Application of a Heat Integrated Post-combustion CO₂ Capture System with Hitachi Advanced Solvent into Existing Coal-Fired Power Plant
Award Number DE-FE0007395

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University of Kentucky - Center for Applied Energy Research

http://www.caer.uky.edu/powergen/home.shtml
Presentation Outline

• Project Overview
• Milestones
• Success Criteria
• Key Findings
Project Overview

• 2 MWth (0.7 MWe) advanced post-combustion CO₂ capture pilot
• Catch and release program
• Designed as a modular configuration
• Testing at Kentucky Utilities E.W. Brown Generating Station, Harrodsburg, KY, approximately 30 miles from UKy-CAER
• Includes several UKy-CAER developed technologies
• Two solvent testing campaigns (MEA baseline and advanced H3-1)
Utility Groups in CMRG
(AEP, Duke, EPRI and LG&E KU)
Co-funding

KY DEDI
Co-funding

DOE NETL Funding

MHPSA
Solvent Provider

EPRI
TEA
3rd Party Evaluation

KMPS
Engineering Design, Fabrication, & Assembly

SMG
EH&S Permitting

Project Partners

Sub-contractors
Project Funding

$25

$20

$15

$10

$5

DOE NETL

DEDI

Project Team

CMRG

$5.77 M Cost Share From Project Team (UKRF, MHPSA & EPRI), KY DEDI and CMRG
Project Participants

DOE NETL
José Figueroa

EPRI
Abhoyjit Bhown
JR Heberle
Scott Hume
Andrew Maxson
David Thimsen

LG&E and KU
Donnie Duncan
Michael Manahan
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Elizabeth Manning
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Worley-Parsons
Mike Bartone

SMG
Clay Whitney
Patricia Mason
Amy Osborn
Sara Smith
Bea Chapin

MHPSA
Song Wu
Project Performance Dates

BP1: October 1, 2011 to January 31, 2013 (16 months)
BP2: February 1, 2013 to August 31, 2013 (7 months)
BP3: September 1, 2013 to March 31, 2015 (19 months)
BP4: April 1, 2015 to September 30, 2016 (18 months)
Project Goal and Objectives

Goal

- Develop a pathway to achieve the US DOE NETL post-combustion CCS target of 90% CO$_2$ capture with a cost less than $40/tonne CO$_2$-captured

Objectives

- To demonstrate a heat-integrated post-combustion CO$_2$ capture system with an advanced solvent
- To collect corrosion data leading to selection of appropriate materials of construction for a 550 MWe commercial-scale carbon capture plant
- To gather data on solvent degradation, water management, system dynamic control and other information during the long-term verification campaigns
- To provide data and design information for larger-scale pilot plant followed by a commercial-scale project
Technology Description

Conditions at Top of Primary Stripper
\( T \approx 200-230 \, ^\circ\text{F}, P \approx 22-50 \, \text{psia} \)

Conditions at Top of Secondary Air Stripper
\( T \approx 180 \, ^\circ\text{F}, P \approx 15 \, \text{psia} \)

Conditions at Top of Absorber
\( T \approx 100 \, ^\circ\text{F}, P \approx 15 \, \text{psia} \)
# Project Key Milestones

