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Accelerating CCS Technologies

ACT Knowledge Sharing Workshop, Rotterdam

ABSALT: Accelerating Basic Solid Adsorbent Looping Technology

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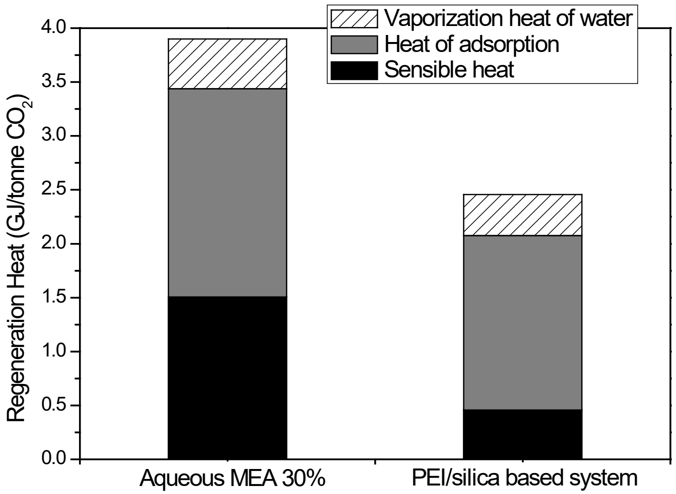
Partners: University of Nottingham (UNOTT), UK; PQ Corporation, UK; BASF, Germany, CEMEX, Switzerland; University of Ulster (UU): UK; University of Bologna (UNIBO), Italy; CPERI-CERTH, Greece and Korean Institute of Energy Research (KIER, International Cooperation Partner).

7 partners, 4 participating countries, 3 industrial.

The goal is to demonstrate that basic silica-polyethylenimine (PEI) in solids adsorption looping technology can achieve low capture costs, achieved through optimising silica-PEI composition, techno-economic and life cycle analyses, with extensive pilot-scale testing.

Background and Motivation – earlier work silica-PEI

- Solid adsorbents show promise as a second-generation technology, with potential to obtain lower regeneration energies and capture costs than amine scrubbing.



- Lower than 3.3 GJ/tCO_2 for an advanced MEA system.
- Sensitivity analysis shows that limiting moisture uptake and recovering a reasonable proportion of heat are required to maintain advantage.

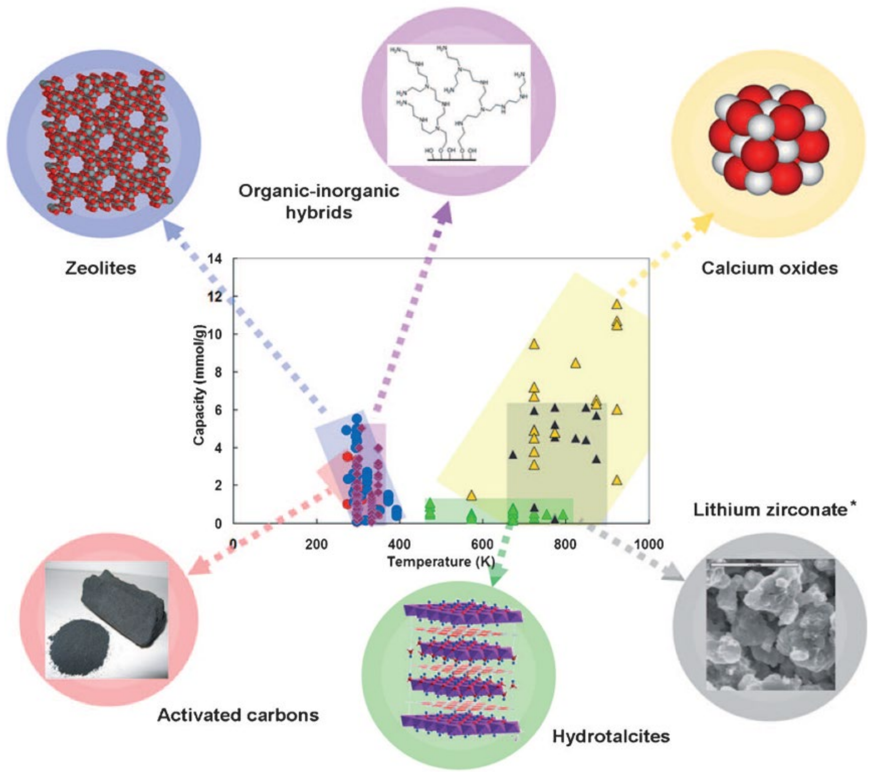
W. Zhang, H. Liu , Y, Sun, J. Cakstins, C. Sun and C.E. Snape, Parametric study on the regeneration heat requirement of amine-based solid adsorbents process for post-combustion carbon capture, Applied Energy, 2016, **168**, 394-405

	w/o CCS*	MEA*	Silica-PEI SALT
550 MWe Supercritical PC power plant – net eff. (%)	**40.8**	**29.4**	**30.9**
555 MWe NGCC power plant net efficiency (%)	**55.7**	**47.5**	**48.1**
Required Regeneration Heat (GJ/tonne-CO_2)	**N/A**	**3.6 - 3.9**	**2.5-3.0**

