



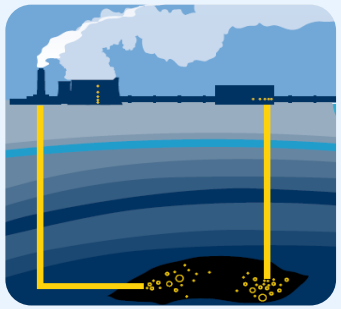



Status of Direct Air Carbon Capture and Storage (DACCS) Technologies

A presentation for CSLF Workshop on CDRs

28th June 2022

carbon sequestration leadership forum

elementenergy
an ERM Group company

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Element Energy, a consultancy focused on the low carbon energy sector

Element Energy covers all major low carbon energy sectors:

CCUS, GGRs & Industry

Energy Networks

Smart Energy Systems

Hydrogen

Low Carbon Transport

Built Environment

Selected clients:

Public sector

Department for Business, Energy & Industrial Strategy

Committee on Climate Change

EUROPEAN COMMISSION

Transport for London

TRANSPORT SCOTLAND

Birmingham City Council

scottishcitiesalliance

seai SUSTAINABLE ENERGY AUTHORITY OF IRELAND

GREATER LONDON AUTHORITY

NGOs

iea International Energy Agency

European Climate Foundation

UNDP

WORLD BANK GROUP

Public-Private Partnerships

energy technologies institute

UK H_2 Mobility

LowCVP low carbon vehicle partnership

FCH FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

Private Sector

OGCI OIL AND GAS CLIMATE INITIATIVE

bp

TOYOTA

NISSAN

equinor

UK Power Networks

HYUNDAI

AIR PRODUCTS

EDF ENERGY

Scottish and Southern Energy

BOSCH Invented for life

British Gas

BOC Member of The Linde Group

NISSAN

Rolls-Royce

ESB Energy for generations

DAIMLER

nationalgrid

zipcar

Agenda

01

Liquid and Solid DACCS

Overview of the two prominent processes

02

DACCS Deployment

Current capacity and major DAC projects

03

DACCS Costs

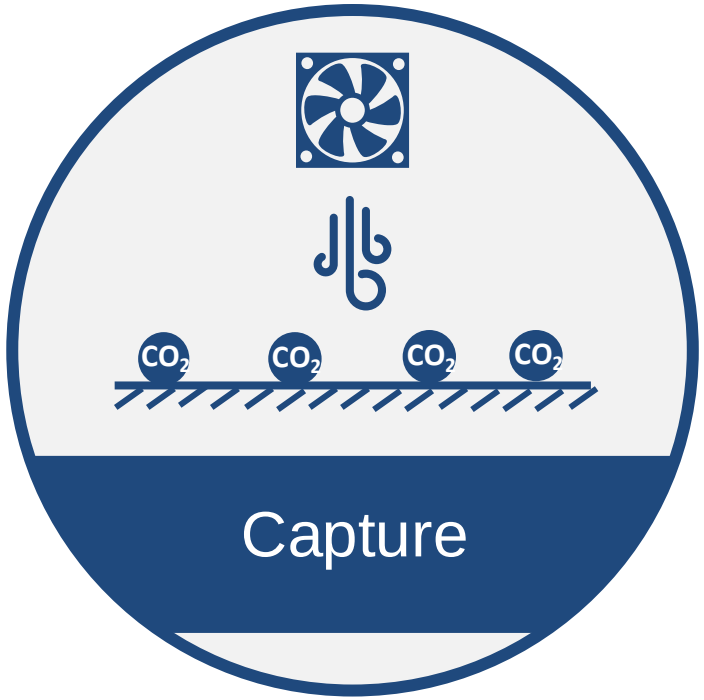
Current/future costs and key sensitivities

