COMBINED SORBENT/WGS-BASED CO$_2$ CAPTURE PROCESS WITH INTEGRATED HEAT MANAGEMENT FOR IGCC SYSTEMS

Cooperative agreement # DE-FE0026388

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OUTLINE

• Project Overview
• Technology Background
• Technical Approach/ Project Scope
• Progress and Current Status
• Summary and Future Plans
Project Overview

**Project Objective:** Conduct laboratory-scale research to develop a combined magnesium oxide (MgO)-based CO$_2$ sorbent/water gas shift (WGS) reactor for precombustion CO$_2$ capture that offers high levels of durability, flexibility, and heat management ability.

**Project Goal:** The ultimate goal is to develop a process to capture 90% of the CO$_2$ for integrated gasification combined cycle (IGCC) applications and reduce the cost of electricity by 30% over IGCC plants employing conventional methods of CO$_2$ capture.
Project Participants and Funding

- **Sponsors and Funding:**
  - DOE/NETL $1,962K
  - Southern Research $491K

- **Project Duration:** 36 months, Oct. 1, 2015 - Sept. 30, 2018

- **Participants and Roles:**
  - **Southern Research:** Overall project management, lab-scale reactor system design and commissioning, CO₂ sorbent preparation and testing with simulated coal-derived syngas, WGS catalyst performance verification, hybrid sorbent/WGS reactor testing, and process/technical modeling and evaluation
  - **IntraMicron:** Laboratory scale heat exchange reactor loading
  - **Nexant:** Economic evaluation support
Technology Background

Major Operations for Commercial IGCC with CO$_2$ Capture

• Gasification
• Particulate Removal
• Contaminant Removal (Tar, NH$_3$, S)
• Water-gas Shift
• CO$_2$ Capture
• Power Generation

Process Intensification to combine
WGS and CO$_2$ capture
Adsorption 600 psig, 350°C
Regeneration 15 psig, 390°C
Feed based on simulated TRIG
or simulated GE gasifier syngas
Technical Advantages

• Combine CO$_2$ capture and WGS into one vessel
• CO$_2$ capture drives equilibrium limited WGS toward CO$_2$ and H$_2$
• Integrated heat management maintains thermodynamically favorable reaction temperatures for both exothermic CO$_2$ capture/WGS and endothermic regeneration
Technical and Economic Challenges

• High levels of CO and CO$_2$ in syngas
• Effect of contaminants in coal syngas
• Heat management
  – Exothermic CO$_2$ capture
  – Endothermic regeneration
• Process integration with IGCC
• Sorbent capacity, kinetics, and durability
• Large scale sorbent manufacture
Process Chemistry*

MgO (s) + CO₂ (g) ↔ MgCO₃ (s); ΔH = -100.7 KJ/mol

MgO (s) + H₂O (g) ↔ Mg(OH)₂ (s); ΔH = -81.1 KJ/mol

Mg(OH)₂ (s) + CO₂ (g) ↔ MgCO₃ (s) + H₂O (g); ΔH = -19.5 KJ/mol

CO (g) + H₂O (g) ↔ CO₂ (g) + H₂ (g) ; ΔH = -41.2 KJ/mol

*298K
IntraMicron’s Microfibrous Entrapped Catalysts (MFEC)

Cu-entrapped Catalyst Particles

**MFEC Allows**
- Use of simpler fixed beds
- Large diameters up to 2-6 inches
- Very high activity catalyst particles
- Isothermal operation

**Resulting in**
- High productivity and selectivity
- Shorter and fewer tubes
- Reduced cost

Images from http://www.intramicron.com
Comparison of Thermodynamic Predictions from Two Sources

