Emerging CO$_2$ capture technologies and their cost reduction potential

Jasmin Kemper
IEA Greenhouse Gas R&D Programme

NETL CO$_2$ Capture Technology Meeting
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Outline

Study overview

Study scope

Background

- Technology readiness level (TRL)
- Levelised cost of electricity
- Cost learning curves

Findings

- Drivers of capture cost
- Energy consumption
- Contributions to cost of electricity
- TRL comparisons

Summary

Conclusions
Study overview

Study commissioned by UK DECC

Study carried out by Mike Haines (former IEAGHG staff), with input from IEAGHG capture team (PM John Davison)

Interim report published as an IEAGHG Technical Review (2014/TR4)

- Not subject to external peer review
- Draft executive summary is included

Aim to publish as a “full IEAGHG report”

- External reviews have been obtained and revisions are being made
- Revised executive summary will be reviewed by IEAGHG ExCo members before publication
Study scope (1)

- Determine cost drivers (fuel/capital/other costs) for power generation technologies with CO₂ capture
- Review theoretical energy consumptions for CO₂ capture and compare to actual consumptions
- Review cost progression for new technologies
Study scope (2)

Identify and review the main emerging capture technologies being developed for power plants

- Post-combustion capture
- Pre-combustion capture
- Oxy-combustion
- Solid looping

Assess current status and Technology Readiness Level (TRL)

Critically assess claims for energy requirements and cost reductions

Capture in non-power industries considered in less detail

Study did not involve detailed assessment of energy requirements and costs of plants with CO₂ capture
## Technology readiness level

<table>
<thead>
<tr>
<th>TRL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Normal commercial service</td>
</tr>
<tr>
<td>8</td>
<td>Commercial demonstration, full scale deployment in final form</td>
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<tr>
<td>7</td>
<td>Sub-scale demonstration, fully functional prototype</td>
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<tr>
<td>6</td>
<td>Fully integrated pilot tested in a relevant environment</td>
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<tr>
<td>5</td>
<td>Sub-system validation in a relevant environment</td>
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<tr>
<td>4</td>
<td>System validation in a laboratory environment</td>
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<tr>
<td>3</td>
<td>Proof-of-concept test, component level</td>
</tr>
<tr>
<td>2</td>
<td>Formulation of the application</td>
</tr>
<tr>
<td>1</td>
<td>Basic principles, observed initial concept</td>
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</tbody>
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### Note:
- TRL is not necessarily an indication of the amount of time and effort required to achieve commercialisation
- TRL 9 does not necessarily represent the be-all and end-all
Estimated LCOE increase

Estimated percentage increases in LCOE due to addition of CO2 capture

Benchmark post, oxy and pre combustion capture

Supercritical steam, coal fired power plant as baseline

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>Percentage Increase above baseline</th>
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</thead>
<tbody>
<tr>
<td>Base plant</td>
<td>0</td>
</tr>
<tr>
<td>Econamine PCC study</td>
<td>80</td>
</tr>
<tr>
<td>Oxy combustion</td>
<td>80</td>
</tr>
<tr>
<td>IGCC no capture</td>
<td>20</td>
</tr>
<tr>
<td>IGCC with Selexol</td>
<td>80</td>
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</tbody>
</table>

- **Capture plant contribution**
- **IGCC Contribution**
Cost learning curve

Capital cost per unit of capacity

- Conceptual cost estimate
- Preliminary design cost estimate
- Pre-commercial cost estimate
- First of a kind commercial plant FOAK
- Nth of a kind plant NOAK
Other cost learning curves
Other cost learning curves
Drivers for cost of capture

Capital cost of capture equipment
- Capital charges, cost of maintenance etc.

Increased fuel consumption

Increased specific capital cost of the host power generation process due to increased fuel consumption

Increased variable operating costs
- Capture solvent make-up etc.

→ Early stage assessments tend to focus initially on energy consumption
- Can be evaluated more scientifically
- A major contribution to capture cost
Energy consumption

**CO₂ separation**
- Theoretical work for post-combustion capture from coal fired power plant flue gas: 0.15 GJ/t CO₂
  - Equivalent to <1.5% points of power plant efficiency
  - Scope to reduce energy consumption but all processes need a significant driving force to reduce equipment size
  - Some capture processes use exergy that is otherwise wasted

**CO₂ compression**

**Miscellaneous power**

**Other losses**
- E.g. shift conversion for pre-combustion capture
Post-combustion capture
Contributions to cost of electricity

Based on NETL baseline cost study

Capture plant variable OPEX

Power plant increase due to capture energy consumption

Capture plant CAPEX

Power plant without capture
Pre-combustion capture
Contributions to cost of electricity

- Baseline integrated gasification combined cycle (IGCC) without capture is more expensive than baseline pulverised coal (PC) plant without capture – need to reduce core IGCC costs
- Extra cost of capture equipment is lower than for PC
Oxy-combustion capture
Contributions to cost of electricity

- Broadly similar to PC with post-combustion capture
Post-combustion capture

**TRL 1 - 3**
- Enzyme catalysed adsorption
- Ionic liquids
- Room temperature ionic liquid (RTIL) membranes
- Encapsulated solvents
- Electrochemically mediated absorption
- Vacuum pressure swing adsorption (VPSA)
- Cryogenic capture
- Supersonic inertial capture

**TRL 4 – 6**
- Bi-phasic solvents
- Precipitating solvents
- Polymeric membranes
- Temperature swing adsorption

**TRL 7 – 9**
- Benchmark amine scrubbing
- Improved conventional solvents
Pre-combustion capture

TRL 1 - 3
• Low temperature separation

TRL 4 – 6
• Hydrogen separation membranes
• Sorption enhanced water gas shift (SEWGS)
• Integrated gasification fuel cells (IGFC)

TRL 7 – 9
• IGCC with Selexol
Oxy-combustion capture

**TRL 1 - 3**
- Oxy-combustion gas turbines: other cycles

**TRL 4 – 6**
- $O_2$ production: ion transport membrane (ITM), $O_2$ transport membrane (OTM), ceramic auto-thermal reforming systems (CARS)
- Oxy-combustion gas turbines: water cycle

**TRL 7 – 9**
- Benchmark coal oxy-combustion
Solid looping processes

TRL 1 - 3
- Sorption enhanced reforming (SER)
- Chemical looping gasification (CLG)
- Chemical looping with oxygen uncoupling (CLOU)
- etc.

TRL 4 – 6
- Calcium carbonate looping (CaL)
- Chemical looping combustion (CLC)

TRL 7 - 9
Summary

Post-combustion capture

Pre-combustion capture

Oxy-combustion capture
Conclusions

Many new technologies for CO$_2$ capture are being developed.

Estimated costs of new capture technologies are subject to high uncertainty, especially at low TRLs.

Processes in which CO$_2$ capture is a more integrated part of the power generation process show high potential for energy and cost reduction but have significant development hurdles:

- E.g. solid looping combustion, oxy-combustion turbines and fuel cells.
Thank you, any questions?

6th HTSLCN Meeting,
1st – 2nd September, Milan, Italy

Contact us at:
john.davison@ieaghhg.org
jasmin.kemper@ieaghhg.org