

Integration of Direct Air Capture (DAC) into Renewable Energy Systems and Industrial Clusters

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1 INTRODUCTION

Achieving net-zero greenhouse gas targets is often accomplished by offsetting residual emissions from “hard-to-abate” sectors (aviation, agriculture, certain industrial activities) through carbon dioxide removal (CDR) technologies. Direct air capture is one methods for carbon dioxide removal with large-scale CO₂ removal potential [1-2]. Due to the highly dilute nature of atmospheric CO₂, around 415 ppm, DAC technologies require substantial energy input, ideally renewable energy [3]. The intermittency of renewable energies is the main challenge for developing renewable-powered DAC systems [4]. Therefore, to minimise the energy use a clever integration with industrial and renewable energy systems in needed.

2 Project Aim and Objectives

Scaling-up DAC technology by combining solid-sorbent DAC process modelling and energy systems modelling to develop least energy, least cost DAC deployment scenarios

Develop DAC model using monolithic contactor and investigate the dynamics of fast cycling DAC plants

Design flexible operating strategies for DAC that leverage spot market price fluctuations to minimise overall carbon removal costs

Investigate the techno-economic feasibility of renewables-powered direct air capture in the UK and select suitable installation sites

3 Methodology

1. DAC modelling

Pressure drop, Mass transfer, Energy transfer



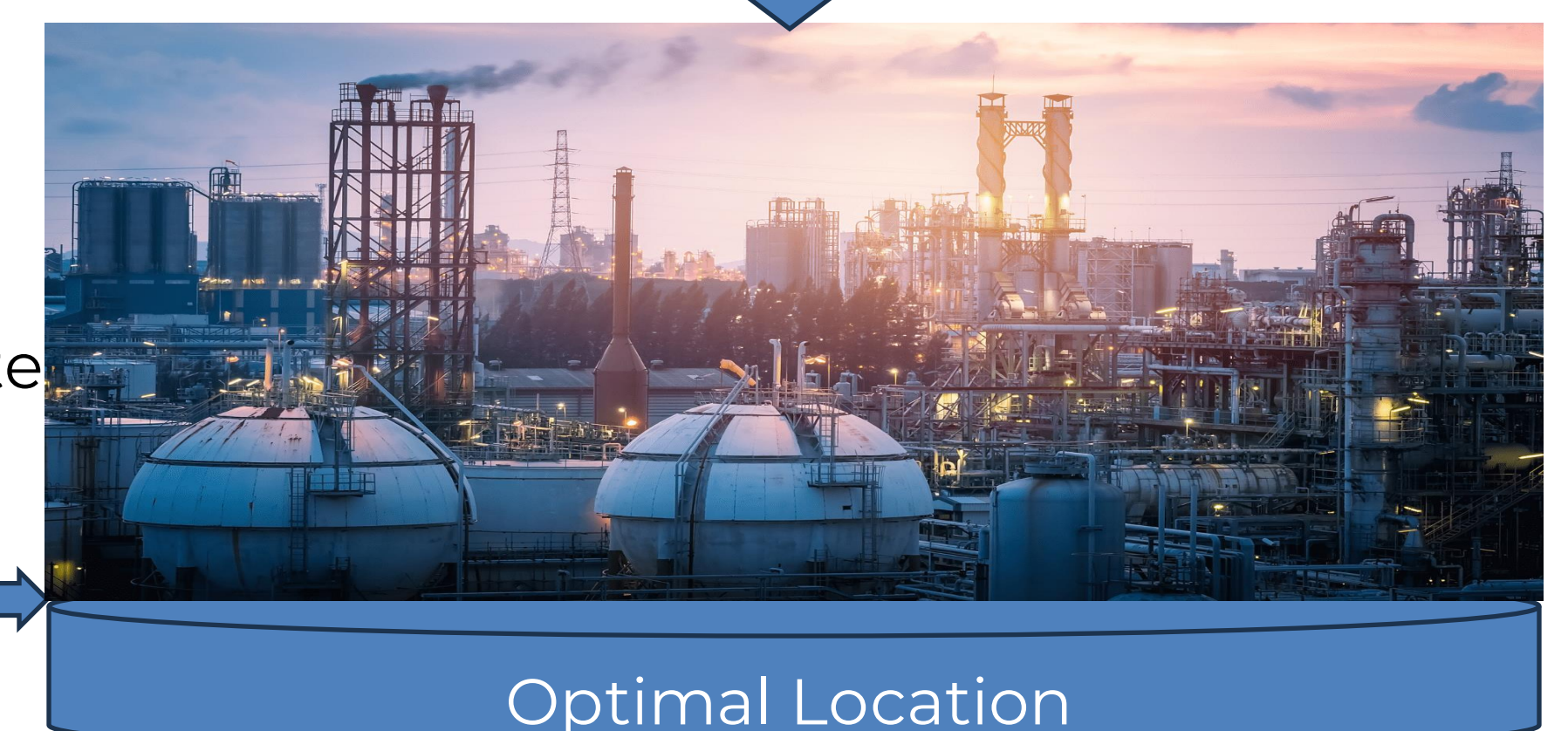
2. Energy system modelling

Intermittency of REs, power curtailment costs, energy distribution profiles



3. Integration & site optimisation

Ambient Air Conditions (Temperature and humidity), Available REs and Hybrid system potential, Industrial Waste heat and higher CO₂ concentration



Techno-economic assessment for scaling-up

4 RESULTS & DISCUSSION

1. Fig.1 shows a TVSA cycle for a solid sorbent DAC process. An adsorption model (Fig.2) was modified for a square-channel monolith contactor - adjusting pressure drop, mass balance, and energy balance equations.

$$\frac{\partial c_k}{\partial t} = \varepsilon_i E_{z,k} \frac{\partial^2 c_k}{\partial z^2} - \frac{\partial(v_g c_k)}{\partial z} - J_k$$

