Cambridge Carbon Capture

CO2Chem
An EPSRC Grand Challenge Network
research clusters
mineralisation

$Mg(OH)_2$ (& high-value by-products) from Serpentines & Olivines for scalable low-energy wet-scrubbing of CO_2 from ambient air & flue-gas

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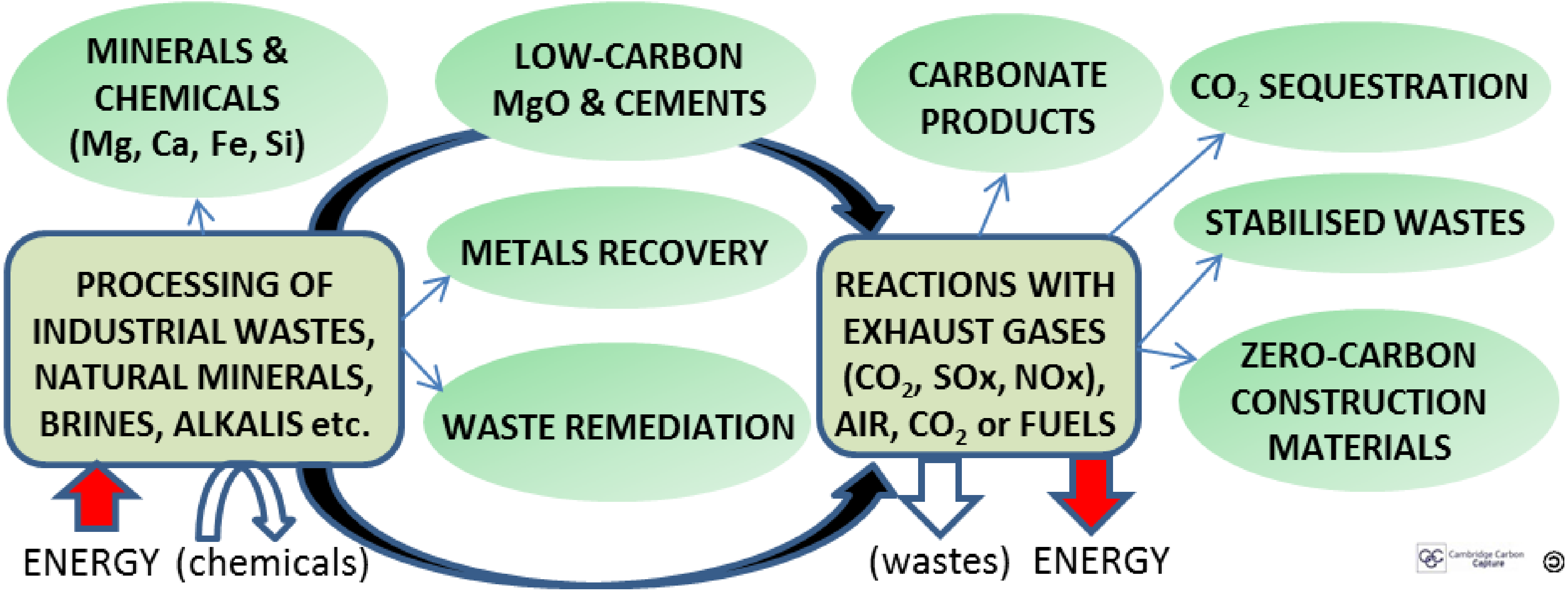
CCC is a Cambridge-based, early-stage venture company developing a unique, profitable Mineral Carbonation process to sequester flue-gas CO_2 directly & permanently as magnesium carbonates.

Presentation overview

- **Scalability of mineral carbonation – what's needed**
- **CCC processes – our approach to scalability**
  - – ***Serpentine/Olivine-to-Brucite***
  - – ***Direct wet scrubbing of low pCO2 - Brucite-to-carbonate***
  - – ***Energy recovery from carbonation***
- **Mineral carbonation on ships – overlaps with ocean liming**
- **Messages from MC community to policy makers ?**

Where does MC fit – CCS or CCU? Niche business or large-scale ?



MINERALS & CHEMICALS (Mg, Ca, Fe, Si)

LOW-CARBON MgO & CEMENTS

CARBONATE PRODUCTS

CO_2 SEQUESTRATION

PROCESSING OF INDUSTRIAL WASTES, NATURAL MINERALS, BRINES, ALKALIS etc.

