Pilot Test of Novel Electrochemical Membrane System for Carbon Dioxide Capture and Power Generation
(DE-FE0026580)

Presented to:
2018 NETL CO₂ Capture Technology Project Review Meeting
Pittsburgh, PA
August 13-16, 2018
Electrochemical Membrane (ECM) Carbon Capture Pilot Plant Project

• Design an ECM-based carbon capture pilot plant (60 T/D) prototypical of a commercial unit
• Fabricate and install the pilot-scale plant at a coal facility
• Conduct pilot plant tests, demonstrating >90% capture (>95% CO₂ purity)
• Complete Techno-Economic Analysis (TEA) of ECM carbon capture applied to a 550 MW baseline supercritical PC plant, achieving 30% less COE compared to amine scrubbers
• Determine Environmental, Health and Safety (EH&S) requirements of ECM Carbon Capture plants
Project Team Structure

- TEA Support (review ECM system design, equipment and plant costing)
- Pilot system key equipment specification and selection
- Flue gas clean-up system design
- Interconnection system design
- Demonstration site host
- Construction management
- Permitting support
- Pilot plant installation and test support
- Site construction
- Plant installation
- Maintenance support
- Engineering Support
  - Instrumentation
  - Electrical
Pilot Demonstration Site

- James M. Barry Electric Generating Station, Alabama Power/Southern Co.
- Location: Bucks, AL
- Nameplate Capacity: 2,370 MWe, Mix of Coal and Natural gas
Work Breakdown Structure

Pilot-Scale ECM System Testing
Project Work Breakdown Structure

- Task 1: Preliminary Techno-Economic Analysis & EH&S Assessment
  - Task 1.1: Project Management and Planning
  - Task 1.2: Briefings and Reports
- Task 2: Pilot-Scale ECM System Design
  - Task 2.1: Systems Analysis
  - Task 2.2: Economic Analysis
  - Task 2.3: Prelim. EH&S Assessment
- Task 3: ECM System Fabrication & Installation
  - Task 3.1: Detailed Process Design
  - Task 3.2: Equipment Specifications and Selection
  - Task 3.3: Detailed Mechanical Design
  - Task 3.4: Detailed Electrical Design
  - Task 3.5: Tie-In Engineering
- Task 4: Final Design & Documentation
  - Task 4.1: Final Design & Documentation
  - Task 4.2: ECM Module Fabrication
  - Task 4.3: BOP Equipment Fabrication
  - Task 4.4: BoP Skid Fabrication
  - Task 4.5: Factory Acceptance Testing
  - Task 4.6: System Installation
- Task 5: ECM System Commissioning, and Testing
  - Task 5.1: System Commissioning
  - Task 5.2: System Testing
- Task 6: Decommissioning
- Task 7: Final Techno-Economic Analysis & EH&S Assessment
  - Task 7.1: Systems Analysis Update
  - Task 7.2: Economic Analysis Update
  - Task 7.3: Final EH&S Assessment

<table>
<thead>
<tr>
<th>All Budget Periods</th>
<th>Budget Period 1</th>
<th>Budget Period 2</th>
<th>Budget Period 3</th>
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### Project Schedule Overview

Completed BP1 tasks and submitted continuation application to initiate BP2

<table>
<thead>
<tr>
<th></th>
<th>BP 1</th>
<th>BP 2</th>
<th>BP 3</th>
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<tbody>
<tr>
<td><strong>Techno-Economic Analysis (TEA) &amp; EHS</strong></td>
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<td>Initial</td>
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<td>Update</td>
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<td><strong>Pilot Plant BOP Design</strong></td>
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<td><strong>Pilot Plant Fabrication</strong></td>
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<td>BOP Equipment</td>
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<td>ECM Module</td>
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<td>Factory Acceptance Tests</td>
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<tr>
<td>Install</td>
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<td><strong>Pilot Plant Operation</strong></td>
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<td>Field Acceptance Testing and Commission</td>
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<td>Test &amp; Evaluation</td>
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<tr>
<td>De-Commission</td>
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**Project Budget:** $34.12 MM  
DOE Share: $15MM, Cost Share: $19.12 MM
Electrochemical Membrane (ECM) Technology Overview
ECM Operating Principle

The driving force for CO₂ separation is electrochemical potential, not pressure differential across the membrane.

Net Results

- Simultaneous Power Production and CO₂ Separation from Flue Gas of an Existing Facility
- Excess Process Water Byproduct
- Complete Selectivity towards CO₂ as Compared to N₂
Modular Technology

ECM Assembly
Using Planar Cells (~9000 cm²)

ECM Stack
(Using ~400 ECM Assemblies)

ECM Module
(4 Stacks)

Modules Utilized in Large-Scale Applications

Enclosed Module
ECM Pilot Plant Development
- Re-application of commercially-proven fuel cell technology for CO₂ Capture
- Opportunity for Co-Production of Syngas or H₂
Modes of Operation

1. 90% Carbon Capture from Coal-fired Boiler (CFB) Flue Gas (FG)
2. Stand-alone: Power generation only, no flue gas processed
3. transient/parametric evaluation:
   - 70% Carbon Capture from CFB FG
   - Dynamic response to reduced FG availability (i.e. turn down)
   - Ability to accommodate variable FG carbon loading (e.g. lower CO₂ conc.)
   - Emergency trip/shutdown