$$J_k = \rho_B M T C_k (q_k^* - q_k)$$

$$E_{z,k} = D_{m,k} + \frac{v_g^2 a^2}{\varepsilon_i 192 D_{m,k}}$$

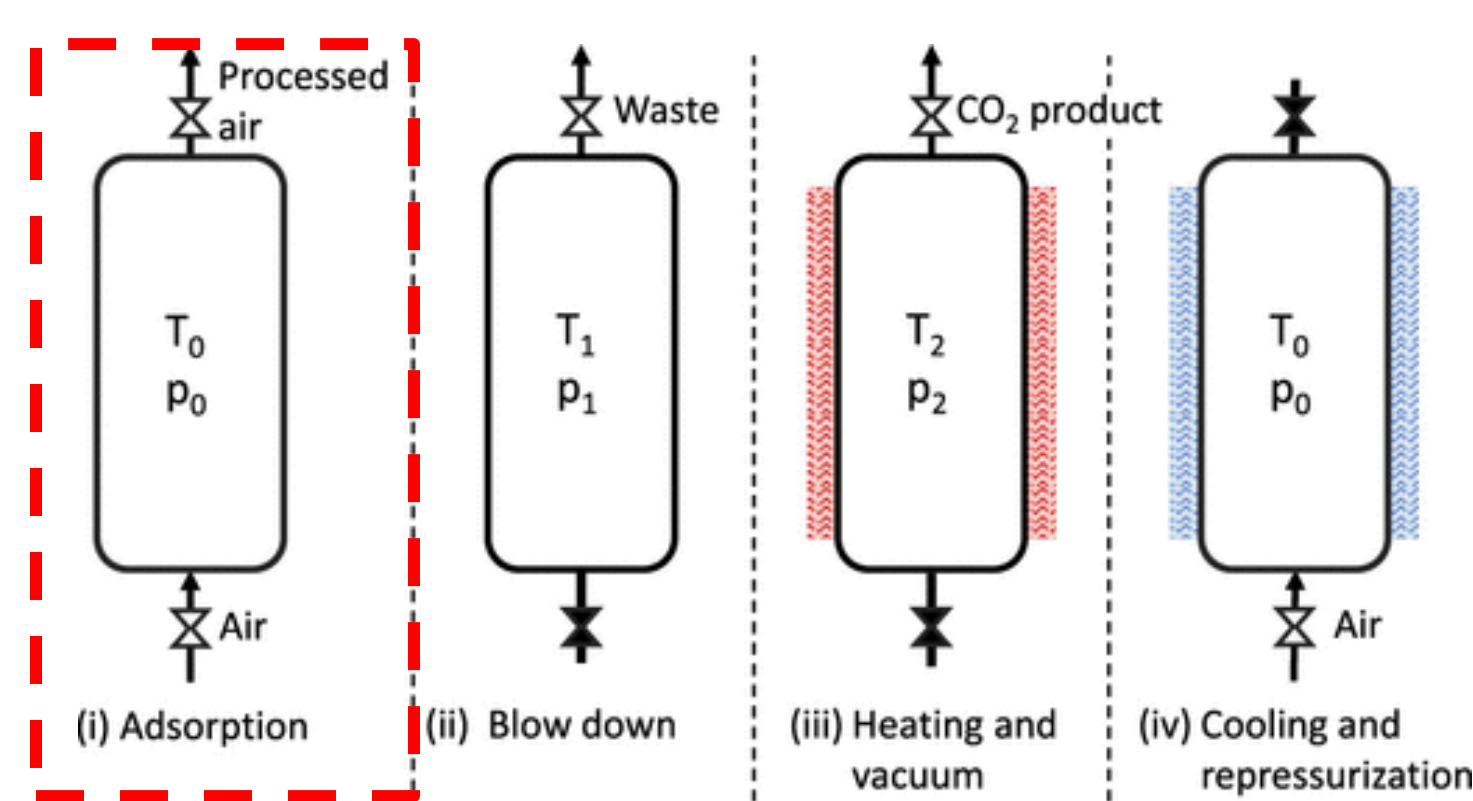


Fig.1. TVSA cycle [5]