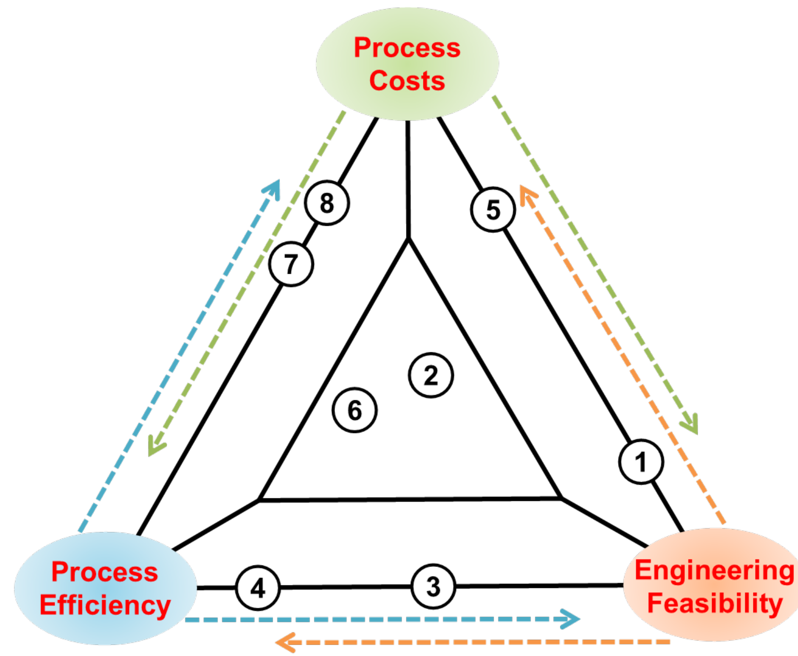
Zhang et al., International Journal of Greenhouse Gas Control 58 (2017) 276–289

Background and Motivation
– moving from lab. to pilot-scale with solid adsorbents

- Solid adsorbents are generally at early stage of development and have not been investigated extensively at pilot-scale and demonstration scale.



R. Xiong, et al., Chem. Eng. Sci., 58 (2003) 4377.



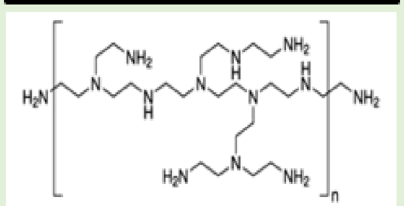
1-Precursor and Preparation Costs
2-Adsorption Heat
3-Physical Shape and Mechanical Strength
4-Density
5-Chemical Stability
6-Adsorption Dynamics
7-Adsorption Capacity and Selectivity
8-Hydrophobicity

- ***None of these has reached small demonstration scale for post-combustion capture!***
- ***Many criteria need to be met.***

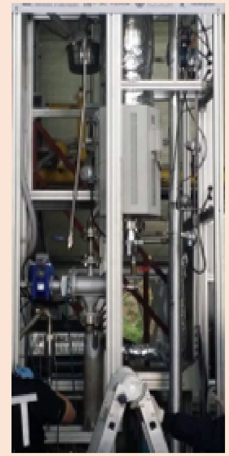
Schematic Representation of ABSALT

WP1 Silica Selection and Properties

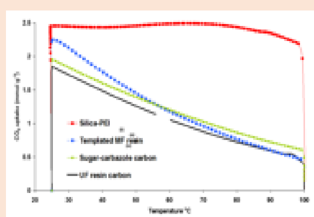
WP2 PEI Preparation and Properties



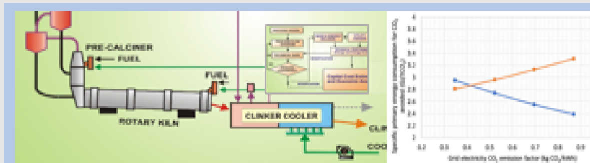
WP3 Additives, Silica-PEI Preparation and Screening



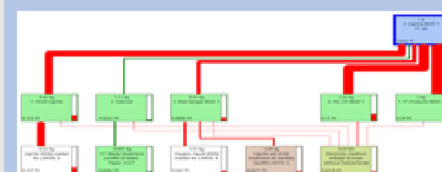
WP4 Pilot-scale Testing



WP5 Regeneration Strategies for PEI



WP6 Techno-economics and High-level Demonstration Plant Design



WP7 Environmental Assessment via Life Cycle Analysis (LCA) and Project Risk Assessment

- Extensive linkages between WPs and the various partners.

