UKy-CAER Heat-integrated Transformative CO₂ Capture Process in Pulverized Coal Power Plants

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http://www.caer.uky.edu/powergen/home.shtml
Executive Summary

- Process oriented technology
- Applicable with any 2nd generation solvent
- All sub-technologies/approaches have been proven
- Experienced team assembled
- Ongoing relationship with host site utility
- Firm financial commitment received from State of Kentucky (Executive Branch and Legislators), University senior management and utilities

<table>
<thead>
<tr>
<th>Process Intensification</th>
<th>Technical Achievement</th>
<th>UKy-CAER History of Experimentally Demonstrated Success</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO₂ Recycling</td>
<td>2012 Bench, 2015-2017 Small Pilot</td>
</tr>
<tr>
<td></td>
<td>Discretized Packing Selection</td>
<td>Common Industrial Distillation Practice, 2013 Modelling, 2017 Bench for CO₂ Capture</td>
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<tr>
<td></td>
<td>Pump Around</td>
<td>2009 Bench, 2015-2017 at Small Pilot</td>
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<tr>
<td></td>
<td>Solvent Recovery System</td>
<td>2015 at Bench, 2018 Small Pilot (planned)</td>
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<tr>
<td>System Integration &amp; Heat Recovery</td>
<td>Two-stage Stripping</td>
<td>2010 Bench, 2015-2017 Small Pilot</td>
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<td></td>
<td>Exergy Loss Minimization</td>
<td>2015 Modelling</td>
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<td></td>
<td>Smart Controls</td>
<td>2016-2017 at Small Pilot</td>
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<tr>
<td></td>
<td>Hybrid System</td>
<td>2014 Bench, 2018 Small Pilot (planned)</td>
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</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
<th>Year Partnering with UKY</th>
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</thead>
<tbody>
<tr>
<td>LG&amp;E-KU</td>
<td>Host site</td>
<td>2005</td>
</tr>
<tr>
<td>KMPS</td>
<td>ISBL</td>
<td>2009</td>
</tr>
<tr>
<td>WP</td>
<td>OSBL</td>
<td>2011</td>
</tr>
<tr>
<td>CCSL</td>
<td>Solvent Supplier</td>
<td>2013</td>
</tr>
<tr>
<td>EPRI</td>
<td>TEA and 3rd Verification</td>
<td>2008</td>
</tr>
<tr>
<td>SMG</td>
<td>EIV</td>
<td>2010</td>
</tr>
<tr>
<td>HCERI</td>
<td>Engineering Aspect</td>
<td>2010</td>
</tr>
<tr>
<td>UT</td>
<td>Solvent &amp; Emission Aspect</td>
<td>2008</td>
</tr>
<tr>
<td>Trimeric</td>
<td>Cost and Engineering Audit</td>
<td>2010</td>
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Project Overview
Funding (DOE and Cost Share) and Project Performance Dates

<table>
<thead>
<tr>
<th>Project Funding Profile</th>
<th>Government Share</th>
<th>Cost Share</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Funding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$941,997</td>
<td>$235,553</td>
<td>$1,177,550</td>
</tr>
<tr>
<td>Cost share %</td>
<td>80.00%</td>
<td>20.00%</td>
<td>100%</td>
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</tbody>
</table>

04/01/18 to 07/31/19
16 Months in Duration
One Budget Period
Phase II Application Due 3/31/2019
Project Overview
Project Participants and Responsibility

Phase I Task Assignment and Contribution to Phases II and III
UKy-CAER

- Trimeric and HCERI
  - Engineering Audit and In-house Support

- KMPS
  - CCS Design, Fabrication and Module Assembly

- WP
  - System Integration and Construction
    - Site and Available Utilities
    - OHSA, EH&S, State Requirements

- Host Site
  - LGE Trimble County Plant

10 MWe Heat Integrated CCS Plant

- EPRI
  - TEA and Third-party Evaluation

- MTR
  - Membrane

- CCSP
  - CCS Design, Fabrication and Module Assembly

- UTA
  - Emissions

- UTA
  - System Integration and Construction
    - Site Survey, Tie-in Design, Installation, Commissioning

- SMG
  - EIV

- Chemical Handling PPE and SOP EH&S Report

- NEPA

- Flue Gas and Utilities Operation Assistance, Permit

- Updated Economic/Cost and Support for Sensitivity Analysis

- OHSA, EH&S, State Requirements

- Site Survey, Tie-in Design Preparation, Installation, Commissioning
Project Overview

Overall Project Objectives

Advance the UKy-CAER post-combustion CO₂ capture technology, demonstrating an achievable COE with CCS of < $30/tonne CO₂ captured when natural gas is used to provide CCS electricity and steam.

