Update on Pilot Unit of Sorbent Based Post-Combustion CO₂ Capture
Project # DE-FE0012870
Dr. Jeannine Elliott and Dr. Fei Yi

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Project Objectives

• The objective is to develop solid sorbent capture technology that captures CO₂ at less than $40 per tonne without TS&M.

• Demonstrate alkalized alumina sorbent technology under realistic conditions at 0.5 MWₑ (~10 tpd) scale in National Carbon Capture Center (NCCC) to collect data necessary for scale up to next level plant.
Project Scope

DoE Project DE-FE0012870
Funding - Total Project $6,480,377

- **Budget Period 1: Optimization & Design**
- **Budget Period 2: Construction & Installation**
  - Pilot Unit Construction
  - Sorbent Production Scale-up and Quality Assurance
  - Pilot Unit Installation
- **Budget Period 3: Shakedown & Operation**
TDA’s Approach

TDA Research has developed:

- A low-cost, alkalized alumina adsorbent
- A CO₂ capture process designed specifically for this sorbent (A unique CO₂ capture process to run adsorption and regeneration at near isothermal conditions)
- Multiple patents on the process

Advantages over moving bed

- Moving bed had expensive conveyors, although the beds would be smaller
- Selected Multiple fixed bed design
  - Basic duct work
  - Low cost construction
  - Simple bed design
  - Eliminates parasitic power needed to move the sorbent
- Lower overall cost than moving beds
Pilot Unit System
0.5 MW Demonstration

2 Sorbent Bed Trailers
• Sorbent trailers house 10 sorbent beds (5 in each trailer) and manifold piping
• Each trailer is insulated and heated to provide an isothermal environment

Service Unit/Instrument Trailer
• Pressure, temperature, and flow control for process gases
• Each process gas routed to both sorbent bed trailers
• Houses the control system and all electrical components for power allocation
• A full suite of on-board analyzers to evaluate system performance
Preliminary Techno-Economic Analysis

- Integration with greenfield supercritical 550 MW coal fired power plant
  - CO₂ feed 13%
- Analysis followed DoE guidelines
- Work performed with University of California at Irvine (UCI)
  - Dr. Ashok Rao of Advanced Power and Energy Group developed ASPEN model around process and determine cost of CO₂ capture
TEA on Improved Process

- Based on experimental data (SV, steam usage) for optimized process
- Boiler Feed Water used to heat flue gas (coal derived heat)
- Included costs of 10 beds, air blower, and condenser on air purge outlet
- Optimized design system demonstrated in bench-scale experiments has $41.2/tonne CO₂ capture without TS&M and $58/tonne CO₂ avoided

<table>
<thead>
<tr>
<th>CO₂ Capture Technology</th>
<th>No Capture Case 11</th>
<th>Amine Capture Case 12</th>
<th>TDA Case 3</th>
<th>TDA Case 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Captured, %</td>
<td>0</td>
<td>90</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Steam Turbine Power, KWe</td>
<td>580,400</td>
<td>662,800</td>
<td>658,313</td>
<td>658,848</td>
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<tr>
<td>Total Auxiliary Consumption, KWe</td>
<td>30,410</td>
<td>112,830</td>
<td>108,003</td>
<td>108,848</td>
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<tr>
<td>Net Power Output, KWe</td>
<td>550</td>
<td>550</td>
<td>550</td>
<td>550</td>
</tr>
<tr>
<td>% Net Plan Efficiency, HHV</td>
<td>39.3</td>
<td>28.4</td>
<td>29.51</td>
<td>29.85</td>
</tr>
<tr>
<td>As-received coal feed, kg/h</td>
<td>185,759</td>
<td>256,652</td>
<td>247,258</td>
<td>244481</td>
</tr>
<tr>
<td>Natural Gas Feed, kg/h</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Raw Water Withdrawal, min³/min</td>
<td>20.1</td>
<td>38.1</td>
<td>34</td>
<td>33.8</td>
</tr>
<tr>
<td>1st year cost of electricity (COE), $/MWh, 2007$</td>
<td>58.9</td>
<td>100.9</td>
<td>92.8</td>
<td>94.7</td>
</tr>
<tr>
<td>1st year CO₂ capture cost w/o TS&amp;M, $/tonne, 2007$</td>
<td>-</td>
<td>42.1</td>
<td>38.0</td>
<td>37.0</td>
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<tr>
<td>1st year CO₂ capture cost w/o TS&amp;M, $/tonne, 2011$</td>
<td>46.9</td>
<td>42.4</td>
<td>41.2</td>
<td></td>
</tr>
<tr>
<td>1st year CO₂ avoided cost w/o TS&amp;M, $/tonne, 2011$</td>
<td>68.0</td>
<td>59.1</td>
<td>58.0</td>
<td></td>
</tr>
</tbody>
</table>

