Performance Analysis of Low Carbon Heat-Driven Direct Air Capture

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Priority topic area: Clean Energy and Climate Action

1. Direct Air Capture – Barriers to entry

Direct Air Capture (DAC) is a critical technology for capturing widespread anthropogenic CO_2 emissions from hard-to-decarbonise sectors such as transport. A major challenge lies in the high operational costs, driven by the energy-intensive fans used to process large air volumes required for effective CO_2 removal. The reliance on electricity creates significant economic barriers. This project proposes an innovative solution: utilising a solar chimney configuration and buoyancy-driven airflow to replace traditional fans. By harnessing passive energy sources, this approach aims to reduce energy consumption and operational costs, offering a more efficient and sustainable pathway for scaling up DAC technologies.

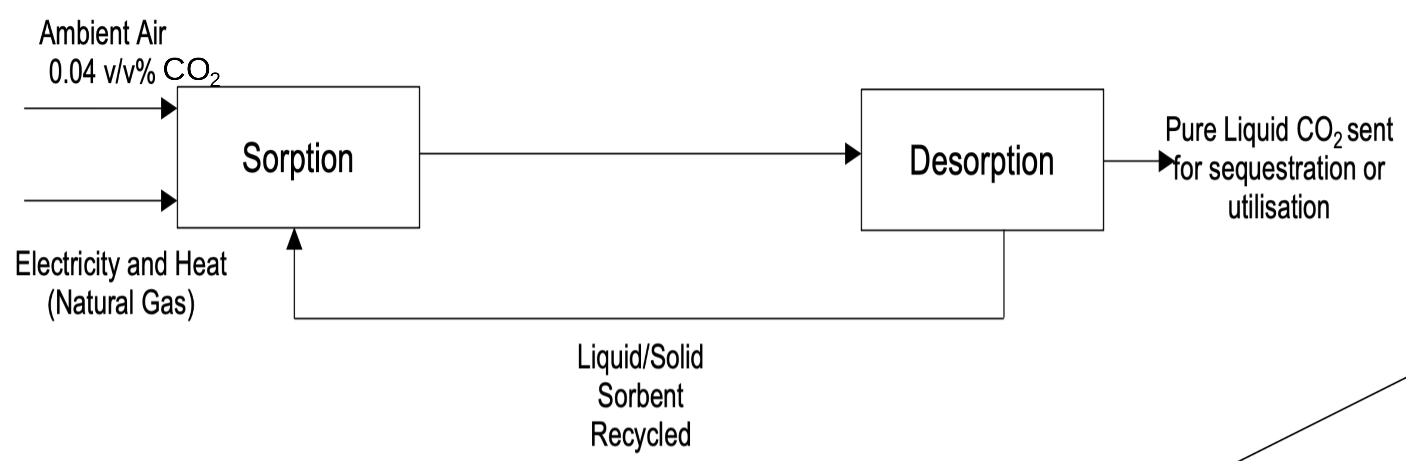


Figure 1. Conventional DAC process

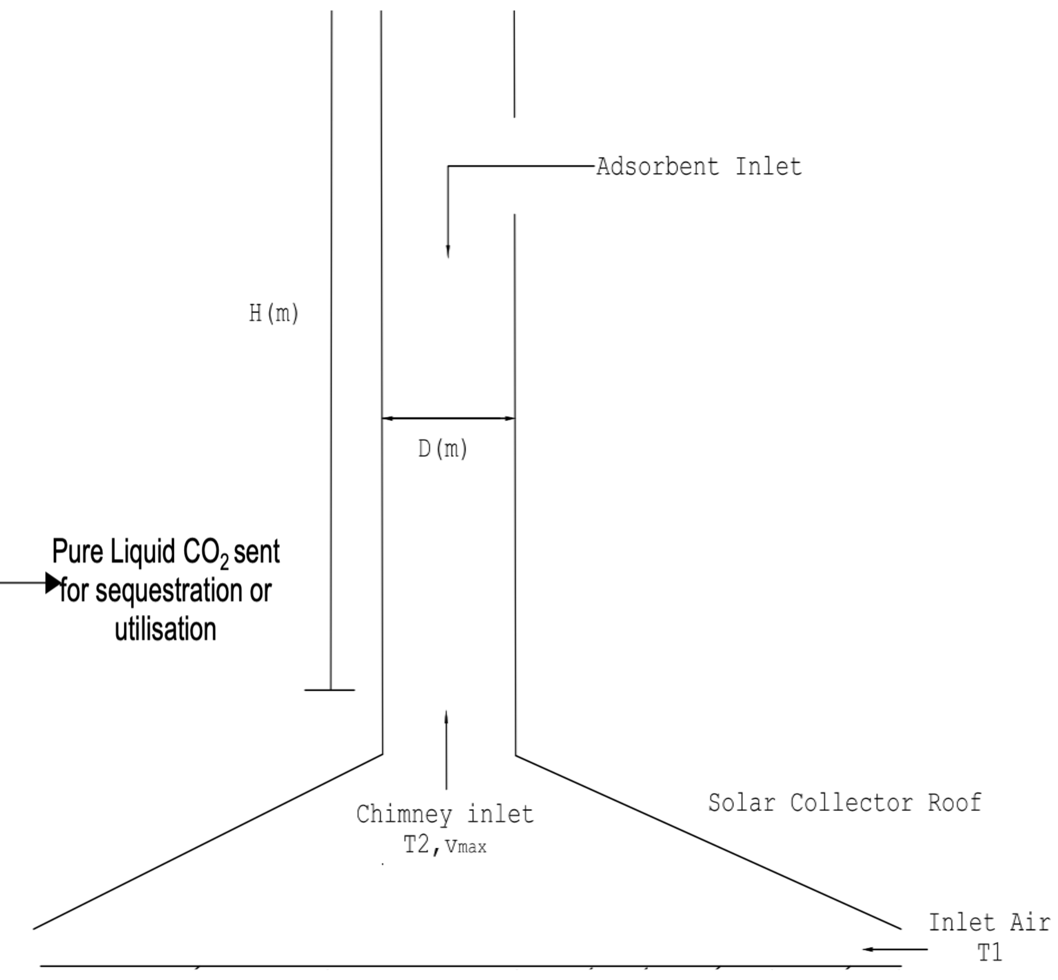
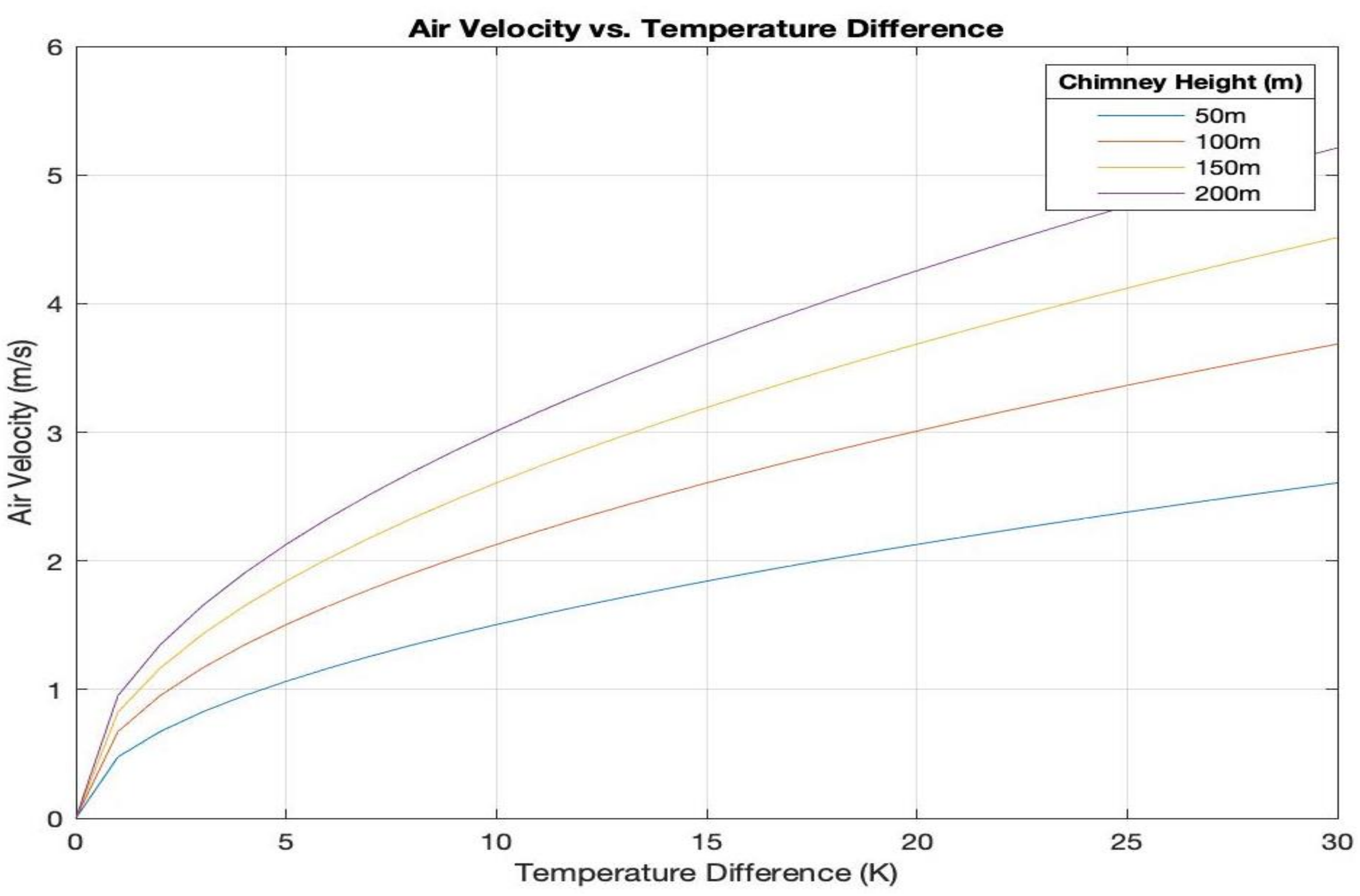