### Pilot Plant Performance

<table>
<thead>
<tr>
<th>Operating Mode</th>
<th>90% Capture Coal-Derived FG</th>
<th>70% Capture Coal-Derived FG</th>
<th>Stand-Alone (No FG Available)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCFC Gross Power, DC</td>
<td>1863.4 kW</td>
<td>2542.9 kW</td>
<td>3112.3 kW</td>
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<tr>
<td>Energy &amp; Water Input</td>
<td></td>
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<tr>
<td>Natural Gas Fuel Flow</td>
<td>169.4 scfm</td>
<td>243.2 scfm</td>
<td>329.9 scfm</td>
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<tr>
<td>Fuel Energy (LHV)</td>
<td>2877.8 kW</td>
<td>4087.0 kW</td>
<td>5723.1 kW</td>
</tr>
<tr>
<td>Water Consumed/(Produced)</td>
<td>(1.8) gpm</td>
<td>(2.4) gpm</td>
<td>(0.3) gpm</td>
</tr>
<tr>
<td>AC Power Consumption</td>
<td>(611.0) kW</td>
<td>(911.6) kW</td>
<td>(206.0) kW</td>
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<tr>
<td>Inverter Loss</td>
<td>(74.5) kW</td>
<td>(101.7) kW</td>
<td>(124.5) kW</td>
</tr>
<tr>
<td>Total Parasitic Power Consumption</td>
<td>(685.6) kW</td>
<td>(1013.3) kW</td>
<td>(330.5) kW</td>
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<tr>
<td>Net Generation &amp; Efficiency</td>
<td></td>
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<tr>
<td>CEPACS Plant Net AC Output</td>
<td>1177.8 kW</td>
<td>1529.6 kW</td>
<td>2781.8 kW</td>
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<tr>
<td>Electrical Efficiency (LHV)</td>
<td>40.9 %</td>
<td>37.4 %</td>
<td>48.6 %</td>
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<tr>
<td>Carbon Capture</td>
<td></td>
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<tr>
<td>Total Carbon Capture, %</td>
<td>92 %</td>
<td>75 %</td>
<td>N/A</td>
</tr>
<tr>
<td>Carbon Capture from FG, %</td>
<td>90 %</td>
<td>70 %</td>
<td>N/A</td>
</tr>
<tr>
<td>Total CO₂ Captured, Tons per Day</td>
<td>67 T/D</td>
<td>93 T/D</td>
<td>0 T/D</td>
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<tr>
<td>CO₂ Purity</td>
<td>99.6 %</td>
<td>99.6 %</td>
<td>N/A</td>
</tr>
</tbody>
</table>

- Pilot Plant is designed to capture up to 90 tons per day of CO₂
- The system is net water producer during the above modes of operation
• Cleanup equipment train design, specifications, and RFQ process completed in partnership with AECOM
• Vendor bids selected for each piece of equipment, ready for purchasing
Anode Gas Compressor

- **Key Design Features:**
  - Fuel cell anode exhaust contains the “captured” CO₂ from the flue gas.
  - Carbon capture process requires anode exhaust gas be compressed from ~18 psia to 265 psia.
  - Includes inter-stage cooling and water knockout.

- Engineering specification created to obtain bids from five (5) vendors:
- Evaluated bids for Reciprocating (3) and Screw Type (2) compressors.
- Selected compressor based on lower power consumption and lower price than comparable units.
Key Design Features:

- Absorption technology selected to utilize thermal energy of process, raising system efficiency by avoiding parasitic power penalty of mechanical chiller
- Chiller performance specified to be ~ 100 Tons
Site Plan Overview
Techno-Economic Analysis
Large Scale Coal Capture System

**Combined Electric Power and Carbon-dioxide Separation (CEPACS) System**

- Concept Implementation for 550 MW Reference Supercritical PC Plant*

- 4.3 Million tons of CO₂ capture per year
- 319 MW ECM-based system would capture 90% of CO₂ from 550-MW plant
- 2.5 GWh power generated per year @ 40.7% Efficiency (based on HHV NG)
- Large-scale field-erected stack enclosures can be operated independently, allowing for high plant availability
- Incremental process innovations have reduced ECM stack count from 1792 to 1664 (vs. previous TEA in prior project)
- Packaging improvements have been implemented to incorporate CO₂ purification BoP equipment within ~7 acre footprint

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* Cost and Performance Baseline for Fossil Energy Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity, Revision 2a, DOE/NETL-2010/1397, September 2013.
• PC plant retrofitted with CEPACS system has 31% lower COE than the plant with amine scrubbing for CO₂ Capture

• ECM-Based CEPACS System can meet DOE Target of <$40/tonne CO₂ captured (2011 USD)
Large Scale Future Systems
- 320-MW plant for capture from 550-MW coal system, developed in DOE program: 18,000 tons/day CO₂ capture
- 160-MW plants for capture from 500-MW NGCC developed in ExxonMobil program: >5,000 tons/day CO₂ capture

ECM-based projects
- Single or multiple-unit system
- Coal and natural gas power plants
- Industrial thermal systems
- Commercial CO₂ offtake or sequestration
- 1 to 50-MW fuel cell power
- Up to 3000 tons/day CO₂ capture

ECM-Based Pilot project at Plant Barry, AL
- On line in 2019
- 90% capture from coal flue
- Demonstration of natural gas capture under ExxonMobil program
- 60 tons/day CO₂ capture
Techno-Economic Analysis and Environmental Health and Safety analysis completed for ECM technology applied to a reference supercritical PC plant
- Estimated COE is 31% less than baseline approaches (amines), with cost of CO$_2$ captured estimated at $34/tonne (2011 USD)

BP1 engineering design of pilot system complete

Tie-in engineering effort (AECOM-led) complete

Continuation application to proceed to BP2 of the project was submitted to DOE

Ready to initiate BP2 tasks for plant construction
Acknowledgements

Support from DOE/NETL (Co-operative Agreement DE-FE0026580) and guidance from: José Figueroa, Lynn Brickett, John Litynski, Angelos Kokkinos, and others at NETL