METALS RECOVERY

WASTE REMEDIATION

REACTIONS WITH EXHAUST GASES (CO_2, SOx, NOx), AIR, CO_2 or FUELS

STABILISED WASTES

ZERO-CARBON CONSTRUCTION MATERIALS

ENERGY (chemicals)

(wastes) ENERGY

Alcoa: red mud waste stabilisation

C8S: APC wastes to building blocks

CCC: olivine-to-$Mg(OH)_2$ & SiO_2 for scalable CCS

What needs to be done (for scalability) ?

- **Life-cycle process optimisation**
  - process improvements to minimise energy & chemical inputs needed to activate minerals
  - react directly with low-*p*CO2 exhaust gases (not pure CO_2)
  - Reliable, appropriate, consistent methodologies for LCA

- **Scale processes & business case for gigatonnes of CO_2**
  - process energy minimisation
  - recovery of carbonation energy
  - product & process development for profitable integration into large-scale construction materials sector
  - recovery of valuable trace metals from mineral feedstocks

CCC process schematic – digestion step 1

(alkaline digestion of serpentine or olivine to convert to brucite & silica)

USP: profitable, low-energy, silicate digestion process

PROCESS COSTS:

€12 0.8t olivine

€105 0.5t NaOH

(/tCO_2 sequestered)

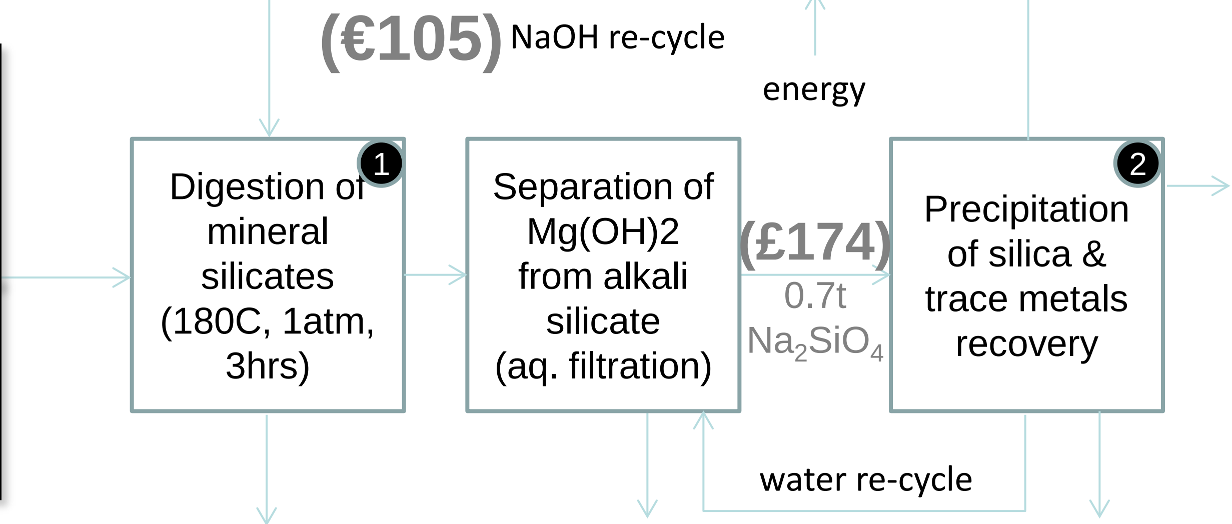
Overall: $Mg_2SiO_4 + 2H_2O \Rightarrow 2Mg(OH)_2 + SiO_2$ dH=-12kJ dG=+9kJ

❶ $Mg_2SiO_4 + 2NaOH + H_2O \Rightarrow 2Mg(OH)_2 + Na_2SiO_3$ dH=-115kJ; dG=-68kJ

❷ $2Na^+ + SiO_2(OH)_2^{2-} \Leftrightarrow SiO_2(ppt) + 2Na^+ + 2OH^-$ dH=+12kJ; dG=+5kJ

