Large Pilot CAER Heat Integrated Post-combustion CO$_2$ Capture Technology for Reducing the Cost of Electricity
Award Number    DE-FE0026497

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University of Kentucky - Center for Applied Energy Research

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

- Project and Process Overview
- Project Organization and Team Members
- Project Schedule and Deliverables
  - Tasks
  - Work Delegation
  - Additional Reports
    - Absorber Internals Sensitivity Analysis
    - Solvent Sensitivity Analysis
    - Technology Gap Report
  - Design – Status Update
Project Overview

• 10MWe advanced post-combustion CO₂ capture large pilot including two heat-pump loops, enhanced absorber and water wash design

• Designed as semi-modular system: free-standing and modular components

• Host site will be Louisville Gas and Electric Company’s, Trimble County Generating Station, approximately 80 miles from UKy-CAER

Project Goal and Objectives

Goal

• Develop a pathway to meet the DOE post-combustion CCS targets and bridge the gap to commercialization by showcasing the unique UKy-CAER process, advancing it from TRL 5/6 to 7/8, and to provide a platform to boost public awareness and confidence in CCS technology

Objectives

1) Detailed the design associated with capture facility including site preparation and utilities to validate the UKy-CAER mass transfer intensification and heat integration techniques for improved CCS performance, which can be applied to any advanced solvent

2) Sensitivity study on packing and solvent to select appropriate column internals and operating parameters

3) Identified twelve Technology Gaps that currently hinder commercial application of CCS technology
Project Funding and Team

Phase 1 Project Funding: $1,249,786 in total
- $999,070 from DOE NETL
- $250,716 cost share from the team

Phase 1 Period of Performance:
October 1, 2015 – September 30, 2016

UKy-CAER

0.7 MWe Project
Team Members
(DE-FE00007395)

- Koch Modular Process Systems – Original Process Equipment Manufacturer (OPEM)
- Worley Parsons – Economic Analysis, Cost Verification
- EPRI – TEA, Process & Equipment Modeling, and 3rd Party Verification
- Smith Management Group – EH&S
- CMTA – Owner’s Engineering Firm
- LG&E and KU – Host Site

10 MWe Project
Team Members
(DE-FE00024697)

- Worley Parsons – PI&D BOP Design and Cost Estimation, Economic Analysis
- EPRI – Process & Equipment Modeling, TEA, and BOP Consultation
- Smith Management Group – EH&S
- CMTA – In-house Engineering Support
- LG&E and KU – Host Site
Process Description

- Process Intensification
- Heat Integration
- Advanced Solvent
- UKy-CAER CO₂ Capture Technology
Process Description
# Phase 1: Project Schedule

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Qtr 3</th>
<th>Qtr 4</th>
<th>2016</th>
<th>Qtr 1</th>
<th>Qtr 2</th>
<th>Qtr 3</th>
<th>Qtr 4</th>
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<td>1</td>
<td>1 Budget Period 1 Project Management and Planning</td>
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<td>2</td>
<td>2 Basic Process Specification and Design</td>
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<td>2.1 Aspen modeling of base case at 10MWt scale (UKy Lead)</td>
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<td>2.2 Preliminary carbon capture system design (KMPS Lead)</td>
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<td>10/29</td>
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<td>2.3 Major equipment identification and selection (KMPS Lead)</td>
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<td>2.5 Phase 2 cost estimate (KMPS and WP Lead)</td>
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<td>2.6 Techno economic analysis (TEA) (EPRI and WP Lead)</td>
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<td>2.7 Continuously update and revise the TEA with data collected from 0.7MW UKy-CAER small-pilot (UKy, EPRI and WP)</td>
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<td>2.8 Identification of EPC candidates (WP, UKy and LG&amp;E-KU)</td>
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<td>2.9 Technology gap analysis (UKy Lead)</td>
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<td>2.10 Sensitivity study - solvent selection (UKy Lead)</td>
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<td>2.11 Sensitivity study - absorber column internal configuration determination (UKy and KMPS)</td>
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<td>2.12 CO2 compression equipment selection (UKy and WP)</td>
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<td>3 Complete EH&amp;S Evaluation</td>
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<td>3.1 Evaluation of Host Site Emission Permitting and Acquire Permit (if Necessary)</td>
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<td>3.3 EH&amp;S Assessment (SMG Lead)</td>
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<td>22</td>
<td>4 Host Site Selection and Financial Agreements</td>
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<td>23</td>
<td>4.1 Host Site Agreement Complete (UKy Lead)</td>
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<td>4.1.1 Host Site Selection (LG&amp;E-KU)</td>
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<td>4.1.2 Host Site Agreement</td>
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<td>26</td>
<td>4.2 Prepare Host Site Preparation/Integration Plan (UKy, KMPS and LG&amp;E-KU)</td>
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<td>4.3 Finalize Project Cost-Share Agreements (UKy Lead)</td>
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</table>
Absorber Internals – Sensitivity Study