Figure 2. Proposed Solar Chimney DAC process



2. Aims and Objectives

This research explores the process synthesis and analysis of a Solid DAC (S-DAC) process and a Solar Chimney, to reduce electricity consumption and Operational Expenditure (OPEX). This was achieved by:

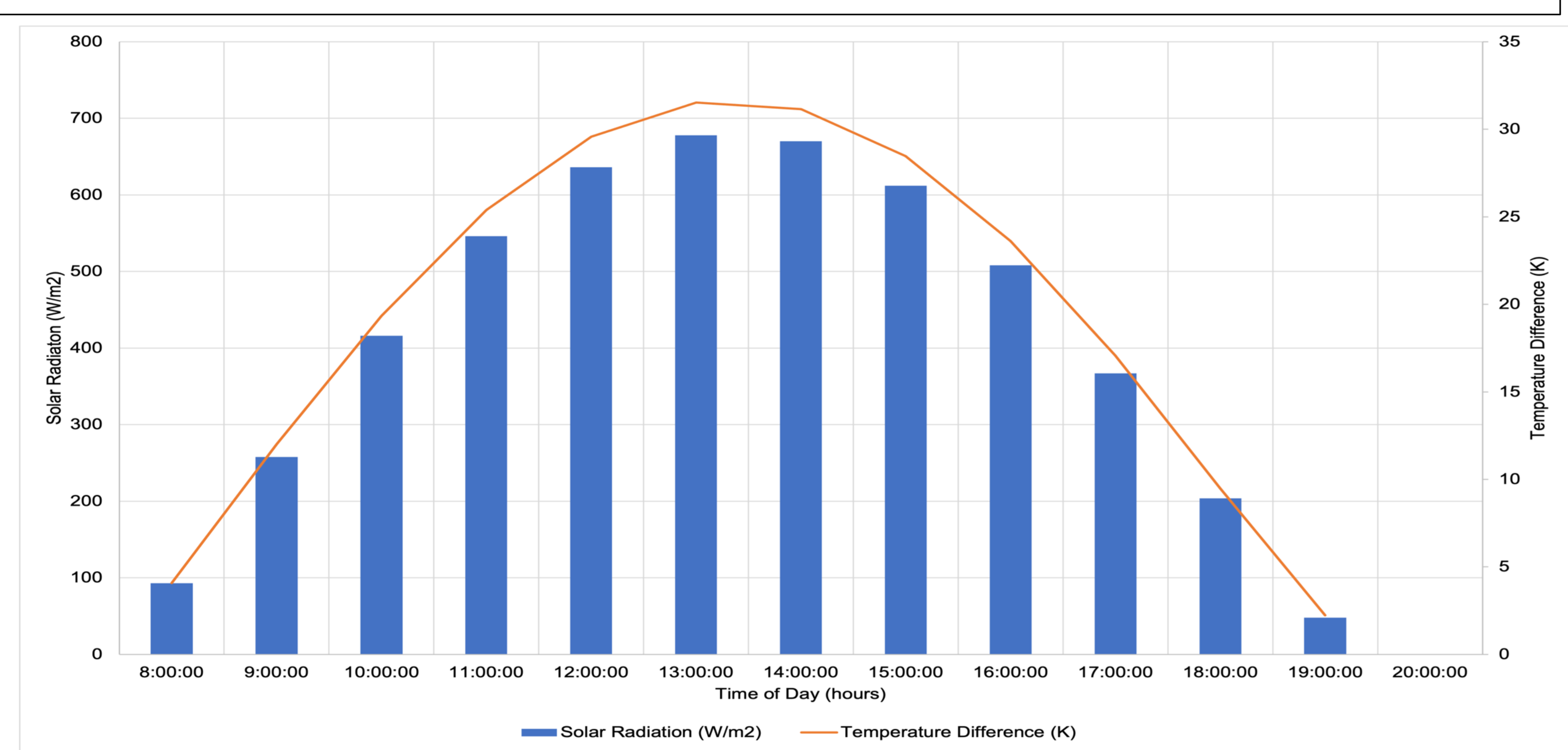
- **Process modelling** and analysis of the maximum achievable air velocity. Higher velocities enable greater air intake, increasing overall throughput.
- **Sensitivity analysis** of system variables such as temperature difference (ΔT), solar variation and chimney height on air velocity. UK based-data was used to evaluate the system under realistic conditions.
- **Particle carryover**: Assessing the risk of sorbent particle ejection from the chimney by terminal velocity analysis.
- **OPEX analysis**