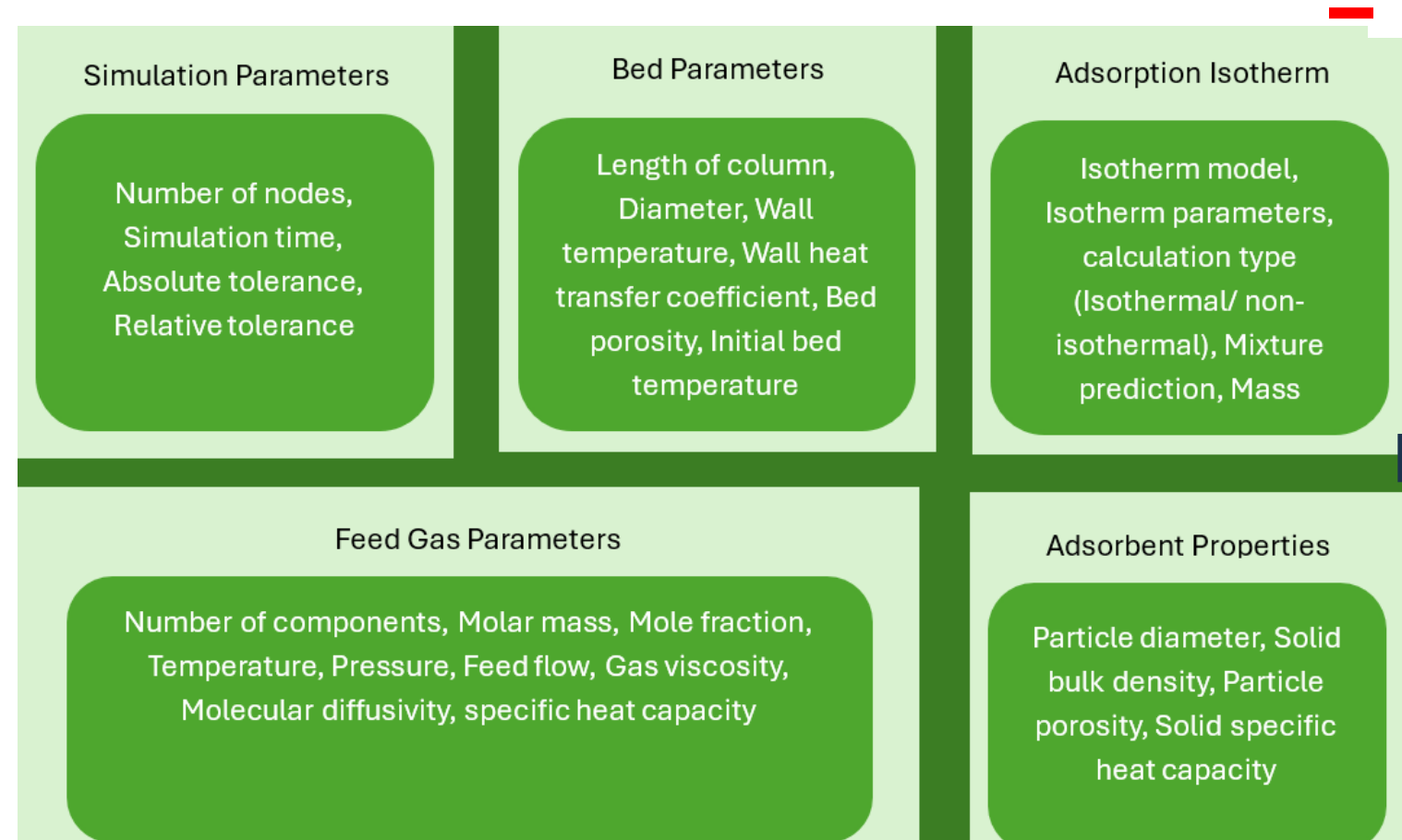


Fig.2. Model framework

Molar Loading
Mole Fractions
Temperature
Pressure
normalized mole fraction

2. Effective parameters influencing adsorption in a monolith configuration (Fig.3) were investigated, and among these, bed porosity, gas velocity, and mass transfer were found to have significant impacts.