- Diameter based on flooding management
  - Determined by temperature
  - Packing also affects flooding
  - Leads to underutilization of some sections of the column
## Solvent – Sensitivity Study

<table>
<thead>
<tr>
<th>Factor</th>
<th>Solvent A</th>
<th>Solvent B</th>
<th>Solvent C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Development Status</strong></td>
<td>Tests at various sites from bench and pilot-scale</td>
<td>Pilot tests at various sites</td>
<td>Tests at CAER on lab- bench- and pilot scale</td>
</tr>
<tr>
<td><strong>Energy Penalty</strong></td>
<td>Up to ≥30% savings</td>
<td>~30% savings</td>
<td>~20 - 25% savings</td>
</tr>
<tr>
<td><strong>Solvent Circulation Rate</strong></td>
<td>~35-45% reduction</td>
<td>~40% reduction</td>
<td>~30% reduction</td>
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<tr>
<td><strong>Cyclic Capacity</strong></td>
<td>~1.5X</td>
<td>~2X</td>
<td>~1.5X</td>
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<tr>
<td>Physical Properties:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) Viscosity</td>
<td>2.5 – 3X</td>
<td>3 – 3.5X</td>
<td>~1.5X similar</td>
</tr>
<tr>
<td>(b) Surface Tension</td>
<td>~0.6X</td>
<td>~1.2X</td>
<td></td>
</tr>
<tr>
<td>**Degradation Products/</td>
<td>Low thermal and oxidative degradation/Medium</td>
<td>Low thermal degradation/ Medium</td>
<td>Medium/Low</td>
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<tr>
<td>Environmental Impact**</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Technology Gap Analysis

Tear 1: Breakdown

Tear 2: Focus Areas and Technology Gaps Identified

*Points of Discharge and Management* 
- Gas Emission
- Solid
- Liquid/Slurry

*Multi-variable controls*
- Forward Feed
- Energy Estimator
- Integrated Heat

*Heat Integration*
- Plant-wide
- Flue Gas
- Sensible Heat

*Intensified Process*
- CO₂ Enrichment
- CO₂ Recycling
- Membrane Pre-concentrating

*Process Design and Enhancement*
- CO₂ Enrichment prior to Absorber
- Packing Selection
- Lean Load Stability

*Solvent Properties*
- CO₂ Enrichment prior to Absorber
- Lean Load Stability

*Advanced Manufacturing and Installation*
- Cost Effective
- Equipment Sizing vs. Energy
- CCS Internal Stripper

*Secondary Environmental Impact*
- OPEX
- CAPX

*Equipment Sizing*
- Non-fuel chemicals
- Fabrication and Construction

*Process Control and routine operation*
- Enhanced
- Mixing

*Energy Consumption*
- Mass Transfer
- Scale-up Effectiveness

*CO₂ Compression*
- In-situ Heat Management
- Smart Packing
- Intensify Mixing

Targeted Aqueous Post-Combustion CO₂ Capture Technology (90% capture and $40/ton CO₂)
Technology Gap Analysis

**Near-term technical gaps:**

1. Cost effective solvent with high stability, high cyclic capacity and fast kinetics
2. Gas/liquid distribution to prevent channel flow
3. Waste management and point of discharge (gas and liquid)
4. Equipment sizing vs. operating costs
5. Material and methods of construction
6. Process intensification
7. Unit operation to maintain the performance
8. Heat integration

**Long-term technical gaps:**

9. Smart packing
10. Appropriate absorber temperature profile
11. Heat exchange
12. Smart operations
Indication of Channel Flow

- Gas/Liquid Distribution disturbance yields channel flow
- The variation of local L/G and channel flow will lead to variation in temperature readings
- 160°F corresponds to normal operation
- The changing temperature values were caused by uneven flow or channel flow
Impact on Absorber Performance

Capture Efficiency vs. Height

- 10% channel flow at 50% conversion
- 90% normal flow at 99.5% conversion
- The overall conversion of 95% is equivalent at \( h/H = 0.5 \)

Effect of 10% Channel Flow:
- Equivalent to 50% reduction in height/stages
## Host Site Consideration

<table>
<thead>
<tr>
<th>Type</th>
<th>Proposed 10 MWe Pilot</th>
<th>Current 0.7 MWe Pilot</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>Out of Plant</td>
<td></td>
<td></td>
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<tr>
<td>Land</td>
<td>1-2</td>
<td>0.1</td>
<td>acres</td>
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<tr>
<td>Electric Design Load</td>
<td>2,500</td>
<td>150</td>
<td>kW</td>
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<tr>
<td>Flue Gas Feed</td>
<td>100,000</td>
<td>6,871</td>
<td>lbs/hr</td>
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<tr>
<td>Plant Water</td>
<td>25</td>
<td>1.5</td>
<td>gpm</td>
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<tr>
<td>Superheated Steam</td>
<td>42,000</td>
<td>3,000</td>
<td>lbs/hr</td>
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<tr>
<td>Instrument Air</td>
<td>500</td>
<td>100</td>
<td>scfm</td>
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<tr>
<td>Plant Air</td>
<td>Not significant during normal operation</td>
<td></td>
<td></td>
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<tr>
<td>Return to Plant</td>
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<tr>
<td>Flue Gas Condensate/Soda</td>
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<tr>
<td>Ash Waste</td>
<td>40</td>
<td>2.8</td>
<td>gpm</td>
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<td>Flue Gas to Stack</td>
<td>160,000</td>
<td>11,000</td>
<td>lbs/hr</td>
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<tr>
<td>Steam Condensate Return</td>
<td>42,000</td>
<td>3,000</td>
<td>lbs/hr</td>
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<td>Miscellaneous</td>
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<td>Solvent Supply</td>
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<td>0.3</td>
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<td>Solid Waste</td>
<td>150</td>
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<td>kg/day</td>
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<td>Air Emissions (absorption reagent)</td>
<td>5</td>
<td>0.5</td>
<td>lbs/hr</td>
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### Daily Estimates