MINERAL MINE

INDUSTRIAL WASTE



TRACE METALS

€19 .2%Ni

$Mg(OH)_2$

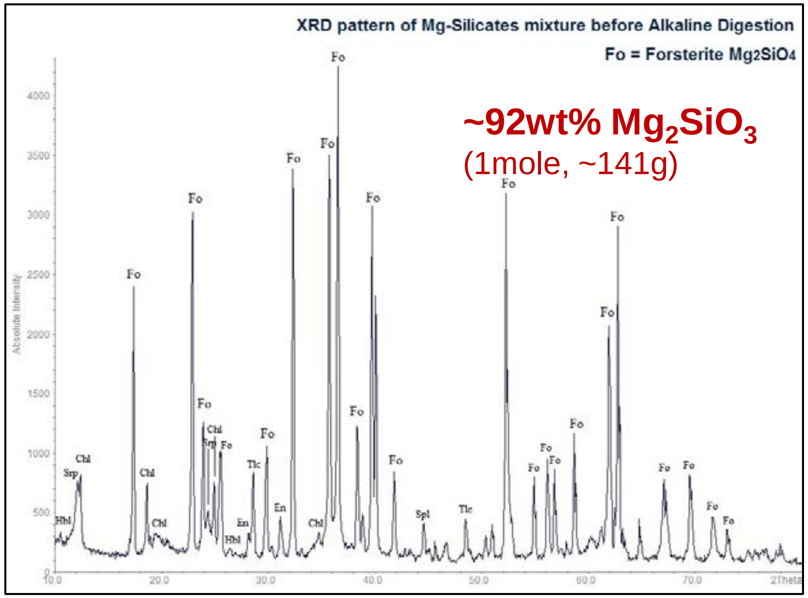
(€133)
0.7t

SiO_2

€205
0.3t APS

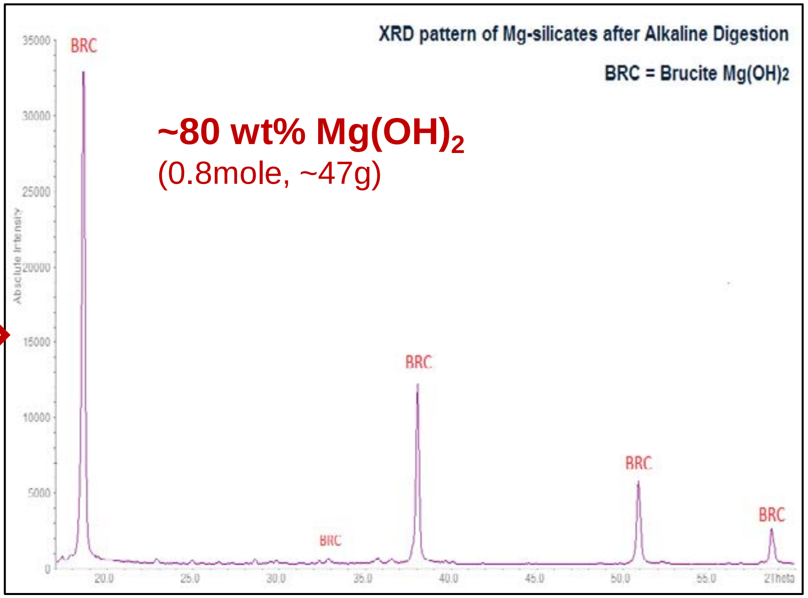
CCC Process: Olivine-to-Brucite conversion at high-pH

Before Digestion



~92wt% Mg_2SiO_3
(1mole, ~141g)

After Digestion



~80 wt% $Mg(OH)_2$
(0.8mole, ~47g)

single-step, fast, low-energy conversion of magnesium silicate to magnesium hydroxide e.g. low-carbon alternative to portlandite

CCC process schematic – carbonation step 2

(direct carbonation of brucite (magnesium hydroxide) with flue-gas into ocean or products)

Overall: $2Mg(OH)_2 + 4CO_2 \Rightarrow 2Mg(HCO_3)_2$ dH=-268kJ dG=-140kJ

③ $4CO_2 + 4OH^- \Rightarrow 4HCO_3^-$

④ $2Mg(OH)_2 + 4HCO_3^- \Rightarrow 2Mg(HCO_3)_2 + 4OH^-$

Diesel exhaust

$Mg(OH)_2$

(€133)

