CO₂ Capture R&D at EPRI

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Palo Alto, CA

NETL CO₂ Capture Technology Meeting
Pittsburgh, PA
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EPRI Overview

Mission
To conduct research, development and demonstration on key issues facing the electricity sector on behalf of our members, energy stakeholders, and society

Members
450+ participants in more than 30 countries
EPRI members generate approximately 90% of the electricity in the United States
International funding of nearly 25% of EPRI’s research, development and demonstrations
Three Key Aspects of EPRI

Independent
Objective, scientifically based results address reliability, efficiency, affordability, health, safety and the environment

Nonprofit
Chartered to serve the public benefit

Collaborative
Bring together scientists, engineers, academic researchers, industry experts
CCS Status Today

• In 2007, there were 50+ large-scale carbon capture and storage projects proposed; over 30 have been cancelled and none are operating

• What happened?
  – Bad economy, lack of sufficient financial incentives, lack of regulatory clarity
  – Storage and transportation issues caused some cancellations
  – Economic and energy penalty of current technologies too high

• CCS projects still needed to improve technologies and gain public acceptance
## Post-Combustion Capture
### Beyond Lab and Bench Scales

<table>
<thead>
<tr>
<th>Type, TRL</th>
<th>Size MWe</th>
<th>$, millions Source</th>
<th>Now</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha-pilot TRL 5-6</td>
<td>1-2</td>
<td>10’s Private Public+Private</td>
<td>Dozens</td>
<td>Existing Facilities – dozens New Facilities – dozens</td>
</tr>
<tr>
<td>Beta-Pilot TRL 6-7</td>
<td>10-20</td>
<td>100’s More Private Less Public</td>
<td>~5</td>
<td>Existing Facilities – handful New Facilities – handful</td>
</tr>
<tr>
<td>Demo &amp; Commercial TRL 8-9</td>
<td>100 - 200+</td>
<td>100’s-1000’s Mostly tax and rate payers</td>
<td>1 (almost)</td>
<td>New Facilities – Scaled back ~15-20 now at various stages</td>
</tr>
</tbody>
</table>
Post-Combustion CO$_2$ Capture R&D at EPRI

- **Process Simulations**
- **Materials Development**
- **Lab Tests**
- **Bench Tests**
- **Alpha Pilot (~1 MWe)**
- **Beta Pilot (~25 MWe)**
- **Pre-commercial Pilot (~150 MWe)**
- **Commercial Demo (~500 MWe)**

**TRL**
1. Process Simulations
2. Materials Development
3. Lab Tests
4. Bench Tests
5. Alpha Pilot (~1 MWe)
6. Beta Pilot (~25 MWe)
7. Pre-commercial Pilot (~150 MWe)
8. Commercial Demo (~500 MWe)
9. Demos

**Institutions**
- EPRI, VRI
- U of TX, ION*, MKS, LBNL*, UC Berkeley*
- NJIT, U Colorado*, LANL*, U of Colorado
- 3H*, U of KY, InnoSepra*
- URS*, Linde*, U of KY*
- ADA-ES*, MTR*
- National Carbon Capture Center*
- Alstom, MHI

**Technologies**
- Absorption
- Adsorption
- Membrane
- Biological/Mineral/Other

*NETL and ARPA-E

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Mountaineer Overview

• Alstom’s chilled ammonia CO₂ post-combustion capture
  – ~20-MWₑ demonstration at AEP’s Mountaineer Plant in WV
  – Designed for ~100,000 tonnes CO₂/year
  – Injection occurred in saline reservoir using two on-site wells
  – Capture started in September 2009 and storage in October 2009;
  – 51,000 tonnes captured and 37,500 tonnes stored
  – Capture project completed in May 2011, storage monitoring nearing completion

• EPRI’s role:
  – Managed collaborative (20 power companies)
  – Measured and reported on CO₂ capture performance and economics
  – Monitored storage activities and reported findings
## Performance Results: Base Case Kenosha

<table>
<thead>
<tr>
<th></th>
<th>Pre-CAP PCC Retrofit (No CO₂ Recovery)</th>
<th>Post-CAP PCC Retrofit (with CO₂ Recovery)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ Vented (100% Basis) STPD (MTPD)</td>
<td>16,950 (15,377)</td>
<td>1,649 (1,496)</td>
</tr>
<tr>
<td>CO₂ Recovered (100% Basis), STPD (MTPD)</td>
<td>-</td>
<td>15,302 (13,882)</td>
</tr>
<tr>
<td>CO₂ Recovered %</td>
<td>-</td>
<td>90%</td>
</tr>
<tr>
<td><strong>Power Generation, MW:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam Turbine Gross Output</td>
<td>815.2</td>
<td>694.7</td>
</tr>
<tr>
<td>Extraction BPST Gross Output</td>
<td>-</td>
<td>5.3</td>
</tr>
<tr>
<td>Total Turbine Generator Gross Output</td>
<td>815.2</td>
<td>700.1</td>
</tr>
<tr>
<td><strong>Auxiliary Loads, MW:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Plant Equipment Loads</td>
<td>65.2</td>
<td>64.9</td>
</tr>
<tr>
<td>CAP PCC CO₂ Recovery Loads</td>
<td>-</td>
<td>70.7</td>
</tr>
<tr>
<td>Total Consumption</td>
<td>65.2</td>
<td>135.6</td>
</tr>
<tr>
<td><strong>Net Power Export, MW</strong></td>
<td>750</td>
<td>564.5</td>
</tr>
<tr>
<td><strong>Net Plant Efficiency, % HHV</strong></td>
<td>38.4%</td>
<td>28.9%</td>
</tr>
<tr>
<td><strong>Net Efficiency Loss, Percentage Points HHV</strong></td>
<td>-</td>
<td>9.5</td>
</tr>
</tbody>
</table>
Plant Barry Overview