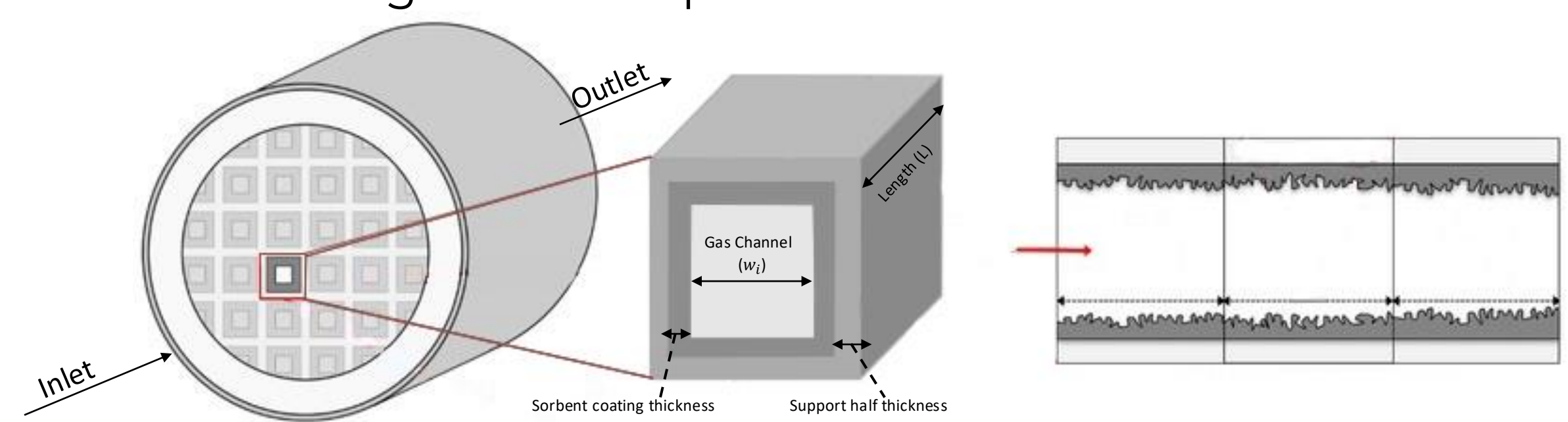


Fig.3. Monolith Configuration [6]

3. Fig. 4 represents breakthrough curves at air inlet conditions of 25 °C, at atmospheric pressure. Fig. 5 shows the adsorption loading profile at different time steps during the adsorption phase.