Phase I Goals

1) Reinforce the cohesive project team including technology development; solvent development; EH&S; engineering design, fabrication, and construction management; technology commercialization and end-user utilities.

2) Select and secure a host site and CCS location.

3) Update H&M balances with most recent small-scale experimental data and chemical composition to complete and improve accuracy of an EIV and process design package, including the cost and schedule.

4) Secure commitments from a process design firm, NEPA contractor, technology partners and vendors.

5) Update Phases II and III preliminary costs and schedules.

6) Secure commitments for Phases II and III cost share.
**Technology Background**

**UKy-CAER CO₂ Capture Technology**

- **Process Intensification**
- **Two-Stage Solvent Regeneration**
- **System Integration and Heat Recovery**
- **Advanced Solvent**

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**Diagram:**

- **GAS**
- **WATER**
- **STEAM**
- **WASH**
- **CO₂ DEPLETED FLUE GAS**
- **CO₂ PRODUCT STREAM**
- **CO₂ LADEN AIR RECYCLE TO BOILER**

**Components:**

- **DIRECT CONTACT TOWER**
- **ABSORBER**
- **SOLUTION RECOVERY COLUMN**
- **SORBENT RECOVERY COLUMN**

**Labels:**

1: COOLING WATER SUPPLY
2: COOLING WATER RETURN
3: STEAM SUPPLY
4: CONDENSATE RETURN

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**NETL CO₂ Capture Technology Project Review Meeting**

August 13-17, 2018
A Confirmed Heat Integrated PCCC Technology
Robustness Advantage

Versatile

Four solvent campaigns complete with the fifth underway

Steady state at 90% capture achievable within 2-3 hours after a cold startup

Demonstration of amine concentration maintenance and water balance between liquid desiccant and amine loops

Flexible

Typical operations include daily process start-up and shut down with 24-hour per day, 7-day per week operations demonstrated 89% trouble-free startups in 2016 during non-freezing weather 85% trouble-free startups in 2017 during non-freezing weather
All at 90% coal flue gas capture rate and CO₂ compression to 2200 psia.

The UKy-CAER CCS process with an advanced solvent can deliver:
- COE of $119.07/MWh
- Cost of CO₂ captured at $34.51/tonne, excluding TS&M

With a duel fuel system, UKy-CAER technology can deliver:
- COE of $106.52/MWh
- Cost of CO₂ captured, excluding TS&M, of $25.26/tonne CO₂
Technology Background

Challenges We Will Address

Absorber Liquid/Gas Distribution and Redistribution

Absorber performance is significantly reduced with liquid/gas maldistribution.

Thermal Compression and L/R Exchanger Size

Benefits associated with thermal compression reducing the H₂O/CO₂ ratio at the stripper outlet, lowering the reboiler duty are not realized if the L/R exchanger is not properly sized.

Waste Quantity Minimization

Absorber Effectiveness and Column T Profile

With an ideal column temperature profile, the average CO₂ absorption rate can be increased significantly.
Technical Approach/Project Scope
Experimental Design and Work Plan

2000+ Operational Hours

Air Emissions
Amine loss and gas emission evaluated to update commercial scale emissions species and volume estimates

Maintaining Solvent Quality
Heat stable salt formation
RCRA element accumulation
Reclaiming effectiveness
Waste minimization

Corrosion
Lower cost materials evaluated with/without non-metal coatings

Advanced Controls
Fast response variables, such as the CO₂ product flow paired with the absorber gas-side calculated CO₂ capture efficiency
Model predictive control
# Technical Approach/Project Scope

## Project Schedule

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Start</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Qtr 1</td>
<td>Qtr 2</td>
<td>Qtr 3</td>
</tr>
<tr>
<td>1 Project Management and Planning</td>
<td>Sun 4/1/18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Host Site Agreement Amendment</td>
<td>Sun 4/1/18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Aspen Plus® Model Simulation Creation and Update</td>
<td>Sun 4/1/18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Project Schedule and Cost Estimate</td>
<td>Sun 4/1/18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Environmental Information Volume</td>
<td>Sun 4/1/18</td>
<td></td>
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</tr>
</tbody>
</table>
Technical Approach/Project Scope