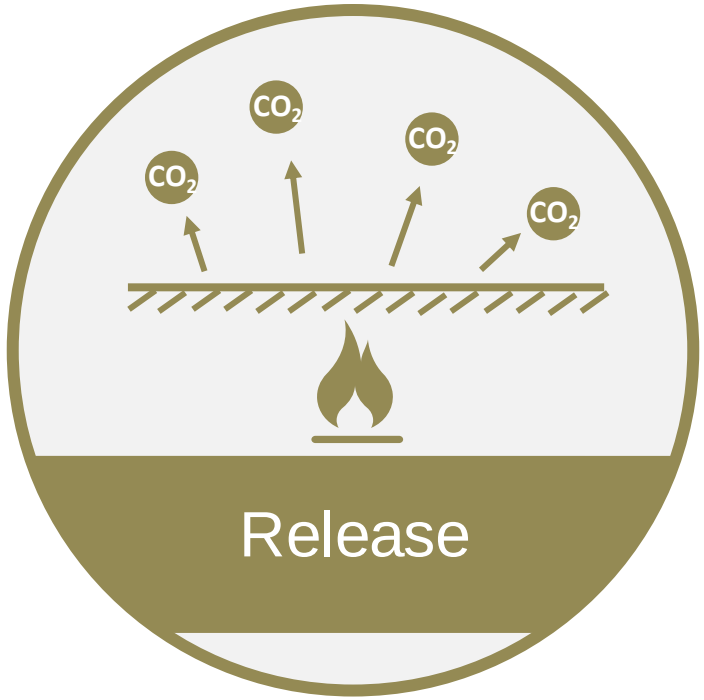
04

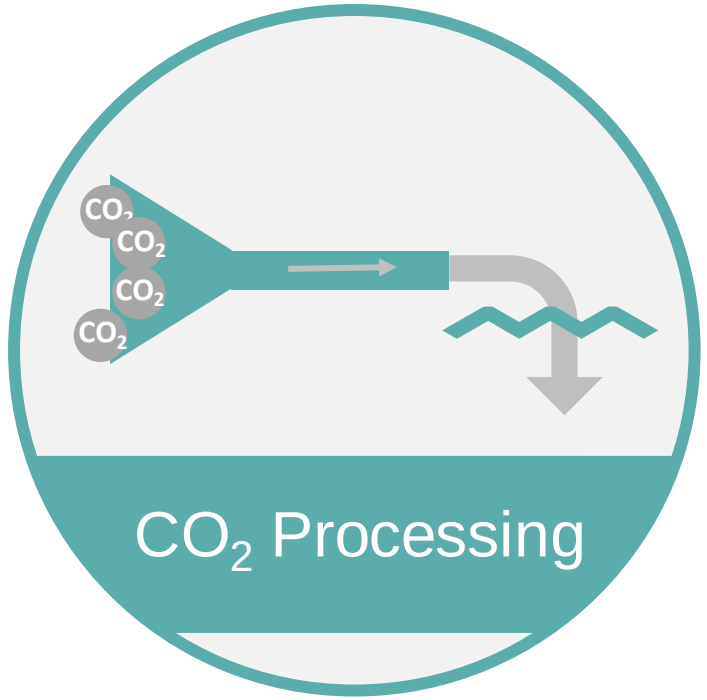
Innovation

Emerging companies and new technologies

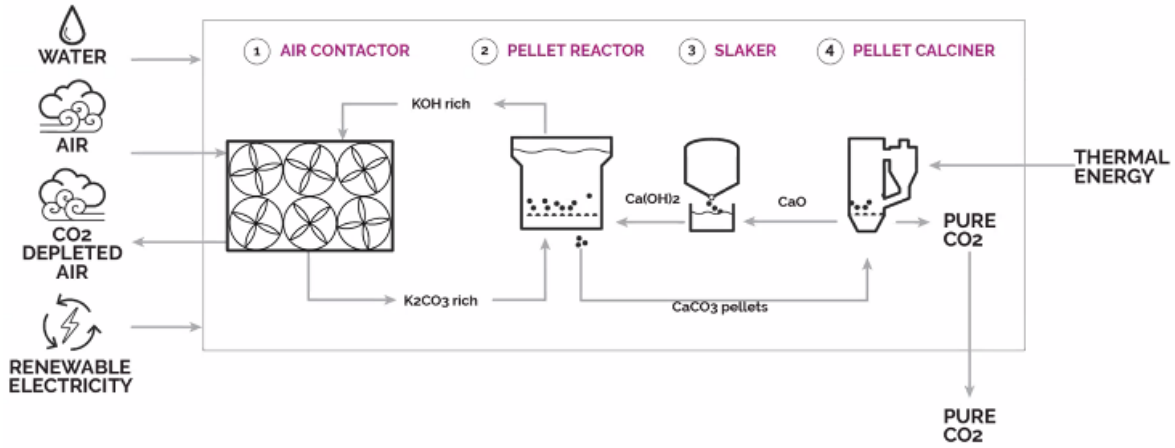
DACCS consists of 3 simple steps

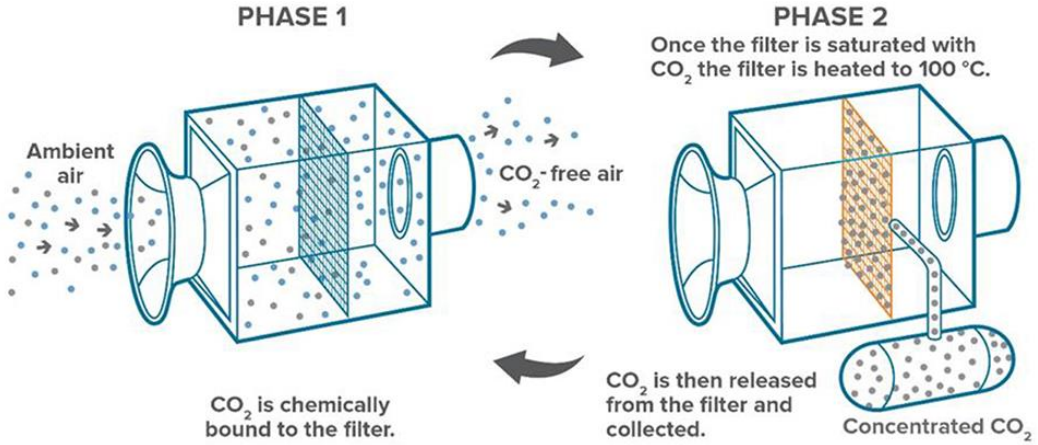






Two ways to do DACCS