0.7t

③ ④

Sequestration via formation of soluble magnesium bicarbonate in seawater (or reaction to solid $MgCO_3$)

decarbonised flue-gas

€35 **1t CO_2**

$Mg(HCO_3)_2$ SOLUTION

Heat, or

CARBON-FREE ELECTRICITY via FUEL CELL

…alternatively,

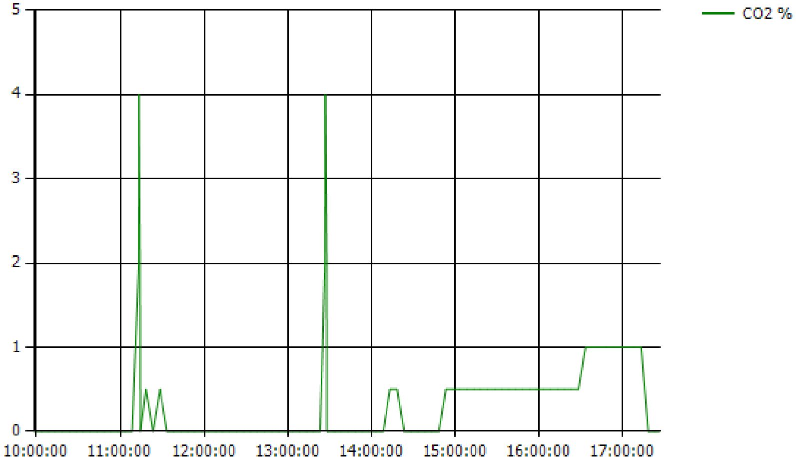
$MgCO_3$ Powder

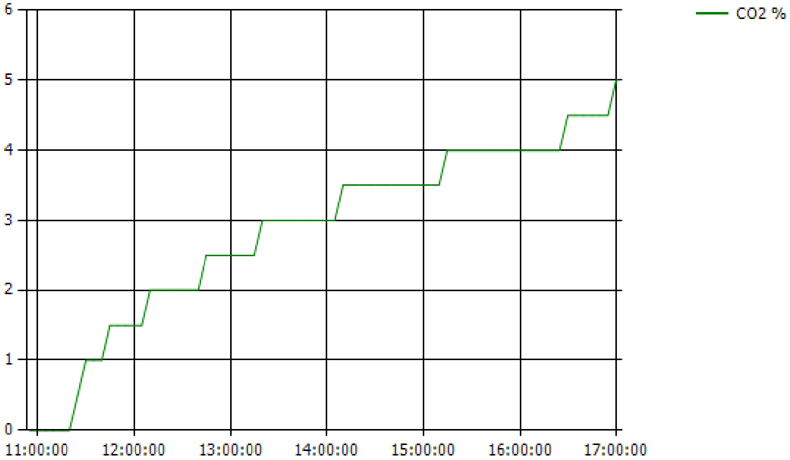
€192 1t

USP: “zero-carbon”, “zero-cost” permanent CO_2 capture & storage

Wet carbonation: Brucite-to-bicarbonate (5% CO2, rtp)

5vol% CO_2 inlet; 0vol% CO_2 outlet
2.25 litres/minute
Ambient Temp. (11C) & Press.(1atm)
0.1 molar $Mg(OH)_2$
10litres recirculating liquid