Key Milestones
1. Multi-party NDA in Place
2. Host Site Agreement Amended
3. Completed EIV
4. Phase I Topical Report Complete

Project Success Criteria
1. A commercial scale CCS model integrated with the power generation unit model using the CCSL solvent with good agreement with the UKy-CAER 0.7 MWe small pilot experimental data.
2. An EIV identifying and estimating all potential waste stream emissions (gas, liquid, solid) from the 10 MWe large pilot facility and solvents, an assessment of the emissions properties for safety, handling, and toxicology, and an accidental release procedure for the large pilot facility.
3. Confirmation that schedule and cost will meet or exceed initial estimates.
# Technical Approach/Project Scope

## Project Risks and Mitigation Strategies

<table>
<thead>
<tr>
<th>Description of Risk</th>
<th>Probability (Low, Moderate, High)</th>
<th>Impact (Low, Moderate, High)</th>
<th>Risk Management Mitigation and Response Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase I Management Risks</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subcontract Agreement Delay</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Dedicated UK staff will be identified.</td>
</tr>
<tr>
<td>Subcontractor Financial Stability</td>
<td>Low</td>
<td>Moderate</td>
<td>Alternate subcontractors will be identified.</td>
</tr>
<tr>
<td><strong>Phase I Resource Risks</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Host Site Withdraws Support</td>
<td>Low</td>
<td>High</td>
<td>Several host sites have expressed interest in partnering with UKy-CAER for the large pilot project in addition to LG&amp;E and KU. If necessary, UKy-CAER will continually seek new candidates.</td>
</tr>
<tr>
<td>Solvent Supplier Withdraws Support</td>
<td>Low</td>
<td>High</td>
<td>The UKy-CAER CCS is flexible enough to use most advanced solvents. While the CCSL solvent is the prime solvent for the project, two alternative solvents with suppliers on the project team have been identified to mitigate risk to the project: the HCERI and the CAER solvents.</td>
</tr>
<tr>
<td><strong>Phase I Technical Risks</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>Low</td>
<td>Moderate</td>
<td>An alternative solvent will be used or a system modifications will be made, depending on the environmental problem identified.</td>
</tr>
<tr>
<td>Process Model does not Accurately Reflect Solvent Properties</td>
<td>Low</td>
<td>Moderate</td>
<td>The CCSL solvent has been successfully modeled with ProTreat® and this will be used as an alternate modeling software.</td>
</tr>
</tbody>
</table>
Progress and Current Status of the Project

- Team Assembled
- TAB Membership Invitations Extended
- Multi-party NDA in Place
- Aspen Plus® Thermodynamic Model of the CCSL Solvent Complete
- Aspen Plus® Model of Process Complete
- ISBL Preliminary Design and Cost Estimate on Schedule to be Complete by 2/2019
- OSBL Preliminary Design and Cost Estimate on Schedule to be Complete by 2/2019
- EIV Preparation on Schedule to be Complete by 3/2019
Plans for Future Testing/Development/Commercialization

- **Proof of Concept**
- Fundamental Thermodynamic and Kinetic Studies
- **2008**

- **Concept**
- **2010**

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

- **0.7 MWe Process Flow Diagram**

- **2012**

- **Process Simulation/Steam Tables**

- **2014**

- **0.7 MWe Detailed Engineering Design**

- **2016**

- **0.7 MWe Fabrication and Installation**

- **2018**

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

- **2025**

- **150 - 550 MWe Deployment**

- **540 MWe Deployment**
Acknowledgements

**U.S. DOE NETL**: Bruce Lani and Lynn Brickett

**LG&E and KU**: David Link and Mahyar Ghorbanian

**CMRG**: LG&E and KU, Duke Energy and EPRI

**CCSL**: Prateek Bumb, Avinash Patkar, Will Shimer and Gopi Kiran

**EPRI**: Abhojyit Bhown

**HCERI**: Shiwang Gao and Edward Wu

**MTR**: Tim Merkel and Ivy Huang

**UTA**: Gary Rochelle