\[
\text{CEPCI(2011)/CEPCI(2007)} = \frac{585.7}{525.4} = 1.11
\]

\[
\text{Cost of CO₂ Captured} = \frac{(COE_{With \, CC} - COE_{Without \, CC})}{\text{CO₂ Captured}}
\]

CO₂ Capture cost = $41.2/ tonne, $2011
Pilot Unit Construction
Pilot Unit Skids

- Trailer #1
- Service unit
- Trailer #2
- Instrument unit
- Sorbent vessel

Dimensions:
- 11.5 ft (height)
- 32 ft (width)
- 40 ft (length)
Fabrication of Pilot Unit

- Sorbent Trailers and Gas conditioning units were fabricated by Spring Fabrication, Inc. (200,000 sq. ft. facility, 220 employees) in Colorado Springs.

- Instrument control unit was fabricated at TDA.
Fabrication of Pilot Unit

Sorbent Trailers
Fabrication of Pilot Unit

Sorbent Trailers
Fabrication of Pilot Unit

The instrument and control cabinets made by TDA

High Voltage Power Enclosure

Instrument Unit / Electronics Cabinet
Fabrication of Pilot Unit

Skids set in place at Fabrication shop for FAT testing
Factory Acceptance Testing

Tests successfully completed:

- Turn on/off heaters, blowers
- Verify and control each pneumatic valve on the reactors and service unit
- Check analyzer signals to the control box
- Cycle the whole system with basic cycling program
- Confirmed beds hold pressure

Utility used: 480 V power, 90 psig shop air

Max Phillips and Greg McKinnon from Southern CO visited during FAT on October 11, 2017
Test Plan

• The primary objective of the pilot unit field tests is to demonstrate the technical merits of this sorbent-based CO$_2$ capture process. Flue gas = 5000 lb/hr for 0.5 MW.

• Optimize cycle parameters to achieve the following goals:
  – Minimize the amount of regeneration steam used
  – Maximize the flue gas flow rate through the TDA system
  – Minimize purge gas flow

• We will also evaluate the process under both coal derived flue gas and simulated natural gas conditions (diluted flue gas).

• Demonstrate cyclic operation at steady state using the optimized adsorption cycle scheme.

• Evaluation at 90% capture and less than 90% capture rate.
Sorbent Production and Testing

- Sorbent was made by Porocel in Little Rock, AR
- Production was conducted over 3 weeks
- 22 supersacks and 135 bags (45 lbs) produced
Pilot Unit Sorbent Characterization

- Material scaled up on 6" extruder is denser
- Sorbent delivered to NCCC in early November 2017

<table>
<thead>
<tr>
<th>Batch number</th>
<th>Bulk density (g/ml)</th>
<th>BET Surface Area (m²/g)</th>
<th>BJH Adsorption Cumulative Pore Volume of pores (cm³/g)</th>
<th>Adsorption Average Pore Diameter (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot Unit</td>
<td>0.84</td>
<td>99.3</td>
<td>0.3</td>
<td>12.0</td>
</tr>
<tr>
<td>Batch 1</td>
<td>0.728</td>
<td>84.3</td>
<td>0.214</td>
<td>10.15</td>
</tr>
<tr>
<td>TDA-812</td>
<td>0.616</td>
<td>145</td>
<td>0.53</td>
<td>10.3</td>
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</tbody>
</table>

- Physical properties were within expected range
Single Bed Adsorption Breakthrough

• Samples of multiple bags and composites of all bags were evaluated at TDA
• Sorbent performance of composite samples were similar to previous scale up batch made at Porocel (Batch #1)
Skid Installation

Four trucks shipped the three skids plus connecting piping and instruments from Colorado to Alabama in October 2017.
Pilot Unit installed at Pilot Bay #2 at the NCCC PC4 per approved lift plan
Installation at NCCCC

October 23-24, 2017
Sorbent Loading
Sorbent Loading at NCCC

• NCCC assisted in sorbent loading by providing the crane and labor to remove and reinstall pilot unit panels and vessel headers. November 2017
System Integration
System Integration

• NCCC completed inter-connection for the flue, steam, cooling water, drain lines, pneumatic air, electrical and signal connections.