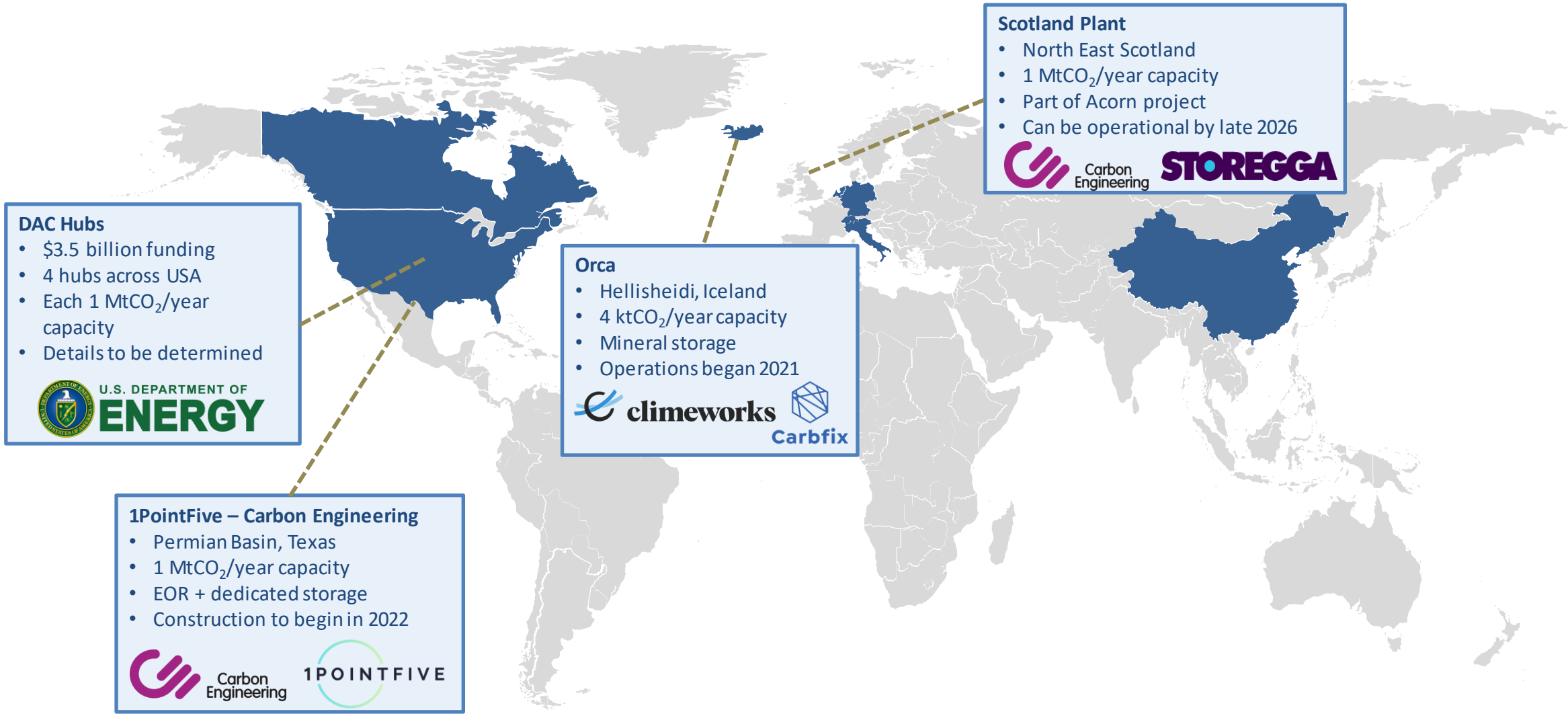




Liquid Solvents	Capture Chemical	Solid Adsorbents
Carbon Engineering	**Example Company**	Climeworks
Very high (~900 °C)	**Temperature**	Low (100-120°C)
Natural Gas + Electricity	**Energy Required**	Electricity + (Optional Heat)
Air Contactors	**Modular Component**	Adsorption/desorption Unit