ABSALT Project Timeline
- all partners underway February 2022

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Work Package / Tasks	Partners	Year 1				Year 2			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
WP1 Silica Selection and Properties	**PQ Corp.**								
WP2 PEI preparation and properties	**BASF**								
WP3 Additives, Silica-PEI Preparation and Screening	**UNOTT, PQ Corp., BASF**								
WP4 Pilot-scale Testing	**UNOTT, KIER**								
WP5 Regeneration Strategies for Silica-PEI	**UNIBO, CERTH UNOTT**								
WP6 Techno-economics and High-level Demonstration Plant Design	**UU, CEMEX, CERTH**								
WP7 Environmental Assessment via Life cycle Analysis (LCA) and Project Risk Assessment	**UU, CEMEX**								

WP1: Silicas – Trade off between pore volume and attrition resistance

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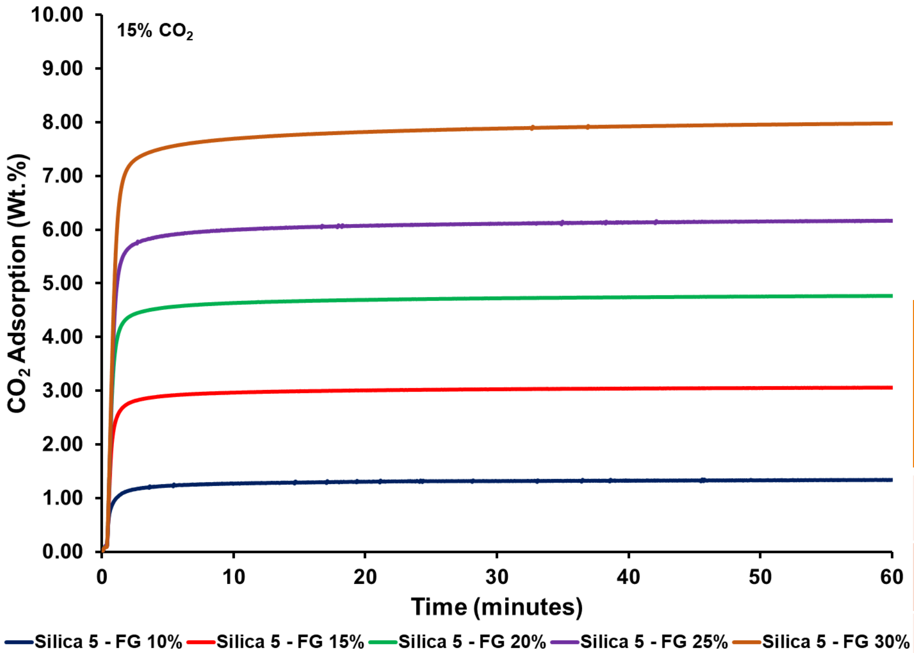
Sample	BET SA (m^2/g)	V_{micro} (%)	V_{meso} (%)	V_{tot} (cm^3/g)	D / nm
PQ 4	284	6.3	93.1	1.75	24.7
PQ 5	323	11.1	88.9	1.08	13.4
PQ 6	344	11.9	87.1	1.01	11.8
PQ 7	191	8.9	50.0	0.90	18.8
PQ 8	209	14.5	69.1	0.55	10.6

BET SA – Specific surface area using BET model between 0.05-0.20 P/Po. Vmicro, Vmeso and Vtot – micro, meso and total pore volumes calculated by D-R and BJH models (Broekhoff-De Boer thickness curve correction) up to 140 nm. D – average pore diameter (4Vtot)/SA).

Drop in total pore volume from PQ 5-8.

- PQ4 used as in all lab scale testing so far.
- Decrease in porosity in silicas 5-8 should reduce wear (attrition) during fluidisation.
- Determining optimum loadings for these silicas.

WP1: Si-PEI-CO_2 Adsorption and Kinetics (15% CO_2) – PQ5



TGA CO_2 adsorption/kinetics method:

- Moisture removal stage in N_2, 1 bar (120 ºC for 30 minutes).
- Adsorption in 15% CO_2, 1 bar 75 ºC.

PEI Loading (%)	CO_2 Uptake[a] (Wt.%)	Kinetics[b] (mins)	
		t_{90}	t_{95}
10	1.35	3.95	12.51
15	3.06	1.93	4.97
20	4.77	1.66	4.20
25	6.17	1.69	4.13
30	7.98	2.03	5.95

a = CO_2 adsorption at 75 ºC on dry basis. b = t_{90} and t_{95} time taken to reach 90 and 95% CO_2 capacity.