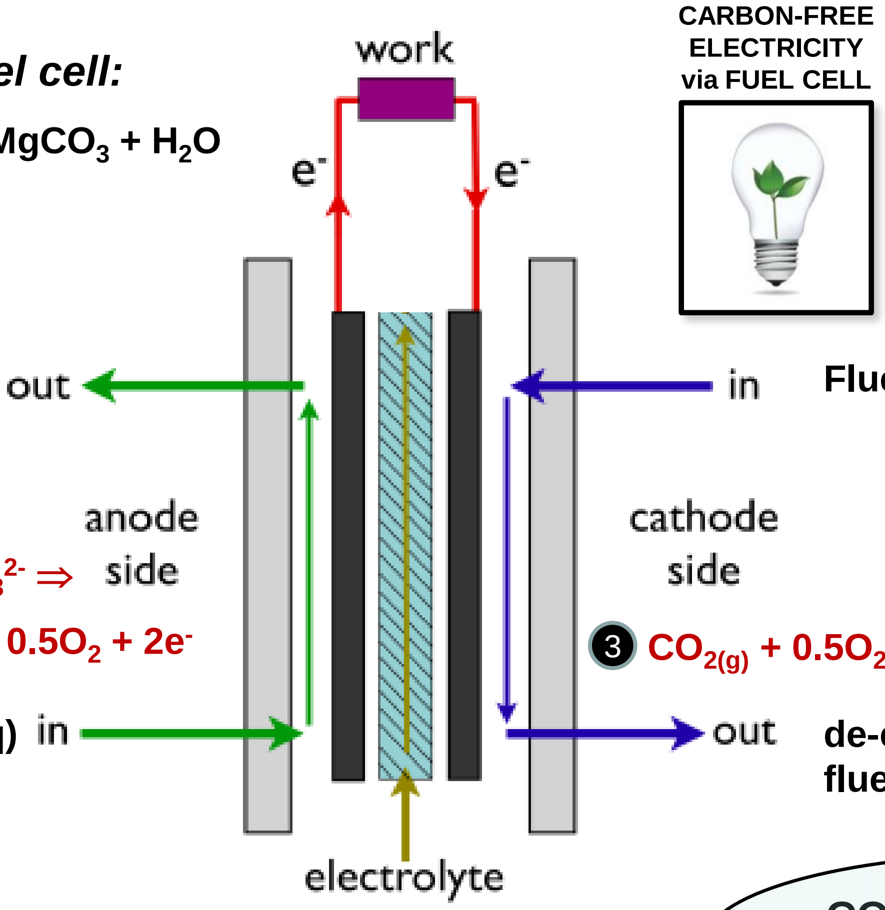
Electrochemical Mineral Carbonation – option for carbonation step 2

(energy of carbonation recovered as carbon-negative electricity via direct CO2 fuel cell)

the direct CO_2 fuel cell:

$Mg(OH)_2 + CO_2 \Rightarrow MgCO_3 + H_2O$

$E_{cell(std)} = 0.44V$



CARBON-FREE ELECTRICITY via FUEL CELL

$MgCO_{3(s)}$ out

Flue-gas in

④ **$Mg(OH)_{2(aq)} + CO_3^{2-} \Rightarrow MgCO_{3(s)} + H_2O + 0.5O_2 + 2e^-$**

③ **$CO_{2(g)} + 0.5O_{2(g)} + 2e^- \Rightarrow CO_3^{2-}$**

$Mg(OH)_2$ (aq) in

de-carbonised flue-gas

(HCO_3^-, CO_3^{2-} ion conductor)

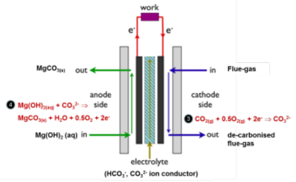
CO_2 can be a fuel to generate electricity

Key R, D & D Challenges – considerable work still to do

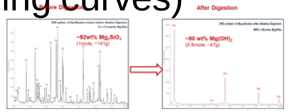
- Process engineering design to offset process energy inputs against reaction energy outputs
- LCA to accurately assess net energy usage/output, net CO2 sequestered
- Assessment of capex & opex – expert engineering design studies & demos needed to answer
- New processes that maximise kinetics of both activation of feedstock minerals and of carbonation while minimising energy/chemicals inputs; and avoiding creation of any wastes
    - Modelling of thermodynamics & kinetics of process steps
    - Particular energy intensity issues: evaporation of solvents; crystallisation/recovery of chemicals; sequential consumption of acids and bases
- Electrochemical approaches for both recovery of carbonation energy and chemicals recovery
- Development of processes optimised to use flue gas directly rather than pre-captured CO2
    - More research to investigate kinetics and thermodynamics in gas-solid and aqueous phase carbonation of magnesium silicates, (hydr)oxides and salts at low pCO2
    - Effects of flue gas impurities on product qualities
- CCSM potentially involves huge volumes of materials – better understanding of materials qualities, market requirements, volumes and prices needed versus MC process options
    - Processes optimised for different feedstocks
    - Processes optimised for different product outputs
    - Research on effects of seawater as solvent system for large-scale CCSM
    - Processes optimised for different market applications and scales of operation
- Much greater funding needed for interdisciplinary R&D and for multiple commercial demos
    - Process concepts need to be reduced to engineering practice and evaluated at pilot scale
    - Disparate R,D & D activities currently, due to sub-critical, fragmented sector, needs coordination and investment to develop a critical mass of activity; dedicated conferences and journals needed