Process diagrams are taken from presentations of Carbon Engineering and Climeworks in Climeworks' 2nd DAC Conference, 2021. [Link]

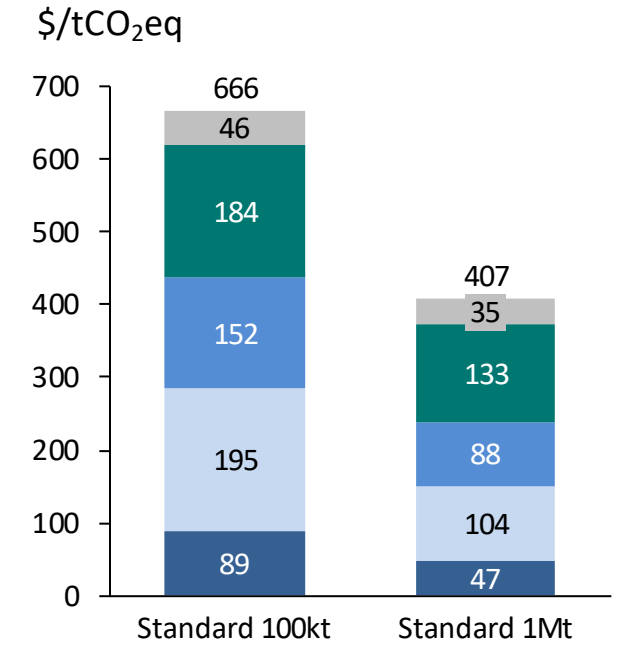
Although several large-scale DAC projects are under planning, current deployment level is only at ~11 $ktCO_2$/year