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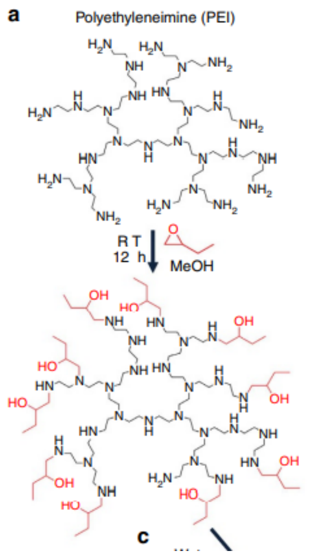
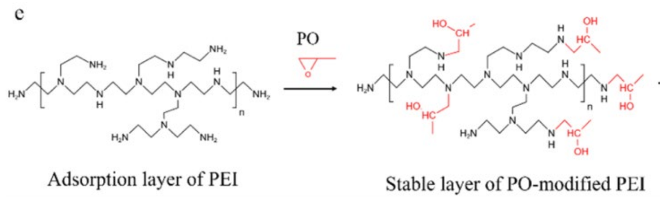
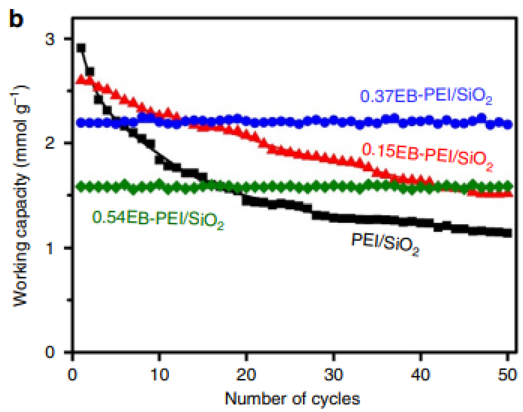
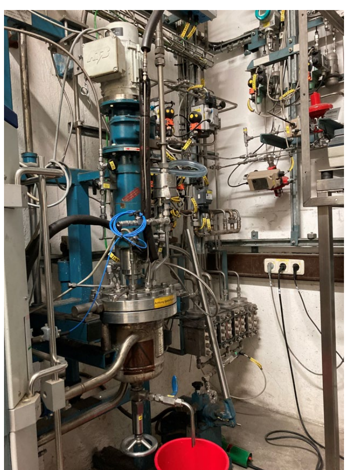
- Optimum loading for PQ 5 at 30% loading.
- More attrition resistant silica only giving 25% reduction in CO2 capacity from CA. 11%.