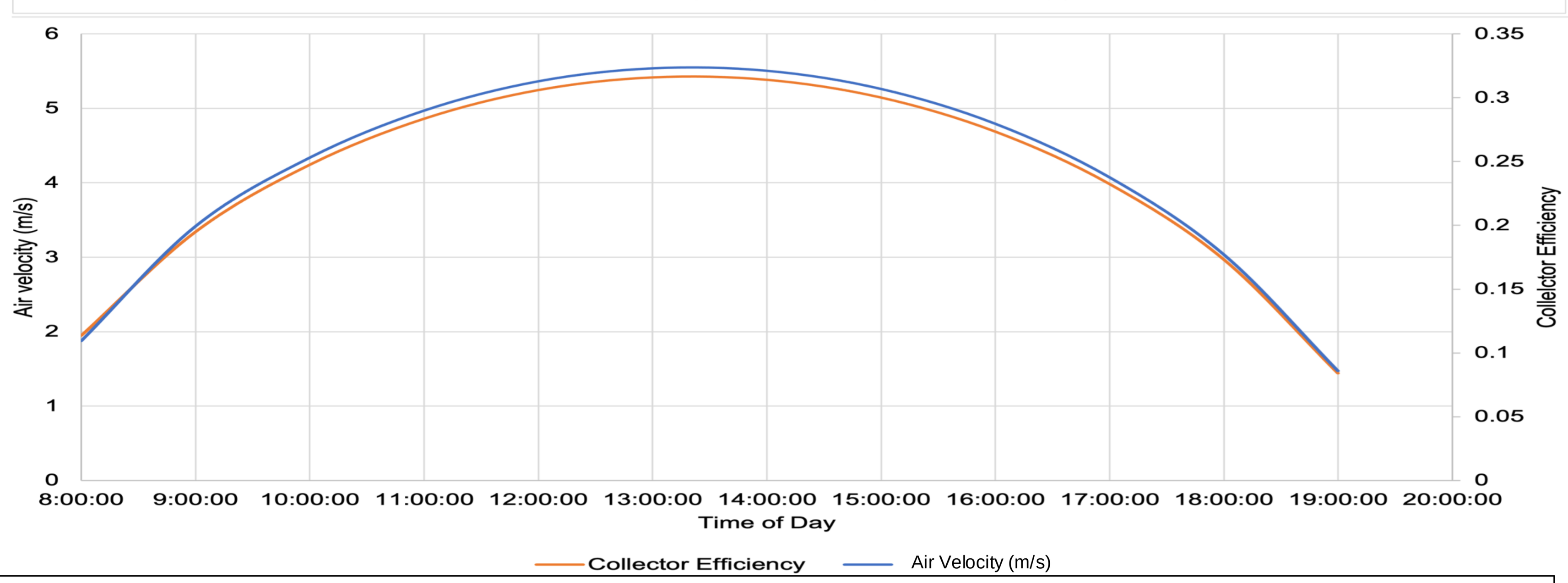
3. Results and findings

The system employs a counter-flow configuration - adsorbents enter from the top of the chimney while air flows upward. Optimisation of air velocity is crucial for ensuring sufficient contact time for CO_2 capture. Operational success is underpinned by the driving force, ΔT.

Mass and energy balances were conducted to develop the model, including evaluation of thermal and optical losses. Solar radiation and ambient input data were sourced from Plymouth, UK - an area with relatively high solar exposure.

- **Air velocity**: Increased solar radiation enhances ΔT resulting in higher air velocities, achieving up to 5.4 m/s.
- **Solar chimney height**: Taller chimneys extend contact time with sorbent particles, enabling increased capture efficiencies.
- **Solar variation**: Intermittent solar energy causes diurnal variations, with peak collector efficiency (~30%) occurring around midday.
- **Particle carryover**: Particle carryover is subject to diurnal variations and particle density. Higher density particles require lower air velocities, thereby a lower ΔT, enabling optimal efficiency during cooler months.
- **OPEX Analysis**: For a 1 Mt/year plant, annual savings are estimated at \$78 million. Compared with conventional S-DAC processes (typically costing around \$200-\$700 per tonne CO_2)[1], this system delivers over 10% in OPEX savings.





5. Next steps

The next phase includes pilot-scale testing to enhance operational efficiency under experimental conditions, optimising mass transfer and residence times. Additionally, incorporating long and short-term thermal energy storage could mitigate the effects of daily and seasonal solar variations.

4. Benefit to society: Widescale Commercialisation

The integrated process reduces OPEX and enables widescale commercialisation and deployment of S-DAC. This will support mitigation of climate-related issues and improve local air quality. It aligns with UK government targets for Nationally Determined Contributions (reduction of all GHG emissions by at least 81% by 2035, compared to 1990 levels)[2] and Net Zero 2050. Globally, it directly supports UN SDG 13, Climate Action, and other targets indirectly. Successful scale-up and deployment will require collaboration across academia, industry, government and society, fostering interdisciplinary partnership aligned with the IChemE Strategy 28+.

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References/Acknowledgements

1. International Energy Agency, 2022. *Direct Air Capture: A key technology for Net Zero*. [Online] Available at: https://www.iea.org/reports/direct-air-capture-2022
2. Department for Energy Security and Net Zero, 2025. *United Kingdom of Great Britain and Northern Ireland's 2035 Nationally Determined Contribution.* [Online] Available at: https://www.gov.uk/government/publications/uks-2035-nationally-determined-contribution-ndc-emissions-reduction-target-under-the-paris-agreement

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