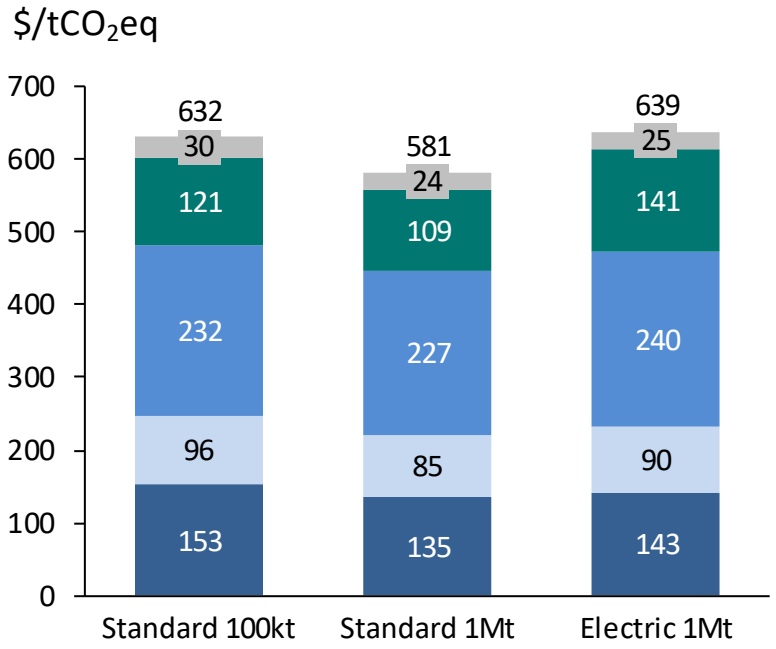
Map and current DAC capacity is based on Carbon 180's The DAC MAPP (18.06.2022) [Link]

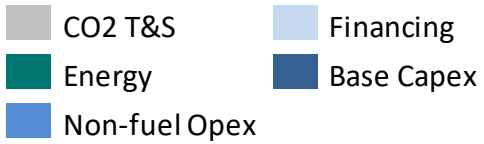
First-of-a-kind (FOAK) DACCS costs

Liquid DACCS FOAK Net Costs[1,2]



Solid DACCS FOAK Net Costs[1,2]





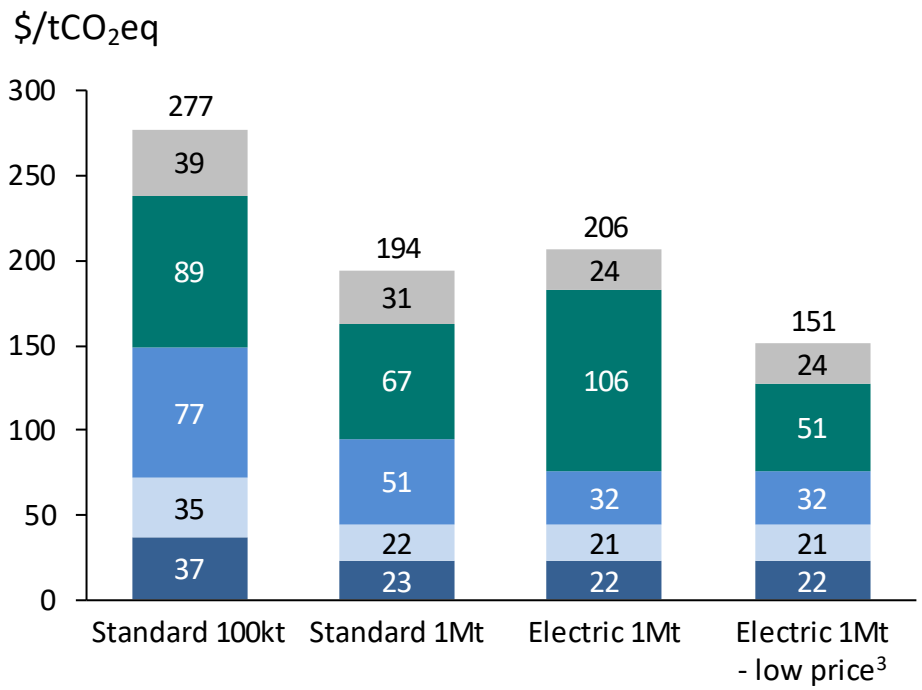
Key Assumptions for base case:

- FOAK: the first couple of sizable plants built in mid-2020s
- Discount rate: 10%
- Electricity: Global solar PV- \$68/MWh_e with 50.9 $kgCO_2/MWh_e$
- Heat: Natural gas for liquids (\$19/MWh gas LHV), nuclear waste heat for solids (\$19.3/MWh_{th})
- CO_2 transport: \$8.2-\$13.4/tCO_2 (large and small plant); CO_2 storage: \$14.2/tCO_2

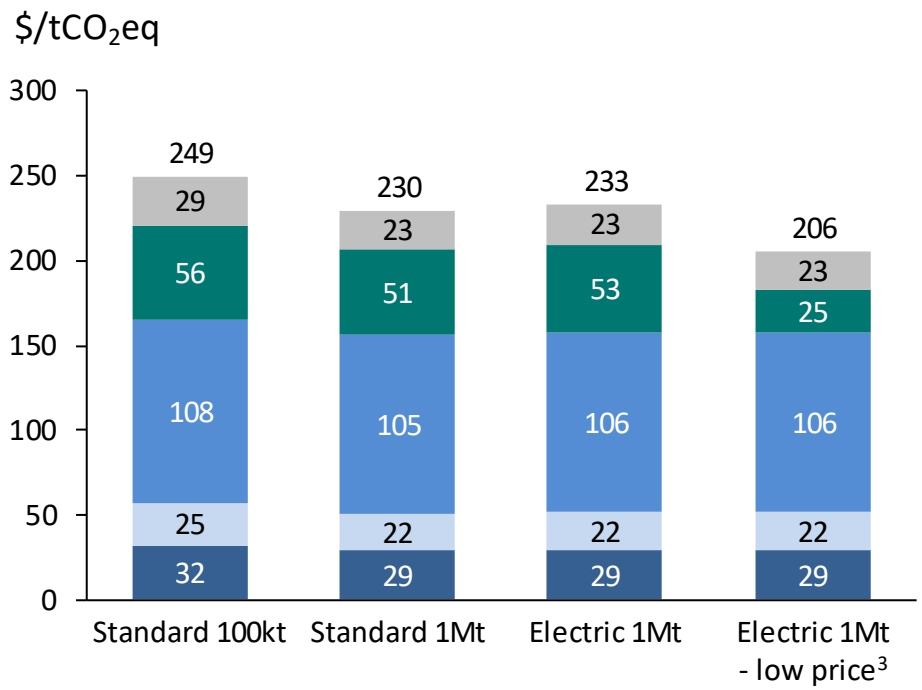
[1] – "Standard" refers to technologies requiring both thermal and electricity input as opposed to full electric. [2] – Net LCOD is the cost of net removal of 1 tonne of CO_2 once lifecycle emissions are taken into account.

Nth-of-a-kind (NOAK) DACCS costs

Liquid DACCS NOAK Net Costs[1,2]



Solid DACCS NOAK Net Costs[1,2]