Aspen™

Barin and Knacke
## Technical Approach/Work Plan and Overall Schedule

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Project Management and Planning</td>
<td>10/1/2015 – 9/30/2018</td>
</tr>
<tr>
<td>2.0</td>
<td>Simulated Syngas Sorbent and WGS Tests (BP1 – 12 months)</td>
<td>10/1/2015 – 9/30/2016</td>
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<tr>
<td>2.1</td>
<td>Lab Skid Design and Fabrication</td>
<td></td>
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<tr>
<td>2.2</td>
<td>Sorbent Parametric Experiments</td>
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<tr>
<td>2.3</td>
<td>Commercial Catalyst WGS Experiments</td>
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<td>2.4</td>
<td>Initial Process Modeling</td>
<td></td>
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<tr>
<td>3.1</td>
<td>Reactor Design and Fabrication</td>
<td></td>
</tr>
<tr>
<td>3.2</td>
<td>CO₂ Capture/WGS Parametric Tests</td>
<td></td>
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<tr>
<td>3.3</td>
<td>Detailed Reactor Modeling</td>
<td></td>
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<tr>
<td>4.0</td>
<td>Extended Tests: CO₂ Capture/WGS Catalyst Durability for 1000 Cycles</td>
<td>4/1/2018 – 9/30/2018</td>
</tr>
<tr>
<td>5.0</td>
<td>Initial Technical and Economic Feasibility Study (BP3 – 6 months)</td>
<td>4/1/2018 – 9/30/2018</td>
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</table>
Major Milestones and Success Criteria

- **BP1: Simulated Syngas Sorbent and WGS Tests**
  - Sorbent capacity of 1.5 mmol/g for at least 1 sorbent with less than 0.5% degradation for 100 cycles
  - Go/No-Go: 90% CO₂ capture, 97% approach to equilibrium conversion of CO to CO₂, potential for 30% reduction in cost of electricity

- **BP2: Combined CO₂ Capture/WGS Catalyst Testing with Integrated Heat Management**
  - One sorbent achieves 2.0 mmol/g in combined CO₂ capture/WGS reactor
  - 90% Removal of CO+CO₂ in combined CO₂ capture/WGS reactor over 100 cycles
  - Go/No-Go: 90% CO₂ capture, 97% conversion of CO to CO₂, potential for 30% reduction in cost of electricity

- **BP3: Extended Tests Sorbent/Catalyst Durability for 1000 Cycles**
  - < 0.5% loss in sorbent capacity over 500 cycles and > 97 conversion of CO to CO₂ over 1000 cycles in combined CO₂ capture/WGS reactor
  - Initial TEA to confirm potential to meet cost targets
## Project Risks and Mitigation Strategies

<table>
<thead>
<tr>
<th>Description of Risk</th>
<th>Probability</th>
<th>Impact</th>
<th>Response/Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technical</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_2$ sorbent does not have desired capacity.</td>
<td>N/A</td>
<td>N/A</td>
<td>Sorbents identified and demonstrated with required capacity and durability over 100+ cycles</td>
</tr>
<tr>
<td>WGS does not have required performance at sorbent conditions.</td>
<td>Very low</td>
<td>Med</td>
<td>Commercial WGS catalyst designed for optimum performance at conditions being used for sorbent available to optimize performance at necessary conditions.</td>
</tr>
<tr>
<td>Integrated sorber/WGS reactor does not manage heat generation (BP2)</td>
<td>Low</td>
<td>Med</td>
<td>Previous successful experience with proposed heat exchange reactor for highly exothermic reactions</td>
</tr>
<tr>
<td>Results do not predict the achievement of the expected economic target (BP2)</td>
<td>Low-Med</td>
<td>Med</td>
<td>Preliminary technical and economic feasibility study updated as experimental data is generated. Milestone and Go-No-Go decision points limit risk to DOE</td>
</tr>
</tbody>
</table>
Progress and Current Status

- Revisited recent MgO sorbent literature
- 14 sorbents prepared and screened by TGA
- Prepared SR-1.3 sorbent (promoted MgO) in powder and pellet form
- Selected formula from US 2013/0195742 for comparison
- Design, procurement, construction for lab-scale CO₂ capture reactor complete
  - Design based on anticipated cycle conditions
  - Sufficient flexibility in design to cover a range of pressure, temperature, space velocity, syngas composition, and regeneration procedure
Pellets made of SR-1.3 stable for over 150 cycles
CO₂ Capture Reactor Design