<table>
<thead>
<tr>
<th>BP</th>
<th>Title</th>
<th>Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Preliminary Technical and Economic Analysis that details the viable</td>
<td>12/18/12</td>
</tr>
<tr>
<td></td>
<td>technical merit of UKy-CAER CCS process for slipstream scale study</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Initial EH&amp;S report that details environmental implication of slipstream</td>
<td>11/27/12</td>
</tr>
<tr>
<td></td>
<td>operation and proposed mitigation for anticipated environmental safety</td>
<td></td>
</tr>
<tr>
<td></td>
<td>obstacles to operation, if any</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Finalize P&amp;ID for slipstream modular unit fabrication</td>
<td>5/16/13</td>
</tr>
<tr>
<td>2</td>
<td>UKy-CAER Finalize Test Plan for slipstream campaigns with completed</td>
<td>5/15/13</td>
</tr>
<tr>
<td></td>
<td>P&amp;ID specifications</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Pouring of foundations for platform for slipstream modular units setup</td>
<td>9/11/14</td>
</tr>
<tr>
<td></td>
<td>which meets engineering design load/specifications</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>KMPS fabricates slipstream modular units and delivers to host site,</td>
<td>8/28/14</td>
</tr>
<tr>
<td></td>
<td>EW Brown Generating Station, for installation</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Control Room/ Field Lab Trailer Assembled, Setup and Permitted</td>
<td>2/20/15</td>
</tr>
<tr>
<td>3</td>
<td>Tie-in piping with power plant complete</td>
<td>3/6/15</td>
</tr>
<tr>
<td>3</td>
<td>Slipstream pilot unit commissioning</td>
<td>3/31/15</td>
</tr>
<tr>
<td>4</td>
<td>MEA long term test campaign</td>
<td>1/15/16</td>
</tr>
<tr>
<td>4</td>
<td>H3-1 long term test campaign</td>
<td>7/1/16</td>
</tr>
<tr>
<td>4</td>
<td>Final Technical Economic Analysis and Final EH&amp;S Assessment</td>
<td>9/30/2016</td>
</tr>
<tr>
<td>4</td>
<td>Project Final Scientific Report</td>
<td>9/30/2016</td>
</tr>
</tbody>
</table>
**Project Key Findings**

- Process can easily capture 90% of CO\(_2\).
- Solvent regeneration energy of 1200–1750 BTU/lb CO\(_2\)-captured, ~13% lower than Reference Case 10 (RC 10).

- Solvent regeneration energy of 900–1600 BTU/lb CO\(_2\)-captured, ~36% lower than RC10.
- Secondary air stripper performs as expected.

- Ambient conditions have an impact on CO\(_2\) capture.
- Absorber liquid/gas distribution has an impact on performance.
  - Lean/rich exchanger performance is critical.
  - Elemental accumulation in the solvent needs to be monitored.

- 90% CO\(_2\) capture and low solvent regeneration energies are possible with a range of solvent concentrations.
Project BP4 Success Criteria - Achieved

A heat-integrated post-combustion CO₂ capture system with:
5-25% less energy consumption compared to the DOE Reference Case 10.

<table>
<thead>
<tr>
<th>Preliminary Experimental Results Compared to the Technical and Economic Analysis</th>
<th>Solvent Regeneration Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE Reference Case 9 (no CO₂ Capture)</td>
<td></td>
</tr>
<tr>
<td>DOE Reference Case 10 (RC 10)</td>
<td>1540 BTU/lb-CO₂</td>
</tr>
<tr>
<td>UKy-CAER CCS process MEA case, according to TEA</td>
<td>1340 BTU/lb-CO₂, 13% lower than RC 10</td>
</tr>
<tr>
<td><strong>UKy-CAER CCS process MEA case, experimental parametric campaign</strong></td>
<td><strong>1200 to 1750 BTU/lb-CO₂</strong></td>
</tr>
<tr>
<td>Range due to changing operating conditions during parametric campaign.</td>
<td></td>
</tr>
<tr>
<td>UKy-CAER CCS process H3-1 case, according to TEA</td>
<td>973 BTU/lb-CO₂, 36% lower than RC 10</td>
</tr>
<tr>
<td><strong>UKy-CAER CCS process H3-1 case, experimental parametric campaign</strong></td>
<td><strong>900 to 1600 BTU/lb-CO₂</strong></td>
</tr>
<tr>
<td>Range due to changing operating conditions during parametric campaign.</td>
<td></td>
</tr>
</tbody>
</table>

The assumptions made in the TEA seem reasonable, based on the parametric campaigns.
Project BP4 Success Criteria - Achieved

A heat-integrated post-combustion CO₂ capture system with:

Partial CO₂ recycling (10-20% of CO₂ captured) to enhance gaseous CO₂ pressure at the absorber inlet.
Project BP4 Success Criteria - Achieved

A heat-integrated post-combustion CO₂ capture system with:

- Much cooler recirculating cooling water, 3-9 °F compared to a conventional cooling tower at the same ambient conditions.
Project BP4 Success Criteria - Achieved

A heat-integrated post-combustion CO$_2$ capture system with:

An advanced solvent that has 15-20% less corrosivity than a 30 wt% MEA.