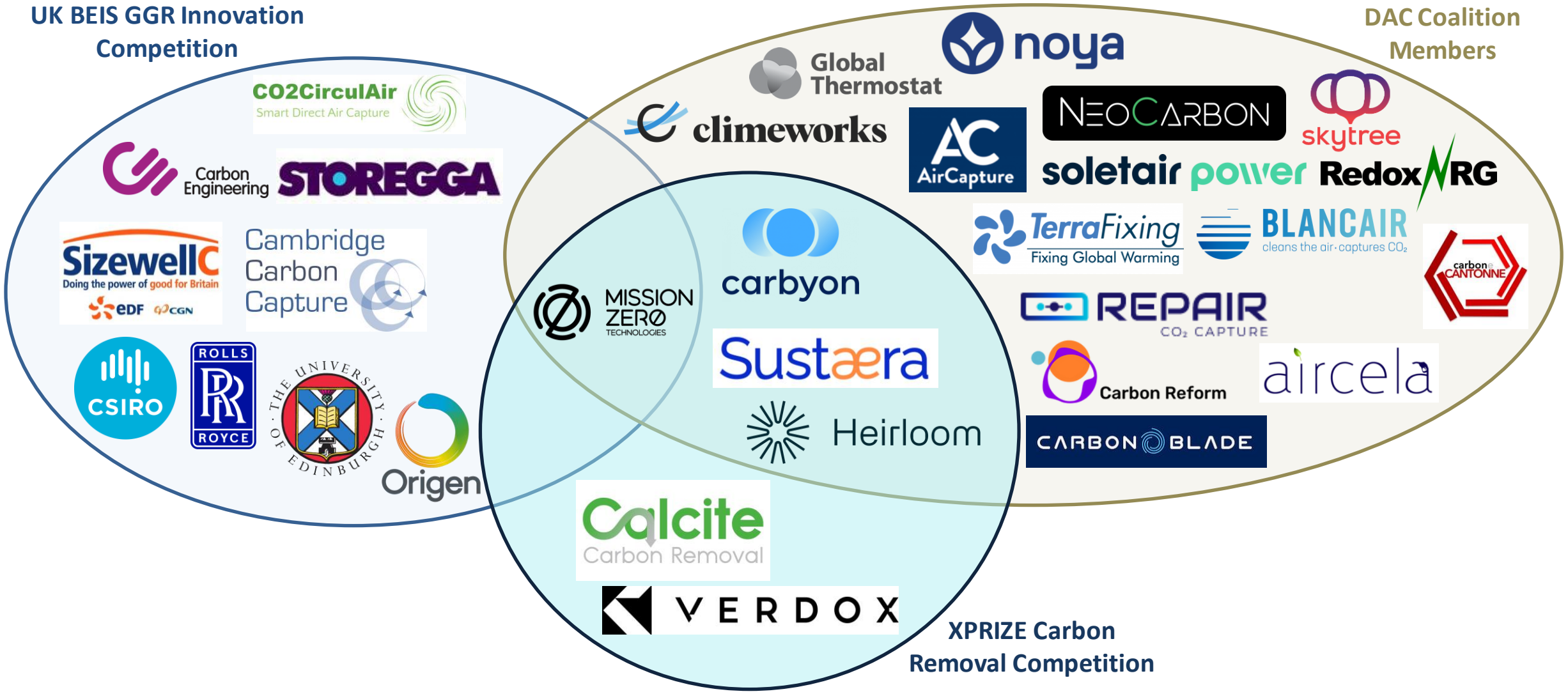
CO2 T&S
Energy
Non-fuel Opex
Financing
Base Capex

Key Assumptions for base case:

- NOAK: Assumed to be in 2050, representing 5-7 doublings of capacity
- Discount rate: 5%
- Electricity: Global solar PV- \$50/MWh_e with 24.8 $kgCO_2/MWh_e$
- Heat: Natural gas for liquids (\$8.5/MWh gas LHV), nuclear waste heat for solids (\$19.3/MWh_{th})
- CO_2 transport: \$8.2-\$13.4/tCO_2 (large and small plant); CO_2 storage: \$14.2/tCO_2

[1] – "Standard" refers to technologies requiring both thermal and electricity input as opposed to full electric. [2] – Net LCOD is the cost of net removal of 1 tonne of CO_2 once lifecycle emissions are taken into account. [3] – Hypothetical case with low-cost solar at \$24/MWh based on average USA power purchase agreements.

Recently a myriad of DAC companies have emerged, fuelled by early public and corporate funding



There are many areas for further innovation

Innovative air contacting

- Designs with lower energy demand
- Leveraging natural airflow – passive DACCS

Improved liquids & solids

- Better capture chemicals
- Processes with alternative energy sources
- Efficiency through process design

Novel processes

- Electro swing adsorption
- Moisture swing adsorption
- Cryogenic DAC
- CO_2 crystallisation
- Membrane separation

New business models

- Cooling tower retrofits
- Vehicle air conditioning retrofits
- Indoors air purification

Key takeaways

DACCS is an essential technology to reach climate targets

DACCS may not reach its $100/tonne target as quickly as the industry expects

Many exciting projects are in the pipeline, but need urgent government support to be realised

The rhetoric on DACCS is moving away from the liquids/solids divide as newer technologies are developed

Remaining questions

What is the role of DACCS in decarbonisation of industrial clusters?

What are the best regions for DACCS deployment?

What are the best policies to enable DACCS deployment in different contexts?

What are opportunities for further innovation and how they may be funded?

Thank you

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