- **Flue Gas Feed:** 1,500 tons/day
- **Steam Used:** 500 tons/day
- **CO₂ Removed:** 240 tons/day
LG&E Trimble County Generating Station

- 2,200 acres near Bedford, Ky
- Lowest cost coal fired unit in LG&E/KU territory and provides base load power
- Pollution Controls
  - Low NOx burners
  - SCR
  - Wet FGD
  - Dry ESP
  - Lime Injection
  - Baghouse
- **Host Site Agreement signed and submitted in June**

Large Pilot 10MWe CCS Location

CCS Specification and Design

Highlighted Tasks and Accomplishments

- Scale-Up and System Design (KMPS and UKy)
- Host Site Survey and BOP Design (WP, LG&E-KU, UKy)
- Phase 2 Cost Estimate (KMPS, WP)
CCS Specification and Design

Highlighted Tasks and Accomplishments

- Scale-Up and System Design (KMPS and UKy)
- Host Site Survey and BOP Design (WP, LG&E-KU, UKy)
- Phase 2 Cost Estimate (KMPS, WP)
BOP Design
BOP Design
**Advantage of the UKy-CAER Process using the Hitachi Advanced Solvent***:

- A lower COE by $19.6/MWh, a 13.3% reduction, equivalent to a 29.5% incremental reduction
- A lower LCOE by $24.81/MWh, also a 13.3% reduction
- A lower cost of CO$_2$ captured by $12.96/tonne CO$_2$, a 19.5% reduction
- A lower cost of CO$_2$ avoided by $28.10/tonne CO$_2$, a 29.3% reduction

*Advanced solvent analysis is based on the H3-1 solvent*
EH&S Evaluation

- Evaluation based on UKy-CAER small pilot research, literature review and solvent suppliers
- Recommended appropriate storage measures for chemicals
- Recommended proper PPE and handling methods
- Toxicity is minor for solvents:
  - Irritation only after direct contact (no ecotoxicity)
- Continue monitoring for nitrosamines as those compounds pose significant human risk even at low concentrations
- No significant EH&S risks identified to affect implementation of the proposed project
Summary

• Phase 1 Completed
  • Briefs and Reports (submitted before 3/31/16)
    • TEA
    • Technology Gap Assessment
    • EH&S Report and Environmental Questionnaires
    • Topical Report on Pilot Plant and Proposal for Phase 2
    • Design Package Topical Report
    • Solvent and Absorber Column Internals Sensitivity Analysis
    • Quarterly Reports
  
  • Project Cost Share agreements and Host Site agreement
    (submitted on 6/30/2016)

• Phase 2 begins 10/1/2016, if awarded
Technology Development Pathway

- **Scale**
  - 0.7 MWe Operation
  - 0.7 MWe Process Design Package (P&ID etc.)
  - 0.7 MWe Fabrication and Installation
  - 10 MWe Design, Fabrication, Installation and Testing
  - 150 - 550 MWe Deployment

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

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

- **Process**
  - Test on 0.03 MWe (0.1 MWth) Lab-scale Unit
  - Process Simulation/Steam Tables
  - 0.7 MWe Detailed Engineering Design

- **Deployment**
  - 0.7 MWe Operation
Acknowledgements

• DOE NETL: Bruce Lani and David Lang

• Carbon Management Research Group (CMRG): David Link, Doug Durst, Curtis Sharp, Michael Kennedy, and Abhoyjit Bhown

• LG&E and KU: David Link, Michael Manahan, Mayhar Ghorbanian, Jeff Joyce, and Jim Dimas

• WorleyParsons: Jim Simpson, Yonie Tamayo and Lawrence Grybosky

• Smith Management Group: Clayton Whitney, Daniel Hardin, Stewart McCollam and Sarah Carty

• Koch Modular Process Systems: John Rec, Lindsay Turner, Stan Lam and Elizabeth Manning

• Electric Power Research Institute: Abhoyjit Bhown and J.R. Heberle

• CMTA Engineers: Kevin Mussler

• University of Kentucky: Don Challman, Katherine Adams, Rodney Andrews