WP2: Screening of PEI species and appropriate scale up technology





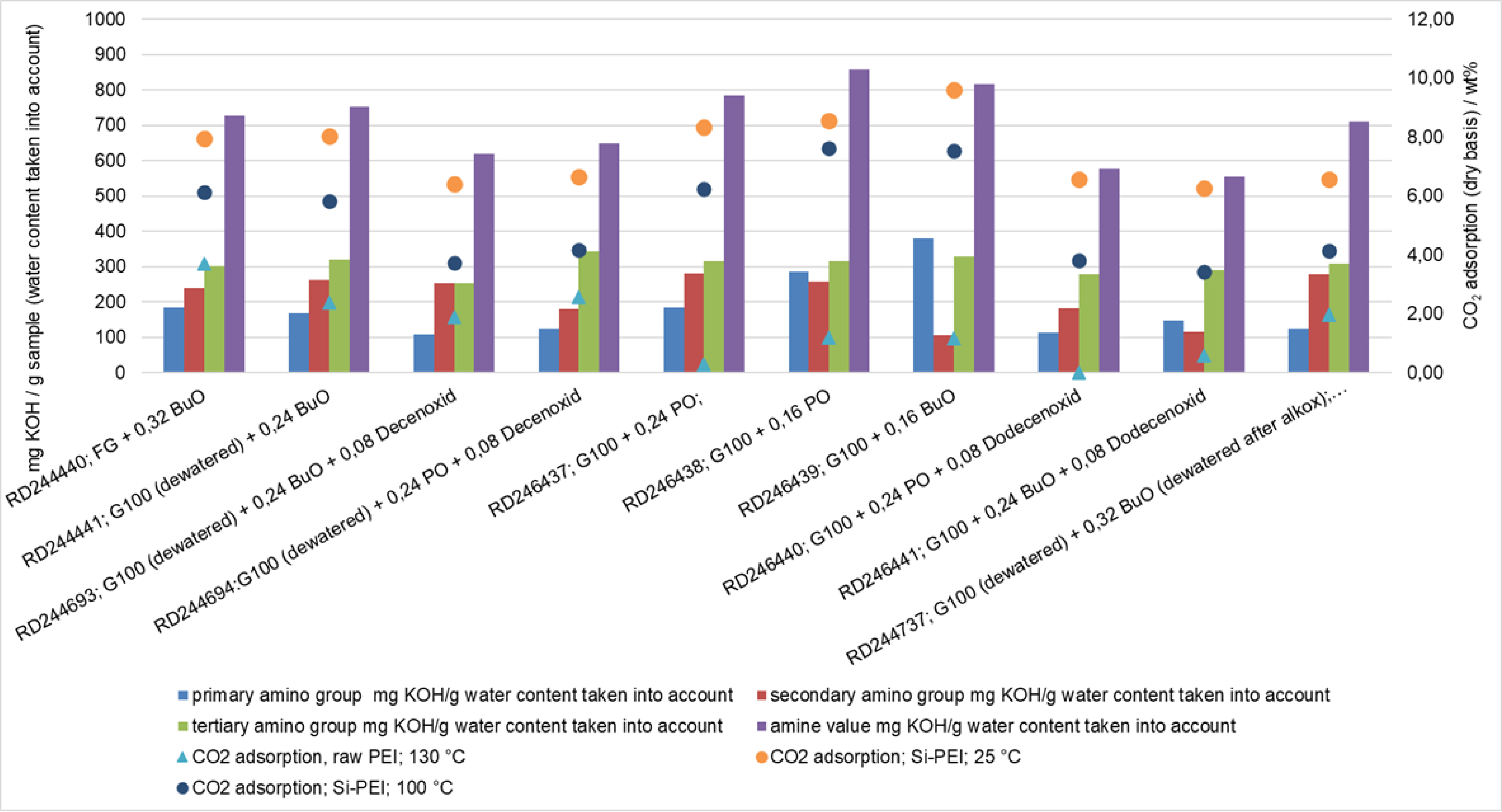




- Lupasol type (FG and G100)
- Alkoxylation PO vs. BuO
- Degree of alkoxylation
- Mixed alkoxylation with higher oxides (C10/12)
- Process development
    - Alkoxylation of aqueous solutions
- Final goal until Q3 2022: fix the PEI species and process for scale up, registration and delivery in 2023

- Goal is to eliminate only those NH_2 groups that trigger decomposition and reduce stability.

WP2: BASF Alkoxylated PEIs – distribution of amine functionality

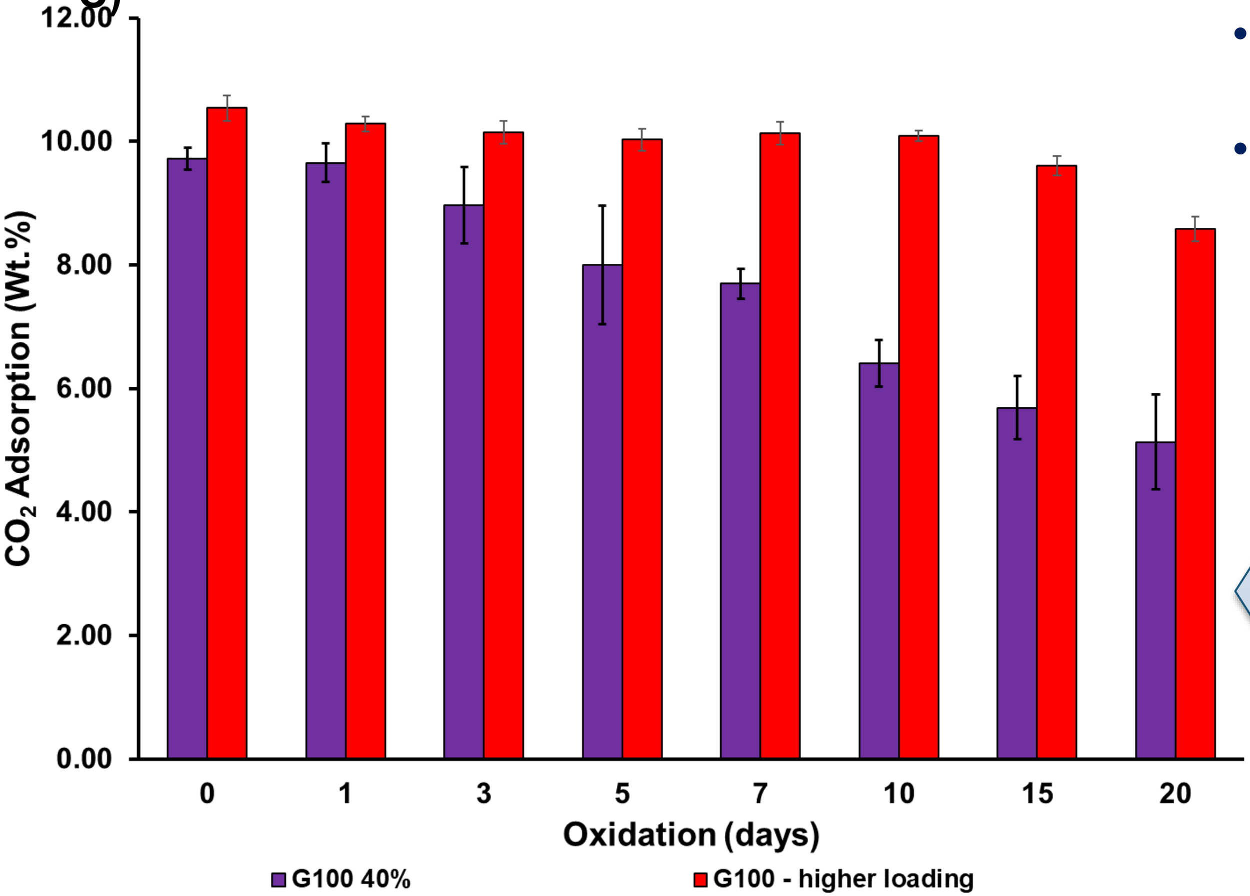


- Total NH and secondary NH high - primary NH and tertiary N low

BASF
We create chemistry

WP3: Si-PEI – Oxidation Study – Si-G100 40% and higher loading

Conditions: 15% CO_2, Adsorption temperature: 75 ºC)



