Commercialization of the Iron-Based Coal Direct Chemical Looping Process for Power Production with In Situ Carbon Dioxide Capture

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August 25, 2017
Project Participants

- Federal Agencies:
  - DOE/NETL
- State Agency
  - Ohio Development Services Agency
- Industry & University
  - The Babcock & Wilcox Company (B&W)
  - The Ohio State University (OSU)
  - Clear Skies Consulting
  - Johnson Matthey (JM)
  - EPRI
  - Dover Light & Power
  - Nexant
  - American Electric Power
  - Dayton Power & Light
  - Duke Energy
  - First Energy
  - CONSOL Energy
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<td>• Design of 550 MWe commercial CDCL power plant</td>
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<td>• Technology gap analysis</td>
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<td>• Cost estimate and schedule for fabrication construction and testing of pilot facility</td>
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<td>• Commercialization path – large-scale testing</td>
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Coal Direct Commercialization Path

OSU’s Laboratory Scale
OSU’s Sub-Pilot 25 kW_{th}
B&W’s Phase I
Phase II
B&W’s 250 kW_{th}
B&W’s 10 MWe
FEED Study
Large Pilot 10 MW_{th}
Demo/ Small plant 70 MW_{th}
Commercial 100 - 550 MW_{th}


Time
CDCL Process Overview

- \( \text{H}_2\text{O} + \text{CO}_2 \) (Ash, Hg, Se, As)
- \( >96\% \) Purity
- Coal
- Fe\text{O}_3
- FeO
- Enhancer
- AIR
- HEAT
- Combustor
- Top Section
  - Volatiles
  - Volatilization
  - Char
  - Bottom Section

Enhancer
### Phase I: Technology Gap Analysis

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<td>Char Residence Time</td>
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<td>10 MWe Large Pilot</td>
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<td>Ash Separation / Enhancer Gas</td>
<td>CFM / 25 kWth Sub-Pilot</td>
<td>CFM / 250 kWth</td>
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<tr>
<td>Char Carryover</td>
<td>CFM / 25 kWth Sub-Pilot</td>
<td>CFM / 250 kWth</td>
<td>10 MWe Large Pilot</td>
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<td>Phase I /25 kWth Sub-Pilot</td>
<td>250 kWth</td>
<td>10 MWe Large Pilot</td>
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<td>CO$_2$ Purity</td>
<td>25 kWth Sub-Pilot</td>
<td>250 kWth</td>
<td>10 MWe Large Pilot</td>
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<td>Small-pilot Unit</td>
<td>10 MWe Large Pilot</td>
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<td>2” BFB Studies</td>
<td>2” BFB Studies</td>
<td>10 MWe Large Pilot</td>
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<td><strong>Combustor</strong></td>
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<td>Heat Exchanger surface</td>
<td>B&amp;W’s CFB Technology</td>
<td>B&amp;W’s CFB Technology</td>
<td>10 MWe Large Pilot</td>
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<td>Auto-thermal Operation</td>
<td>Phase I (Calculation)</td>
<td>250 kWth</td>
<td>10 MWe Large Pilot</td>
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<td><strong>Process</strong></td>
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<tr>
<td>Operation</td>
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<td>250 kWth</td>
<td>10 MWe (modular)</td>
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<td>25 kWth Sub-Pilot / NCCC</td>
<td>250 kWth</td>
<td>10 MWe (modular)</td>
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<td>Safety</td>
<td>25 kWth Sub-Pilot / NCCC</td>
<td>250 kWth</td>
<td>10 MWe (modular)</td>
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# CDCL Technology Comparison

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<th>Base Plant</th>
<th>MEA Plant</th>
<th>CDCL Plant</th>
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<tr>
<td><strong>Coal Feed, kg/h</strong></td>
<td>185,759</td>
<td>256,652</td>
<td>205,358</td>
</tr>
<tr>
<td><strong>CO₂ Emissions, kg/MWh\text{net}</strong></td>
<td>801</td>
<td>111</td>
<td>31</td>
</tr>
<tr>
<td><strong>CO₂ Capture Efficiency, %</strong></td>
<td>0</td>
<td>90</td>
<td>96.5</td>
</tr>
<tr>
<td><strong>Net Power Output, MW\text{e}</strong></td>
<td>550</td>
<td>550</td>
<td>550</td>
</tr>
<tr>
<td><strong>Net Plant HHV Heat Rate, kJ/kWh (Btu/kWh)</strong></td>
<td>9,165 (8,687)</td>
<td>12,663 (12,002)</td>
<td>10,084 (9,558)</td>
</tr>
<tr>
<td><strong>Net Plant HHV Efficiency, %</strong></td>
<td>39.3</td>
<td>28.5</td>
<td>35.6</td>
</tr>
<tr>
<td><strong>Cost of Electricity, $/MWh</strong></td>
<td>80.96</td>
<td>132.56</td>
<td>102.67</td>
</tr>
<tr>
<td><strong>Increase in Cost of Electricity, %</strong></td>
<td>-</td>
<td>63.7</td>
<td>26.8</td>
</tr>
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</table>
Phase II: 250 $\text{KW}_\text{th}$ Pilot Unit Design