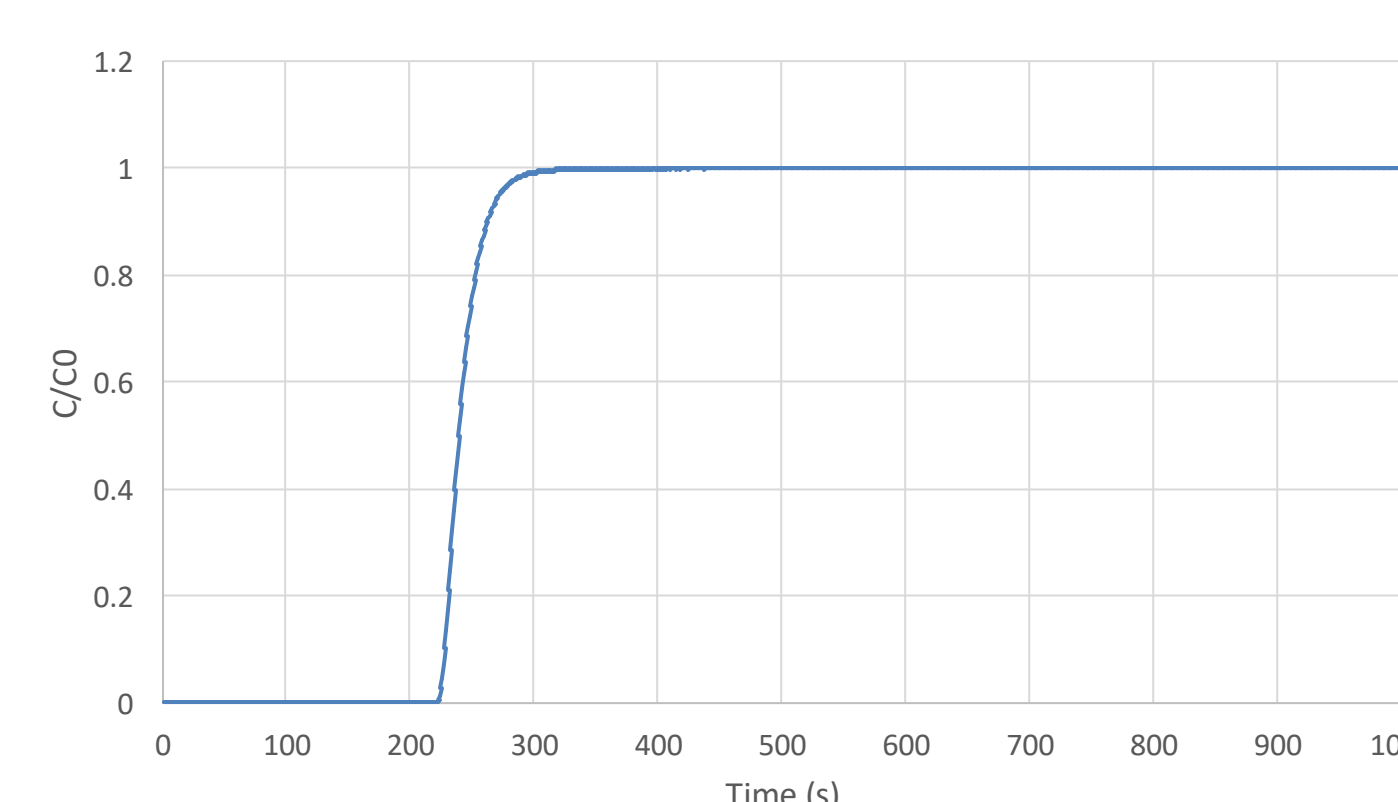


Fig.4. Breakthrough curves

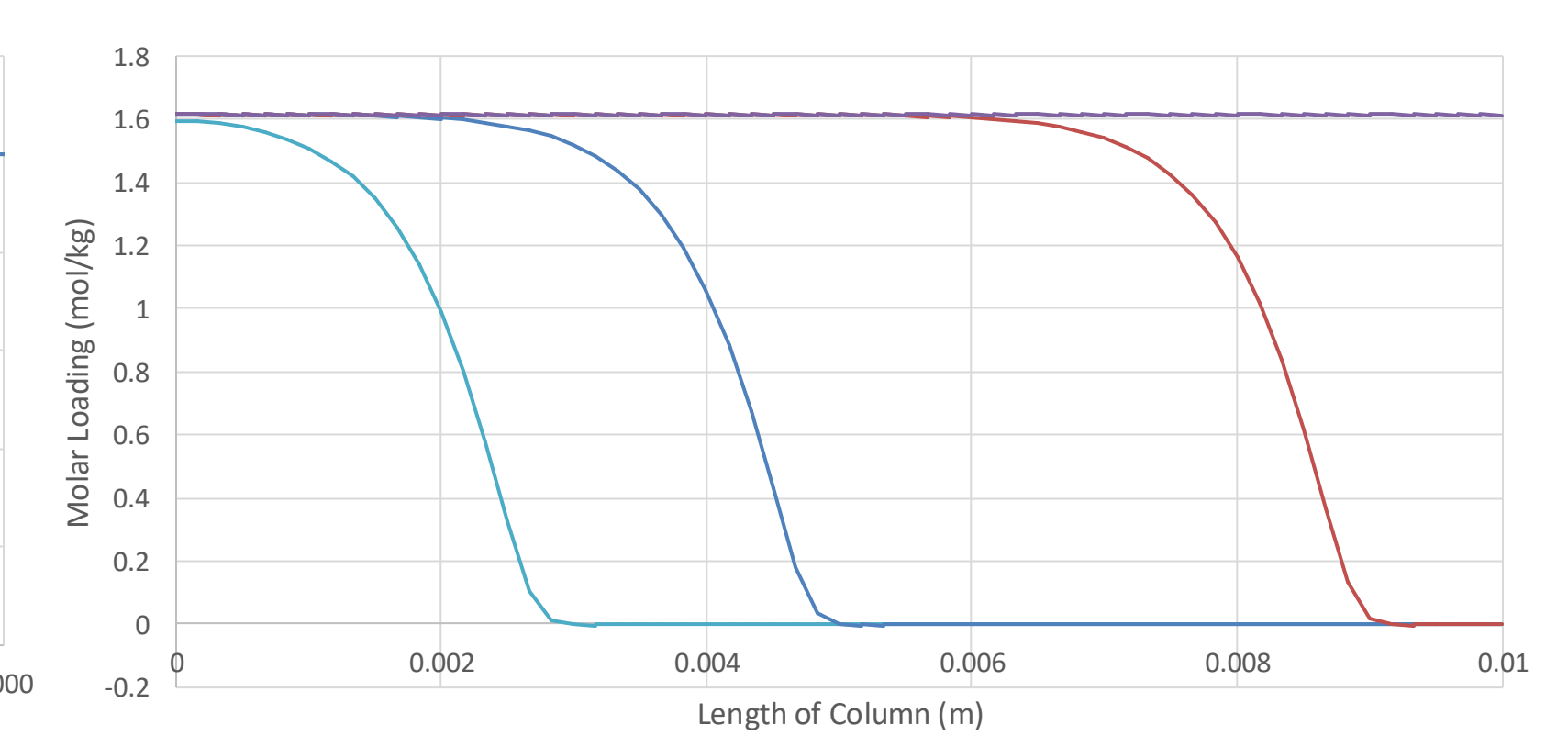


Fig.5. Adsorption loading profile

5 Impacts

Accelerate the UK transition to Net Zero by

1. Providing renewables-powered DAC upscaling solutions
2. Driving innovation
3. Informing industrial decarbonisation
4. Supporting low-carbon futures.

6 References

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