Emerging CO$_2$ Capture Systems

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Not all capture is the same

As the concentration increases the energy required to capture a tonne of CO$_2$ decreases.
Range of problems we study

Including $\text{CO}_2$ recycle to increase composition
### Presentations Summary

See posters during breaks.

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<td>Maria Sanchez del Rio, Jon Gibbins, Hannah Chalmers, Mathieu Lucquiaud</td>
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See also M. Lucquiaud and H. Chalmers for power plant flexibility and solvents research.
Scale is important

In Scotland SEPA reports over 230 industrial emitters with less than 10,000 tonnes per year.

**Top 20 CO₂ emitters (tonnes)**

<table>
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<tr>
<th>Company Name</th>
<th>CO₂ Emissions (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scottish Power Longannet</td>
<td>9,193,984</td>
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<tr>
<td>Petroineos Manufacturing Scotland Limited</td>
<td>1,335,507</td>
</tr>
<tr>
<td>ExxonMobil Chemical Ltd, Fife Ethylene Plant</td>
<td>731,336</td>
</tr>
<tr>
<td>Fortum O&amp;M (UK) Limited, Grangemouth CHP</td>
<td>708,076</td>
</tr>
<tr>
<td>Lafarge Tarmac Cement &amp; Lime Limited</td>
<td>528,733</td>
</tr>
<tr>
<td>INEOS Chemicals Grangemouth Limited</td>
<td>489,612</td>
</tr>
<tr>
<td>Ineos Infrastructure (Grangemouth) Limited</td>
<td>424,348</td>
</tr>
<tr>
<td>E.ON UK Plc</td>
<td>395,983</td>
</tr>
<tr>
<td>RWE Innogy Markinch Limited</td>
<td>382,760</td>
</tr>
<tr>
<td>SSE Generation Peterhead</td>
<td>330,961</td>
</tr>
<tr>
<td>Shell UK, St Fergus Gas Plant, Peterhead</td>
<td>323,713</td>
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<tr>
<td>BP Exploration, Kinneil Terminal, Grangemouth</td>
<td>307,454</td>
</tr>
<tr>
<td>UPM-Kymmene (UK) Limited</td>
<td>291,431</td>
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<tr>
<td>Norbord Europe Limited</td>
<td>267,183</td>
</tr>
<tr>
<td>Cofely Ltd, BP, Sullom Voe Terminal</td>
<td>209,310</td>
</tr>
<tr>
<td>BP Exploration, Sullom Voe Terminal</td>
<td>200,894</td>
</tr>
<tr>
<td>William Grant &amp; Sons Distillers Ltd</td>
<td>200,598</td>
</tr>
<tr>
<td>Apache Beryl I Ltd, Sage Gas Terminal</td>
<td>151,429</td>
</tr>
<tr>
<td>Shell UK Limited, Fife NGL Plant</td>
<td>139,415</td>
</tr>
<tr>
<td>O - I Manufacturing UK, Glasshouse, Alloa</td>
<td>137,865</td>
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**Categories:**

- **Oil & Gas**
- **Chemicals**
- **Other industry**

**Note:** ONLY the first 2 above a million tonnes/year.
Emerging CO₂ capture systems

J.C. Abanades, B. Arias, A. Lyngfelt, T. Mattisson, D.E. Wiley, H. Li, M.T. Ho, E. Mangano, S. Brandani

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a Spanish Research Council, CSIC-INCAR, Francisco Pintado Fe 26, 33011 Oviedo, Spain
b Chalmers University of Technology, Department of Energy and Environment, Division of Energy Technology, 412 96 Göteborg, Sweden
c The Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC), School of Chemical Engineering, UNSW Australia, UNSW Sydney, 2052, Australia
d School of Engineering, University of Edinburgh, The King's Buildings, Mayfield Road Edinburgh, EH9 3JF Scotland, UK
1 Million tonnes/year

Air Products vacuum swing adsorption from steam methane reformer. From 10-20% to 97% CO₂
1 Million tonnes/year