Pilot Design:
- Reducer Design
- Material and Energy Balances
- Support Structure Design
- Detail Construction Drawings

Specifications
- Materials: Refractory lined Carbon Steel
- Overall Height: 32 ft
- Footprint = 10’ x 10’
- Thermal rating: 250 kWth
- Coal Feed Rate: 70 lb/hr
- Coal size: Pulverized coal
- Max Operating Temperature: 2012 °F
- Oxygen Carrier: Iron based
- Reducer: Counter-current moving bed
- Combustor: Bubbling bed
- Particle transport: Pneumatic
- Active metal: Iron based
- Size: 1.5 mm
Phase II: 250 kW<sub>th</sub> Pilot Plant Facility Design

Pilot Plant Facility Design
- Auxiliary Equipment Specifications
  - Coal Handling
  - Gas Heating, Cooling & Cleanup
  - Ash and Oxygen Carrier Handling Equipment
- P&ID Diagrams
- HazOp Analysis
- Equipment Specifications
- Control Specifications
- Cost Estimate
- Fabrication, Construction and Installation Schedules
Phase II: 250 kW\textsubscript{th} Pilot Fabrication
Phase II: 250 kW$_{th}$ Pilot Construction & Installation
Phase II: 250 kW_{th} Pilot Construction & Installation
250 KW$_{th}$ CDCL System

- **Air Fan**
- **Heater**
- **Furnace**
- **Booster Fan**
- **Burner**
- **Quench**
- **Bag House**
- **ID Fan**
- **Stack**

Flow diagram showing the system components and their connections.
250 kW_{th} CDCL Pilot Plant Test Results

Refractory Bake-Out (March-2017)
250 kW th CDCL Pilot Plant Test Results

Refractory Bake-Out (March-2017)
250 kW$_{th}$ CDCL Pilot Plant Test Results

Refractory Bake-Out (March-2017)
Upgrades to the facility

- New Air Fan Blade
- Air Fan
- Trim Heater
- Water Tank
- Low Water Flow Rate
- Quench
- Bag House
- ID Fan
- Stack
- Furnace
- Booster Fan
- Electric Heaters
- Low Fan Pressure High Heat Loses
- Bag House
- Compressed Air
- Burner
- Air NG
- Natural Gas Injection
- Burner NG
250 kW\textsubscript{th} CDCL Pilot Plant Test Results

Second Test Run (June-2017)
250 kW<sub>th</sub> CDCL Pilot Plant Test Results

Second Test Run (June-2017)
250 \textsubscript{kW} CDCL Pilot Plant Test Results

Second Test Run (June-2017)
Conclusions

- CDCL Process represents a 2\textsuperscript{nd} generation oxyfuel combustion technology capable of substantially reducing the cost of electricity increase associated with CO\textsubscript{2} capture

- Phase II 250 kW\textsubscript{th} pilot plant design, construction and commissioning activities are complete
  - Operating temperature for coal injection (~1,800°F) achieved
  - Initial coal testing shows nearly 100% CO\textsubscript{2} purity in flue gas
  - Over 200 hours of operation in two separate runs (>100 hours each)
  - Flue gas cooler / quench unit design verified & improved
  - Particle make-up & coal feed systems demonstrated & calibrated
Acknowledgements

This presentation is based upon work supported by the Department of Energy under Award Number DE-FE0009761 and the Ohio Development Services Agency under Award Number OER-CDO-D-15-02.

B&W Lead Operators
Larry Mohr, Matt Albaugh, Andrew Mackrory

B&W Assistant Operators
Terry Bert, Robert Pelger, Barry Conrad, Jason Fennell, Prasanna Seshadri

OSU Crew
Andrew Tong, Cheng Chung, Tien-Lin Hsieh, Sourabh Nadgouda, Yaswanth Pottimurthy, Dawei Wang, Dikai Xu, Yitao Zhang