After ~100 Long-term Campaign Hours

After ~250 Long-term Campaign Hours

A = absorber location
HR = designates the hot, CO$_2$-rich amine stream
CL = designates the cold, CO$_2$-lean amine stream location
S = stripper location
Project BP4 Success Criteria - Achieved

A heat-integrated post-combustion CO$_2$ capture system with:

An advanced solvent that has 15-20% less corrosivity than a 30 wt% MEA.

H3-1 is \(~90\%\) less corrosive than MEA.
Project BP4 Key Finding

Liquid/gas distribution can significantly reduce the absorber efficiency.

Process data with constant absorber L/G, inlet CO₂ concentration, inlet amine CO₂-loading and temperature.
Project BP4 Key Finding

Liquid/gas distribution can significantly reduce the absorber efficiency.
Project BP4 Key Finding

Understanding the L/R exchanger performance is critical when comparing regeneration energies.

\[
\text{Lean/Rich Exchanger Approach Temperature} = \frac{\text{Lean, In} - \text{Rich, Out (°F)}}{20} \quad \text{L/R Exchanger Approach T}
\]

Corrected for a 20 °F

Regeneration Energy (BTU/lb-CO}_2)
Project BP4 Key Results

80 hours of thermal reclaiming removed ~ 50% of each element.

80 hours of thermal reclaiming performed between 891 and 981 run hours.

- Chromium
- Nickel
- Copper
- Iron

ICP-OES used for analysis. ICP-MS used for analysis.

30 wt% MEA Campaign Run Hours
Project BP4 Key Results

80 hours of thermal reclaiming removed ~ 50% of each element.

Cadmium and silver concentrations remained below limits of detection.

80 hours of thermal reclaiming performed between 891 and 981 run hours.

ICP-OES used for analysis.

ICP-MS used for analysis.

Cadmium and silver concentrations remained below limits of detection.
Project BP4 Key Results

Thermal reclaiming may be necessary to keep elements below the RCRA limits.

<table>
<thead>
<tr>
<th>Element</th>
<th>Average of Replicate Samples (ppm)</th>
<th>RCRA limit (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>0.82</td>
<td>5</td>
</tr>
<tr>
<td>As</td>
<td>&lt; 0.63</td>
<td>5</td>
</tr>
<tr>
<td>Se</td>
<td>3.21</td>
<td>1</td>
</tr>
<tr>
<td>Ag</td>
<td>&lt; 0.13</td>
<td>5</td>
</tr>
<tr>
<td>Cd</td>
<td>&lt; 0.63</td>
<td>1</td>
</tr>
<tr>
<td>Ba</td>
<td>&lt; 2.5</td>
<td>100</td>
</tr>
<tr>
<td>Pb</td>
<td>&lt; 0.63</td>
<td>5</td>
</tr>
</tbody>
</table>
Key Knowledge Gained

• Liquid/gas distribution can significantly reduce the absorber efficiency.

• It is important to consider the L/R exchanger performance when reporting and comparing solvent regeneration values.

• Thermal reclaiming may be needed for RCRA element management.
Technology Development Pathway

- **Proof of Concept**
  - Fundamental Thermodynamic and Kinetic Studies

- **Process Flow Diagram**

- **Process Simulation/Steam Tables**

- **0.7 MWe Fabrication and Installation**

- **0.7 MWe Process Flow Diagram Package (P&ID etc.)**

- **0.7 MWe Detailed Engineering Design**

- **Testing on 0.03 MWe (0.1 MWth) Lab-scale Unit**

- **0.7 MWe Operation**

- **Time**
  - 2008
  - 2010
  - 2012
  - 2014
  - 2016
  - 2018
  - 2025

- **Scale**

- **150 - 550 MWe Deployment**

- **10 MWe Design, Fabrication, Installation and Testing**

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Acknowledgements

José Figueroa, DOE NETL
CMRG Members
Donnie Duncan, David Link, Michael Manahan, Mahyar Ghorbanian, and Jeff Fraley, LG&E and KU
UKy-CAER Slipstream Team