Port Arthur 1
2013

Port Arthur 2
2014

With thanks to Air Products
Five SCCS projects

Collaborations including different SCCS partners

International collaborations

Research in emerging capture technologies

1. Feasibility of a Wetting Layer Absorption...
2. Adsorption Materials and Processes for Gas...
3. Post-Combustion Carbon Capture Using MOFs...
4. H₂ Production from an IGCC...
5. MOF-based Mixed Matrix membranes for CO₂...
Feasibility of a Wetting Layer Absorption (WLA) process based on amine-impregnated silicas

PI – Martin Sweatman, University of Edinburgh
Other Investigators:
SV Patwardhan and AJ Fletcher, University of Strathclyde
S Brandani and X Fan, University of Edinburgh

The project combines four work-packages (WPs):

- WP1: Synthesis and characterisation of bimodal silica materials
- WP2: CO$_2$ absorption experiments in amine-impregnated materials
- WP3: Molecular modelling
- WP4: Regeneration strategy
Materials synthesis

Novel synthesis of bimodal mesoporous silicas obtained with surfactants of different length and with different solvents.

Variation of material properties with surfactant chain length.

N₂ desorption scanning curve hysteresis studies at 77 K to probe connectivity between the secondary (transport) pores.
Sorption experiments

This unit allows to;
- Make vapour-phase impregnated solids
- Measure sorption capacity of gases/vapours on conventional & impregnated adsorbents.
- Generate isotherm + heat of sorption.
- Investigate kinetics and stability

For example,

**Complete New Zero-Length Column unit**

CO₂ ZLC runs with DETA-impregnated MCM-41
Molecular modelling

- Tested molecular models for DETA and MEA by direct simulation of a vapour-liquid interface; results indicate that the molecular models are of good quality.
- MCM-41 pore structure provided by Dr. Tina Düren.
- Obtained DETA adsorption isotherms with a fixed number of particles. However, this method generates large statistical errors.

Currently developing new software to allow simulations at a fixed fugacity.

- Can also predict dielectric spectra (for comparison with microwave heating experiments) of amines using MD simulations.

Dielectric spectra (absorption and loss factors) predicted by several MEA molecular models (lines) compared with experiments (symbols).
Amine regeneration

\[ \text{H}_2\text{O} + \text{NH}_2 \rightarrow \text{HOCN} \]

Microwaves produced in magnetron with adjustable power setting.
Dual-directional coupler measures forward and reverse power → Energy Consumption.

Regeneration of MEA occurs much more quickly and completely by microwaves than thermal conduction, suggesting significant non-thermal effects. Do the microwaves target the ionic product species?
Adsorption Materials and Processes for Gas fired power plants – AMPGAs

Partners (SCCS):

 PI – Stefano Brandani, University of Edinburgh
 Other Investigators:
 PA Wright, University of Strathclyde
 EEB Campbell, E Mangano, MC Ferrari, H Ahn, University of Edinburgh
 HHP Yiu, Heriot-Watt University

Industrial Partner:

Other industrial contributions:

Chemviron Carbon; Purolite; Thomas Swan and UOP
AMPGas – Novel Materials

Zeolites
(University of St Andrews)

Metal organic frameworks
(University of St Andrews)

Amine functionalised Carbons
(University of Edinburgh)

ECR-18  ZSM-25

Cation gating zeolites

13 X

Basic amine moiety interacts with acidic CO$_2$
LETTER

A zeolite family with expanding structural complexity and embedded isoreticular structures

Peng Guo¹,²*, Jiho Shin³*, Alex G. Greenaway⁴, Jung Gi Min³, Jie Su¹,², Hyun June Choi³, Leifeng Liu¹,², Paul A. Cox⁵, Suk Bong Hong⁶, Paul A. Wright⁴⁶ & Xiaodong Zou¹,²⁶

¹Inorganic and Structural Chemistry, Department of Materials and Environmental Chemistry, Stockholm University, SE-106 91 Stockholm, Sweden. ²Barzelli Centre EXSELENT on Porous Materials, Stockholm University, SE-106 91 Stockholm, Sweden. ³Centre for Ordered Nanoporous Materials Synthesis, School of Environmental Science and Engineering, POSTECH, Pohang 790-784, South Korea. ⁴EυSiCHEM School of Chemistry, University of St Andrews, St Andrews KY16 9ST, UK. ⁵School of Pharmacy and Biomedical Sciences, University of Portsmouth, Portsmouth PO1 2DT, UK.