Oxidation method:

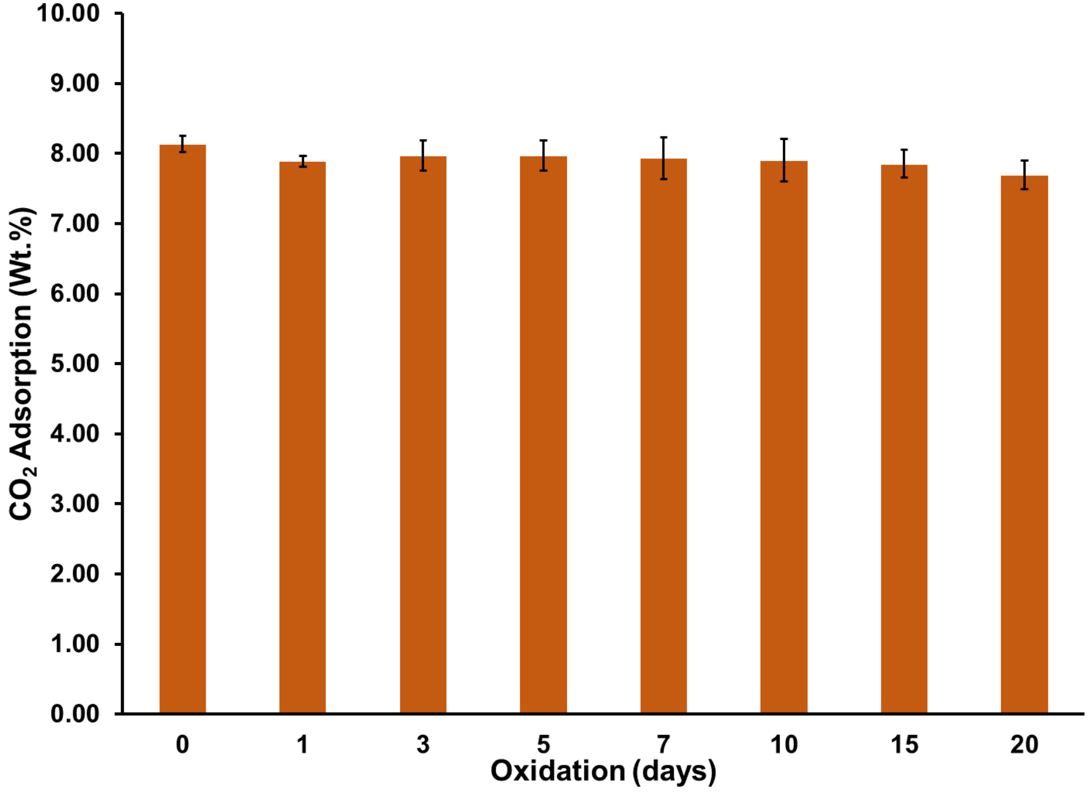
- Fan assisted oven.
- Oxidation at 70 ºC over 20 days in air (1 bar).
- 30 mg removed on days 1, 3, 5, 7,10, 15 and 20 days.

Loss in CO_2 capacity reduces for loadings above 40%

- 47% drop in CO_2 capacity after 20 days oxidation with G100 40% loading.
- Approx. 20% reduction in CO_2 capacity with loadings above 45%..

WP3: Si-PEI – Oxidation Study – Si-RD246439- - Low Alkoxylation

Conditions: 15% CO_2, Adsorption temperature: 75 ºC)