A blueprint for implementation & scale-up

1. **Multiple low-cost demonstrations of industrial $Mg(OH)_2$ carbonation *NOW***
   - Use first in hardest, highest-value industry applications where geo-CCS not suitable
   - Commercial $Mg(OH)_2$ exhaust gas cleaning systems are available to strip low-*p*CO2 into seawater solution or solid carbonate, using natural mineral brucite
   - Multiple demonstrations to get the 22% cost-reduction learning curve underway
   - future R&D on direct-CO_2 fuel cell to recover 0.5MWh electricity per tonne CO_2



2. **R,D&D support to energy-minimise available serpentine-to-brucite/Mg^{2+} processes**
   - e.g. CCC's single-step olivine-to-brucite process; other acid/alkali multi-step processes
   - Demo with expensive natural brucite, transition quickly to cheap serpentine-derived brucite
   - Support for multiple demonstration of commercial serpentine process plants (learning curves)
   - policy support needed for non-electricity CO_2 sequestration (including from air)



3. **R&D support to optimise large-scale feedstock processing for by-product recovery of high-value critical metals and advanced industrial minerals**
   - to provide a sustainable revenue model for large-scale mineral carbonation; work with mining ind.

4. **R,D&D support & policy intervention to integrate/substitute carbonated products into the high-volume construction materials sector**
   - Policy support to introduce new low-carbon construction materials to a highly-traditional sector
   - Value & uses for large-scale MC products essential to minimise carbon pricing

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KEY MESSAGES about CO_2 mineralisation

Get the support & enabling policies right & Mineral Carbonation can deliver:

- Commercial deployment of industrial CO2 sequestration, with potential for giga-tonne CO2 scale
- Learning-curve cost reduction through market-driven volume deployment with no/low carbon price
- Economically viable distributed CCS(M) across the range from car & ships to industry & power
- MC opportunity is more about a disruptive alternative to (G)CCS than “using” CO2
- Without targeted R,D&D & policy support, commercial MC will remain niche & not reduce CO2

Situation today – already commercially niche deployed, but in the *very* slow-lane:

- Niche commercial deployment based on materials valorisation models (even paying for CO2), but very few investors or customers willing to engage with development costs & technical & commercial risks
- Multiple technical approaches with different business models – dangerous to pick “winners”
- Commercial developers & academic researchers are starved of R,D,D&D funding
- Major R&D questions still to be addressed – “downhill” process, but CO2 LCA uncertain
- Increasing academic research, but weakly coordinated & communicated, & little funding

Next-step needs – demonstration funding & industry-academia R&D collaboration:

- Multiple FOAK & NOAK commercial demonstrations required (lots of small projects)
- R&D agenda defined bottom-up by industry needs rather than by top-down CCS policy – economic viability first; CO2 LCA viability second; large-scale CCSM third
- More interdisciplinary R,D&D collaborations; industry partnership critical; funding is critical – process chemists, engineers, modellers, geochemists; mining, metals, minerals, cement, steel, waste, chemicals
- R&D & industry network needed to improve knowledge sharing; more R&D centres = more processes
- Level the playing field with geo-CCS (MC is generally outside scope of CCS programs)
- Policy mechanisms needed to valorise CO_2-sequestration independently of emissions reductions

THANKS

"CCC objective: profitable solutions for industrial customers to valorise ultramafic minerals & wastes and to permanently sequester CO_2 via conversion into valuable minerals, metals & zero-carbon electricity"

Technology Strategy Board

Polarcus

Shell Springboard Regional Winner

EARTH CHALLENGE

CO2Chem An EPSRC Grand Challenge Network

EEDA East of England Development Agency

RENEWABLES EAST

ESL

- University of Cambridge – Depts Materials Science & Metallurgy; Engineering
- University of Nottingham – Centre of Innovation in CCS
- University of Sheffield – Dept. Materials Science & Engineering
- University of Greenwich – School of Science

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