- Pressure Swing Adsorption System (0-600 psig)
- Precise Temperature/Pressure Control
- Sorbent Regeneration via Pressure Swing/Vacuum
- Automated Adsorption/Desorption Cycle
- Reverse Gas flow During Desorption

Space Velocity: 250-5000 hr⁻¹
Temperature: 250-350°C
Pressure: 0-600 psig
Laboratory Scale CO$_2$ Capture Skid
## Major Syngas Components*

<table>
<thead>
<tr>
<th></th>
<th>GE (Oxygen Blown)</th>
<th>TRIG (Air Blown)</th>
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</thead>
<tbody>
<tr>
<td>H₂</td>
<td>34.2%</td>
<td>11.7%</td>
</tr>
<tr>
<td>CO</td>
<td>35.8%</td>
<td>17.5%</td>
</tr>
<tr>
<td>CO₂</td>
<td>13.7%</td>
<td>8.5%</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.12%</td>
<td>2.6%</td>
</tr>
<tr>
<td>N₂</td>
<td>0.8%</td>
<td>50.5%</td>
</tr>
</tbody>
</table>

* H₂O (steam) as necessary for WGS
Combined CO$_2$ Capture/WGS Test without Temp. Swing

- Simulated TRIG Feed
- CO conversion close to 100% before the CO$_2$ breakthrough
- Working capacity similar to the previous separate tests (1.5 mmol/g)
Sorbent Capacity

Working capacity experiments for >100 cycles regenerating with pressure-swing (without temperature swing)

Target: 10% total CO₂ breakthrough (90% capture)
Sorbent Stability

Working capacity at 10% CO₂ breakthrough versus cycle number for syngas feed and downflow regeneration.

Trend was still increasing!
Combined CO$_2$ Capture/WGS Test with Temp. Swing

- Simulated TRIG Feed
- Almost no breakthrough of CO$_2$
- High working capacity (>5.0 mmol/g)
Sorbent Capacity Increase

Sorbent working capacity comparison between with and without temperature swing during the sorbent regeneration

3+ times the capacity with 40 °C temperature swing
Regeneration methods can increase the sorbent capacity but reduce WGS catalyst performance.
Balanced experimental conditions

<table>
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<tr>
<th>Regen Method</th>
<th>Catalyst CO conversion (%)</th>
<th>Sorbent capacity (mmol/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method 1</td>
<td>75 (decreasing over cycles)</td>
<td>6.0</td>
</tr>
<tr>
<td>Method 2</td>
<td>87 (stable)</td>
<td>4</td>
</tr>
<tr>
<td>Method 3</td>
<td>90 (stable)</td>
<td>3</td>
</tr>
</tbody>
</table>

Target: 10% total CO₂ breakthrough (90% capture)
SUMMARY

• A novel hybrid CO₂ capture/WGS reactor with integrated heat management has been developed.
• Promising sorbents have exceeded capacity (TGA test: >4 mmol/g, skid test: >5 mmol/g) and durability targets (over 500 cycles with no degradation).
• Commercial WGS catalyst close to performance targets, 87% - 94% of equilibrium CO conversion.
• With current regeneration methods, sorbent performance and WGS catalyst performance need to be balanced.
• Ongoing technoeconomic analysis suggest that a commercial process based on this technology is a potential for reduction in cost of electricity compared to baseline IGCC with traditional CO₂ capture approaches.
Future Testing

• Current project
  – Regeneration methods for integrated CO$_2$ capture/WGS
  – Extended numbers of cycles to show stability
  – Additional technical and economic modeling

• Scale-up and test on coal-derived syngas for technology development after project completion
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• Isaac “Andy” Aurelio DOE/NETL

• Intramicron: Paul Dimick

• Southern Research E&E Department senior staff, engineers, and chemists
Questions?
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