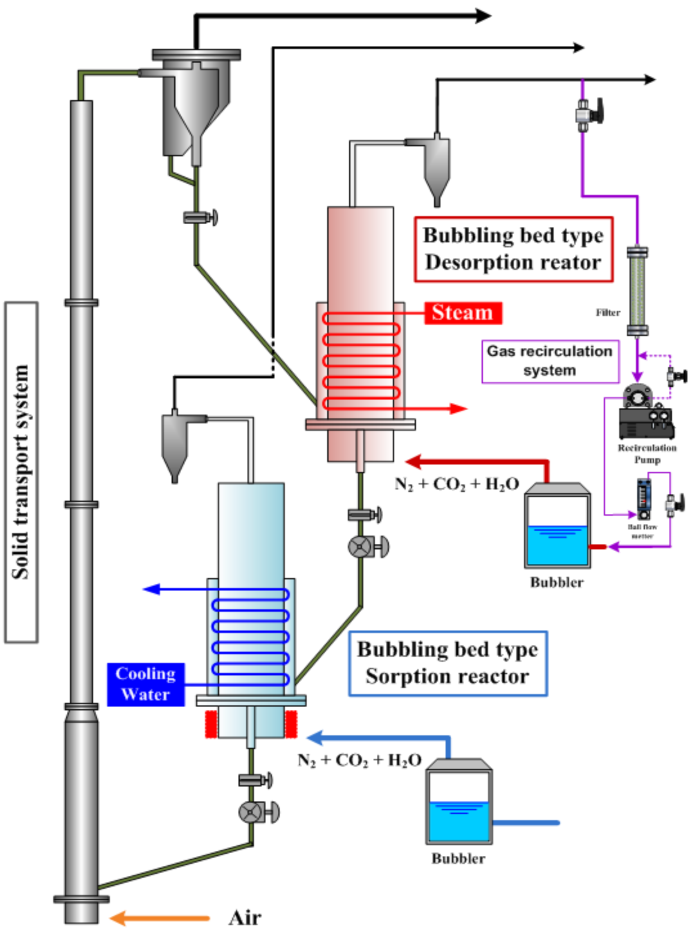
Oxidation method:

- Fan assisted oven.
- Oxidation at 70 ºC over 20 days in air (1 bar).
- 30 mg removed on days 1, 3, 5, 7, 10, 15 and 20 days.

CO_2 capacity = 8.13 to 7.69 Wt.% after 20 days in air.

- Only 5.4% drop in CO_2 capacity after 20 days oxidation.
- Low alkoxylation only reduces initial CO_2 uptake by 20%
- **Optimised formulation for first large-scale batch decided by end of June.**

SALT pilot-scale facility: WP4



(a)

(b)

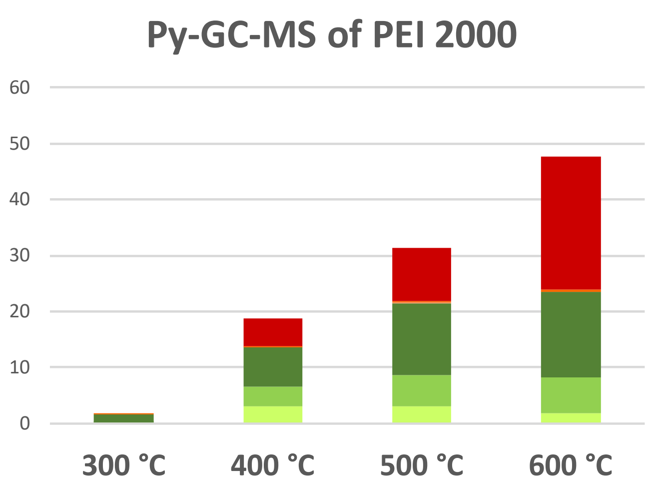
(a) Schematic of pilot-scale facility

(b) Unit at Nottingham for 5 and 20 kg of adsorbents

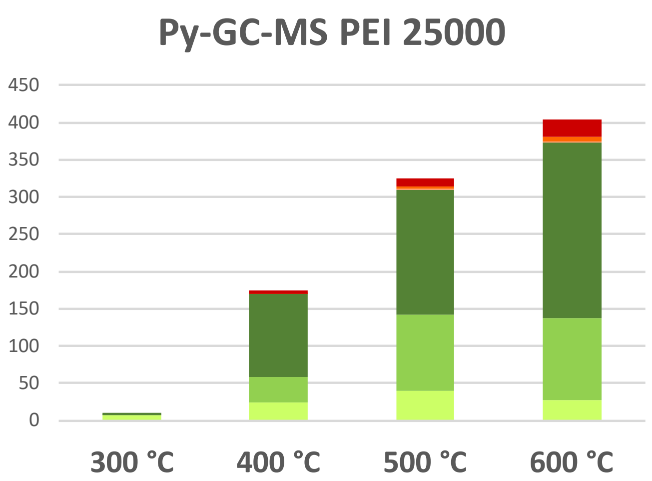
– £0.5M investment, Innovate UK Energy Research Accelerator

- being commissioned in first 8 months of project

WP5: Regeneration strategies for silica-PEI
Py-GC-MS: Effect of temperature and molecular weight on the production of pyrazines and piperazines



PEI 25000 (20 mg mL^{-1} in MeOH) = 10 µL
IS: methyl palmitate (125 µg mL^{-1} in toluene) = 5 µL



