# COMBINED SORBENT/WGS-BASED $CO_2$ CAPTURE PROCESS WITH INTEGRATED HEAT MANAGEMENT FOR IGCC SYSTEMS

Cooperative agreement # DE-FE0026388

2017 NETL CO2 Capture Technology Project Review Meeting August 21 – August 25, 2017

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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.



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# 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, $CO_2$ 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

IntraMicron

Nexant

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# 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) + $CO_2$ (g) ↔ $MgCO_3$ (s); $\Delta H = -100.7$ KJ/mol

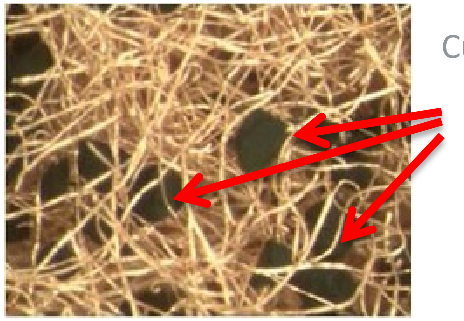
$MgO$ (s) + $H_2O$ (g) ↔ $Mg(OH)_2$ (s); $\Delta H = -81.1$ KJ/mol

$Mg(OH)_2$ (s) + $CO_2$ (g) ↔ $MgCO_3$ (s) + $H_2O$ (g); $\Delta H = -19.5$ KJ/mol

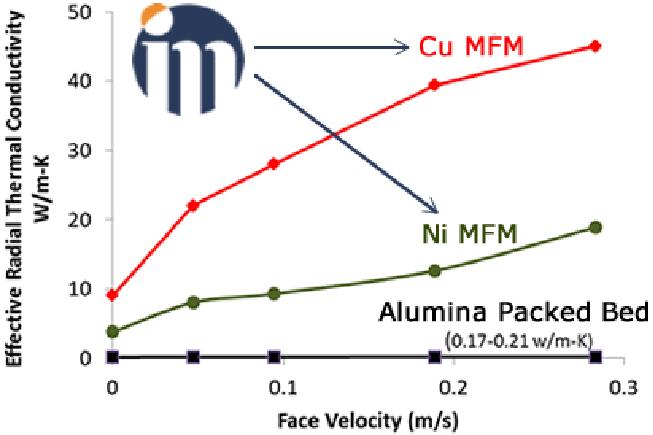
$CO$ (g) + $H_2O$ (g) ↔ $CO_2$ (g) + $H_2$ (g) ; $\Delta H = -41.2$ KJ/mol