July issue of Nature reporting properties of the new zeolites.
AMPGas – Experimental

Experimental approach to material characterisation

- Zero Length Column
  - 10-15 mg
  - Equilibrium
  - Kinetics
  - Stability

- Extended Zero Length Column
  - ~ 50 mg
  - Clear separation
  - Useful for TSA evaluation

- Dual Piston PSA
  - ~ 10 g
  - Heat transfer
  - Mass transfer
  - Pressure drop

- Rotary Wheel Adsorber
  - ~ 1 Kg
  - Full cycle performance
  - Purity
  - Recovery
  - Productivity
AMPGas – Rotary Wheel

- Can treat large volumes of gas
- Lower capital cost
- Low pressure drop
- Can perform rapid temperature swings
- Thermal cycles of few minutes: 10 times faster than traditional TSA in fixed bed
- Significant reduction of the size of the capture plant
FENCO-NET funded project

- Collaborative project with
  - SINTEF (MOF synthesis) – Norway
  - CERTH (Process simulations) – Greece
- MOFs for post combustion CCS

Synthesize up to kg levels
Characterize separation performance
Process study
Sample characterization

- Adsorption Equilibrium and kinetics
- From powders to pellets

![Graphs showing adsorption equilibrium and kinetics](image)

Pelletized samples

Volumetric apparatus
Process study

- Dual Piston PSA apparatus for separation efficiency of MOFs
- Benchmark VSA simulation

DPPSA apparatus

VSA process for CCS
H₂ Production from an IGCC with Carbon Capture

PI – Hyungwoong Ahn, University of Edinburgh
Chang-Ha Lee, Yonsei University

Other Investigators:
S Brandani, University of Edinburgh

H₂ CCS by capturing CO₂ from synthesis gas with a dual-stage Selexol process

Carbon capture unit
(Dual-stage Selexol)

H₂ purification
(Pressure Swing Adsorption)
Ultrapure H₂ Production

12-column, 13-step H₂ PSA step configuration simulated using Cysim, our adsorption process simulator.
PSA Experimental System

Gas compression system

Six adsorption columns inside the oven

Mass spec for gas analysis
Ultrapure H₂ Production with CCS

Improvement of the H₂ CCS process: Increasing H₂ yield and reducing the energy penalty for CO₂ capture and compression.

GB2522015-A: WO2015104532-A1, Hydrogen production process involves recycle loop in which tail gas produced downstream in the process is used upstream of the process at shift reactor, providing heat for drying coal and providing heat for generating carbon dioxide, 2015.
MOF-based Mixed Matrix membranes for CO₂ capture (M4CO2)

Matrix (Polymer)
- Mechanical stability (flexible)
- Easy Processing
- Low Price
- Industry standard

Filler (Molecular sieve)
- Chemical stability
- Gas sieving properties
- Structural diversity

Porous Polymer (Edinburgh)

MOF (St. Andrews)
The Challenge in $M^4CO_2$

Post-combustion CO$_2$ capture

$CO_2$ selective $M^4's$

Polymer

MOF

Nano

Micro-Meso

Macro

Lab

Prototype

Pre-combustion CO$_2$ capture

$H_2$ selective $M^4's$
M⁴CO₂ Consortium
Find out more about our work at www.sccs.org.uk

Or email SCCS Project Manager, Dr Philippa Parmiter, philippa.parmiter@sccs.org.uk