• TDA reinstalled pneumatic valve boxes to operate vessel mounted shut-off valves.

• TDA reinstalled all analyzers and instruments contained within the analyzer cabinet and terminated the heat tracing on all sample lines to keep gas samples in the gas phase.

• TDA vacuumed out bottom valve headers for dust collected from sorbent loading.
Shakedown

• A pre-operation safety review on site at NCCC conducted on January 9, 2018.
• The control system was powered up and run in 24-hour mode.
• The following items have been checked out: manual control for the blowers and heaters, open/close for all the pneumatic valves, the PID control for 13 heat tracing zones, safety monitoring, reactor sequencing, real-time data processing and historical data log.
• Issues related to hard freeze in January were addressed.
• AC unit for electronics box was damaged and was shipped back to manufacturer for repaired.
• Gaston 5 plant shutdown end of February through mid March due to low loading. No steam or flue gas were available during this time.
Additional Sorbent Evaluation

- We used the time during AC repair and flue gas shutdown to further evaluate the pilot unit sorbent.
- We found the scaled-up sorbent degraded significantly during extended cycling.
- This degradation is not acceptable and had not happened with any earlier sorbent batches.

<table>
<thead>
<tr>
<th>Sorbent</th>
<th>CO₂ loading, wt%</th>
<th>CO₂ capture rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batch 1</td>
<td>0.82</td>
<td>89.3%</td>
</tr>
<tr>
<td>Pilot Batch</td>
<td>0.31</td>
<td>66.0%</td>
</tr>
</tbody>
</table>

- Additional characterization determined the sorbent was not fully calcined. Humidity had impacted QA/QC checks.

TDA Bench-scale test unit
- Ten 400 cc Fix Bed Reactors with continuous Adsorption and Regeneration
- Automated control
Sorbent Reprocessing

- Laboratory testing demonstrated that the sorbent could be reprocessed to achieve good performance and stability
- Experiments were conducted to develop the best reprocessing method
- Reprocessing demonstrated in laboratory testing at TDA and Porocel
- Lab batch validated in cycling tests
- Sorbent was unloaded by J.V. Industrial Companies and returned for retreatment

![Graph showing capture rate (%) vs. hours of cycling with and without reprocessing]

- With reprocessing:
  - Sorbent not recalined
  - First reprocessing attempt
  - Reprocessed at TDA
  - Reprocessed at Porocel - lab batch

Steam flow rate: 1.01 SLPM
Pilot Unit Sorbent Reprocessing and Testing

- Pilot unit sorbent successfully reprocessed by the manufacturer in late June 2018
- Sorbent was evaluated at TDA for 350 hours of cycling
  - Performance stabilized by reprocessing
- Some loss of sorbent was unavoidable in reprocessing (breakage during removal, loss in handling, shrinkage in retreatment etc.)
- Reprocessed sorbent was loaded into 8 beds at the pilot unit
- 2 beds filled with modified commercial alkalized alumina (lower performing)
Current Status

- Sorbent reloaded mid-July 2018 and system closed up
- Shakedown continued until NCCC Gaston U5 shutdown on July 25, 2018
- Aug 17 - November 1 outage planned at NCCC
- Pilot Unit Operation to start in November
  - Parametric testing
  - Steady state testing

National Carbon Capture Center located at the E.C. Gaston power plant (Wilsonville, Alabama)
Summary

– Pilot-Unit construction and FAT testing completed.
– Pilot-Unit sorbent produced.
– System delivered and installed at NCCC. Sorbent loaded into 10 reactors.
– System integrated into NCCC site at Pilot Bay #2.
  • NCCC completed inter-connection for the flue, steam, cooling water, drain lines, pneumatic air, electrical and signal connections.
– Shakedown performed in January/February 2018. NCCC shutdown late February (no steam/flue gas).
– Pilot-Unit Sorbent batch showed expected performance initially. Extended cycling test run at TDA showed that the sorbent had poor stability.
– The sorbent was unloaded, reprocessing conditions defined, and the sorbent was successfully retreated by the manufacturer.
– The sorbent is reloaded at NCCC. Work will continue when current outage is completed November 2018.
Acknowledgements

– Project funding provided under DoE Contract # DE-FE0012870
– DoE: Andy O’Palko and Lynn Brickett
– NCCC: Tony Wu