*298K

# IntraMicron's Microfibrous Entrapped Catalysts (MFEC)



Cu-entrapped Catalyst Particles

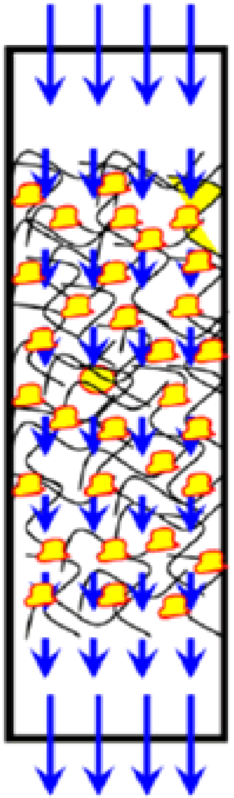



**MFEC Allows**

- 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



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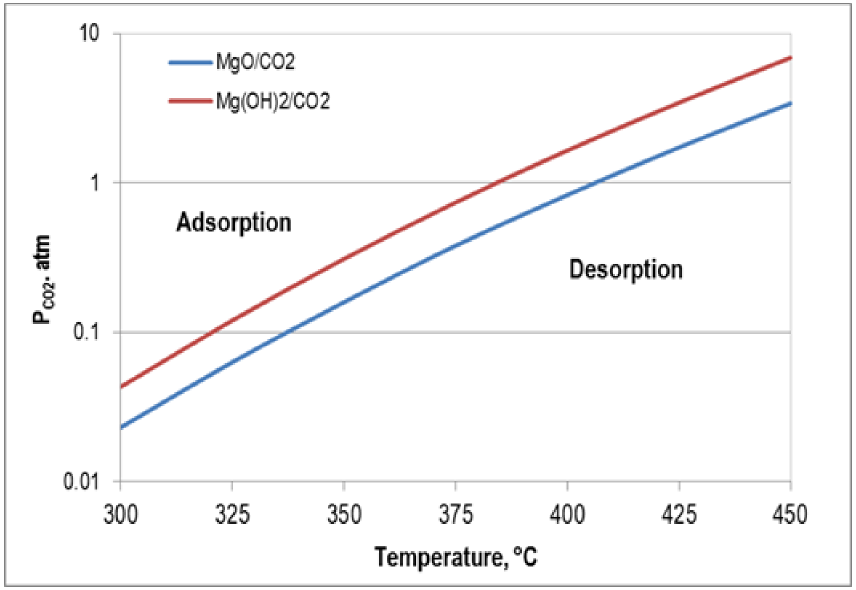
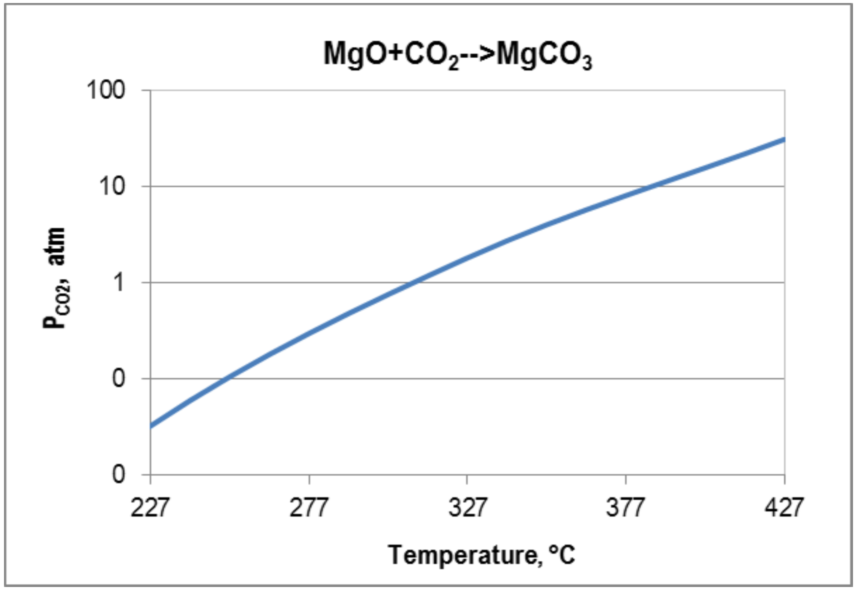
# Comparison of Thermodynamic Predictions from Two Sources




Aspen™




Barin and Knacke

# Technical Approach/Work Plan and Overall Schedule

| Task | Description | Dates |
|---|---|---|
| 1.0 | Project Management and Planning | 10/1/2015 – 9/30/2018 |
| 2.0 | Simulated Syngas Sorbent and WGS Tests (BP1 – 12 months) | 10/1/2015 – 9/30/2016 |
| 2.1 | Lab Skid Design and Fabrication | |
| 2.2 | Sorbent Parametric Experiments | |
| 2.3 | Commercial Catalyst WGS Experiments | |
| 2.4 | Initial Process Modeling | |
| 3.0 | Combined $CO_2$ Capture/WGS Catalyst Heat Exchange Reactor Testing (BP2 – 18 months) | 10/1/2016 – 3/31/2018 |
| 3.1 | Reactor Design and Fabrication | |
| 3.2 | $CO_2$ Capture/WGS Parametric Tests | |
| 3.3 | Detailed Reactor Modeling | |
| 4.0 | Extended Tests: $CO_2$ Capture/WGS Catalyst Durability for 1000 Cycles (BP3 – 6 months) | 4/1/2018 – 9/30/2018 |
| 5.0 | Initial Technical and Economic Feasibility Study (BP3 – 6 months) | 4/1/2018 – 9/30/2018 |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# 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% $CO_2$ capture, 97% approach to equilibrium conversion of CO to $CO_2$, potential for 30% reduction in cost of electricity**
- BP2: Combined $CO_2$ Capture/WGS Catalyst Testing with Integrated Heat Management
  - **One sorbent achieves 2.0 mmol/g in combined $CO_2$ capture/WGS reactor**
  - 90% Removal of CO+$CO_2$ in combined $CO_2$ capture/WGS reactor over 100 cycles
  - Go/No-Go: 90% $CO_2$ capture, 97% conversion of CO to $CO_2$, 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 $CO_2$ over 1000 cycles in combined $CO_2$ capture/WGS reactor
  - Initial TEA to confirm potential to meet cost targets