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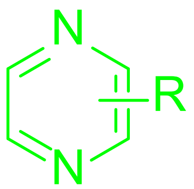
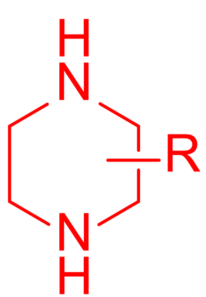
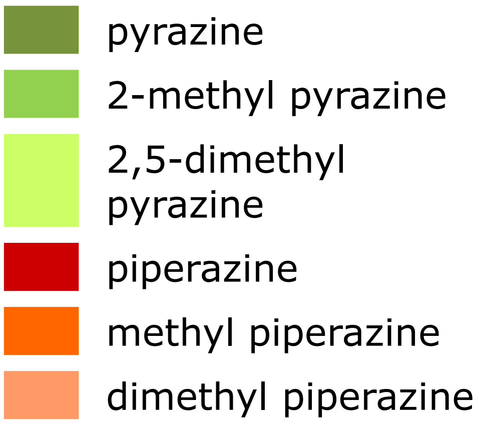






WP6: Techno-economic evaluation and Life Cycle Assessment

Options:

Base Case

Solid adsorbent looping technology

Conventional Amine scrubbing system

Key Performance Indicators

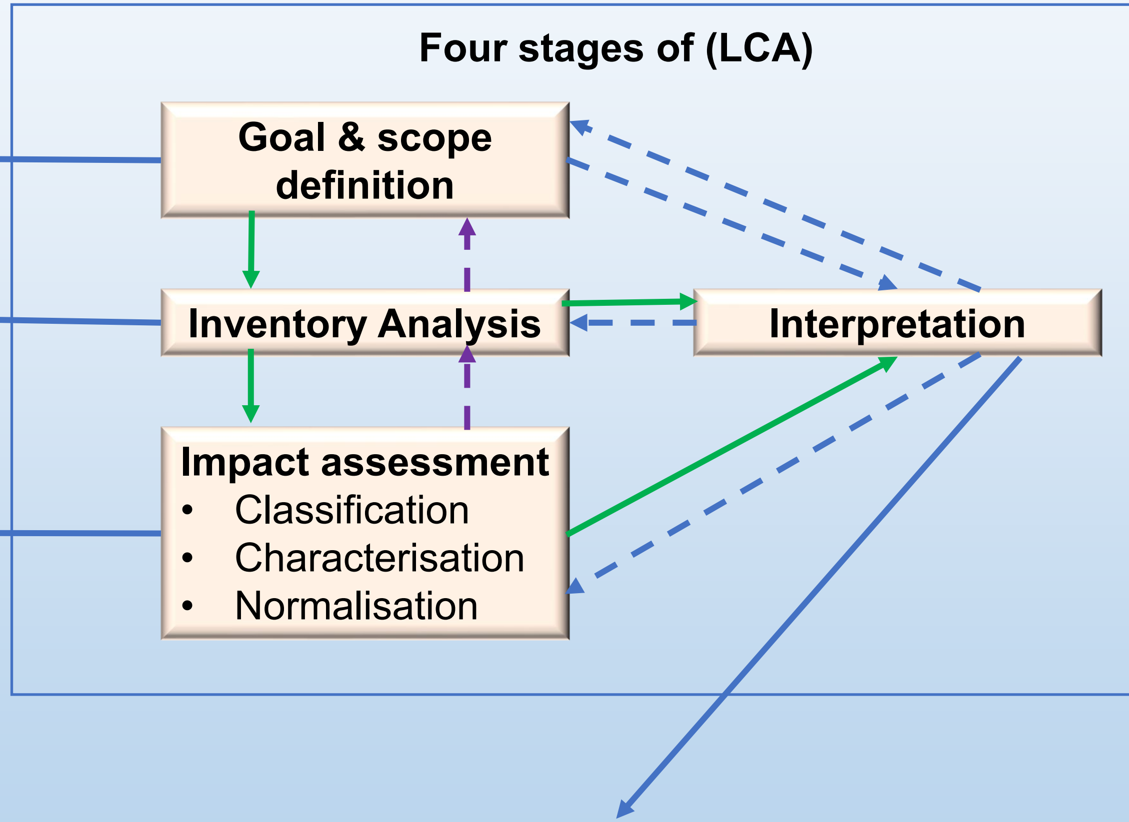
- CO_2 Reduction
- Cost of clinker (Unit cost)
- CO_2 capture cost
- Cost of CO_2 avoided
- SPECA (Specific Primary Energy for CO_2 avoided)

WP6: Life Cycle Assessment (LCA) SimaPro™ Software and Compliance with ISO 14040-14044 standards

Outlines the parameters of the study including any assumptions and limitations.

Input/output analysis of environmentally relevant material and energy flows

Established LCA methods to translate inventory results to environmental impacts



Interpret and analysis results within the context of the goal and scope of the study

WP7: Risk Assessment

The technological risk and impact assessment (CEMEX, All):

Health & safety, impact on CAPEX, impact on a performance

The economic risk associated with Capital Cost Investment and Net Present Value, predicting future cash flows (Ulster)

The economic risk associated with the failure of a component or process, estimating the contingency cost or reserve (Ulster and Cemex)