- MHI KM-CDR advanced amine CO₂ post-combustion capture
  - ~25-MWe demonstration at Alabama Power’s Plant Barry in AL
  - ~500 tonnes CO₂/day
  - Capture started June 2011; ~140,000 tonnes captured
  - Injection started August 2012 at 200 tonnes CO₂/day
  - Over 55,800 tonnes stored in Citronelle oilfield 20 km away
  - Plan is to continue capturing CO₂ for up to 4 more years with the goal to store more than 100,000 tonnes

- EPRI’s role:
  - Manage collaborative (20 power companies)
  - Measure and report on CO₂ capture performance and economics
  - Leading all storage activities including reporting findings
Plant Barry: CO₂ Capture Results

CO₂ Capture Rate

CO₂ Removal Efficiency

Stable operation achieving high CO₂ removal
CCS Comparative Study: Sites and Locations

- Site: Coal Creek
  - Owner: Great River Energy
  - Location: North Dakota

- Site: Powerton
  - Owner: MidWest Generation
  - Location: Illinois

- Site: Lingan
  - Owner: Nova Scotia Power
  - Location: Nova Scotia

- Site: Intermountain
  - Owner: Intermountain Power
  - Location: Utah

- Site: Bayshore
  - Owner: FirstEnergy
  - Location: Ohio
Comparison Summary

• Despite the variances in base plants, all the sites can be retrofitted with 90% post-combustion capture
  – No technical showstoppers with the available technology
  – Cogeneration lowers generating efficiency of Bayshore unit making it an unattractive capture option. (Not a reflection on CFB!)
• The capital investment required can vary considerably:
  – Approximately $2000/kW difference in the PC sites studied
• The LCOE after capture plant can vary considerably:
  – Approximately $37/MWhr difference in the sites studied
• The CO₂ avoided cost can vary between sites:
  – Approximately $30/ton difference in the sites studied
• The more advanced solvents, currently in development, lower the efficiency penalty by ~2.5 percentage points
Process Evaluations And Capture Database

Post Combustion CO2 Capture Database

- On-going activity in technical evaluations of early-stage capture processes
- Capture database on processes
- Provides an overview of the capture landscape
- Able to identify gaps, overlaps, and acceleration pathways

Carbon Capture Processes

The database contains two important elements. The first is "Carbon Capture Processes." It lists each process by developer name, process name, capture method, current technology readiness level (TRL) and the date of the last update. All of the processes can be sorted by clicking on the column headers located at the top of the table. Click once will sort the field by ascending order (A to Z, 0 to 9) and clicking again will sort by descending order (Z to A, 9 to 0). The field of processes can also be filtered by either Capture Method and/or current TRL level. Click on any part of the grid to bring up the profile for the selected capture technology.
Screening of Low-Energy Capture Adsorbents

- Compute properties (UC Berkeley and LBNL) for a database of 4+ million zeolites (Rice Univ)
- Calculate minimal energy consumption for each material (EPRI)
- Thousands of new adsorbents identified

- Most promising materials
- Very broad minimum
- \(2 \times 10^{-4} < \text{Henry’s Coefficient} < 2 \times 10^{-3}\)
- No single defining characteristic
- www.carboncapturematerials.org

Energy penalty of synthesized materials

- 30% lower energy materials relative to MEA (capture and compression)
- Synthesized materials very close to computed parasitic energy line
- Providing guidance and insights not just for new materials, but also how to reduce energy consumption further
Membrane Processes

- Models of solution-diffusion membranes for co-, cross-, and counter-current flow, with and without sweep, incorporated into ASPEN+
- Benchmarked against published results
- Use model to study effect of membrane properties on system performance to support new materials development
- Can modify models for other mechanisms, e.g., facilitated transport
Where Do We Go from Here?

- Integrate models for membranes, adsorption, and solvents into coal and gas power plant models to study hybrids and system integration to drive new materials and process development
- Actively guide development of materials based on predicted system-level performance
- Closely monitor development of capture technologies
- Identify gaps, areas to accelerate, strategic thrusts
- Establish proof of concept, lab-, bench-, pilot-, demo-, and commercial-scale
Together…Shaping the Future of Electricity