# Project Risks and Mitigation Strategies

| Description of Risk | Probability | Impact | Response/Mitigation |
|---|---|---|---|
| **Technical** | | | |
| **$CO_2$ sorbent does not have desired capacity.** | N/A | N/A | Sorbents identified and demonstrated with required capacity and durability over 100+ cycles |
| **WGS does not have required performance at sorbent conditions.** | Very low | Med | Commercial WGS catalyst designed for optimum performance at conditions being used for sorbent available to optimize performance at necessary conditions. |
| **Integrated sorber/WGS reactor does not manage heat generation (BP2)** | Low | Med | Previous successful experience with proposed heat exchange reactor for highly exothermic reactions |
| **Results do not predict the achievement of the expected economic target (BP2)** | Low-Med | Med | Preliminary technical and economic feasibility study updated as experimental data is generated. Milestone and Go-No-Go decision points limit risk to DOE |



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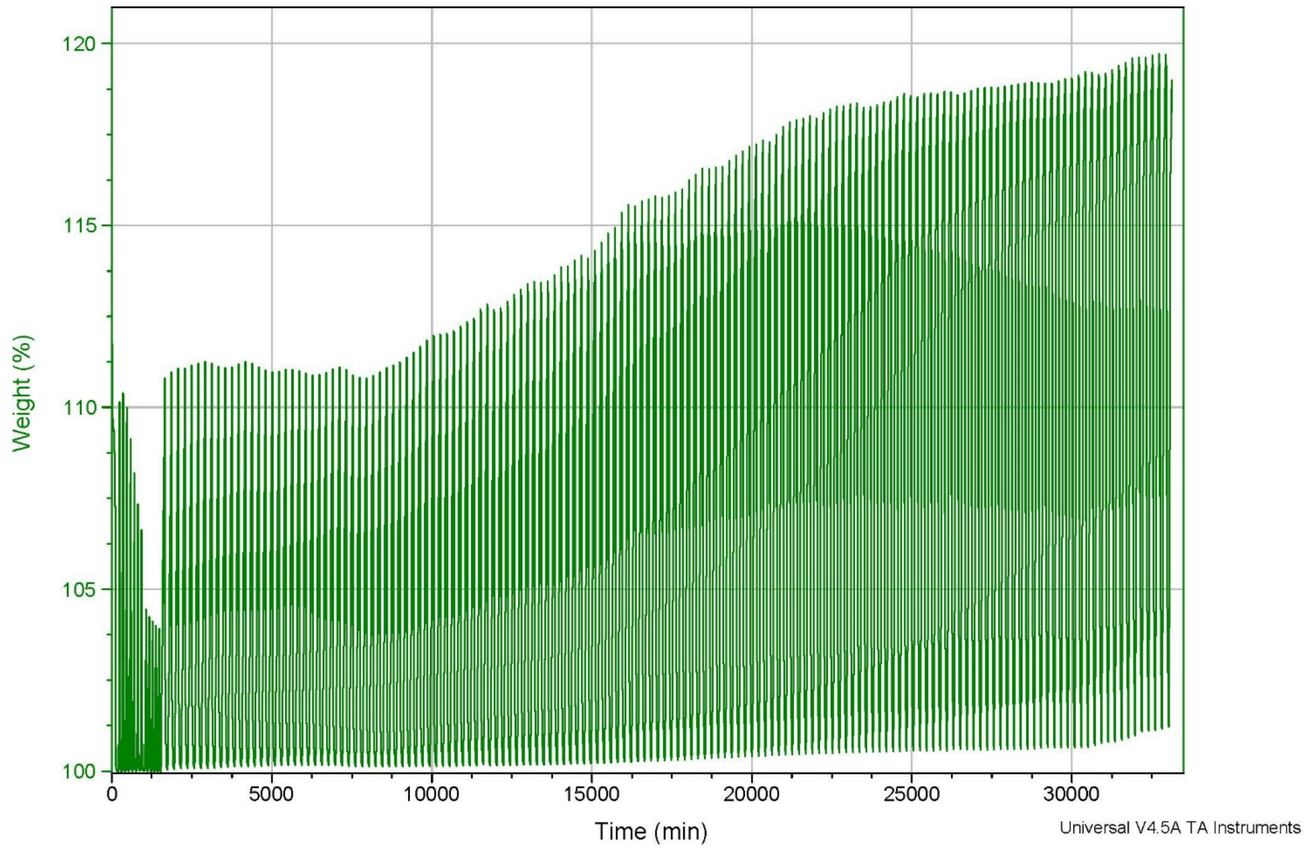
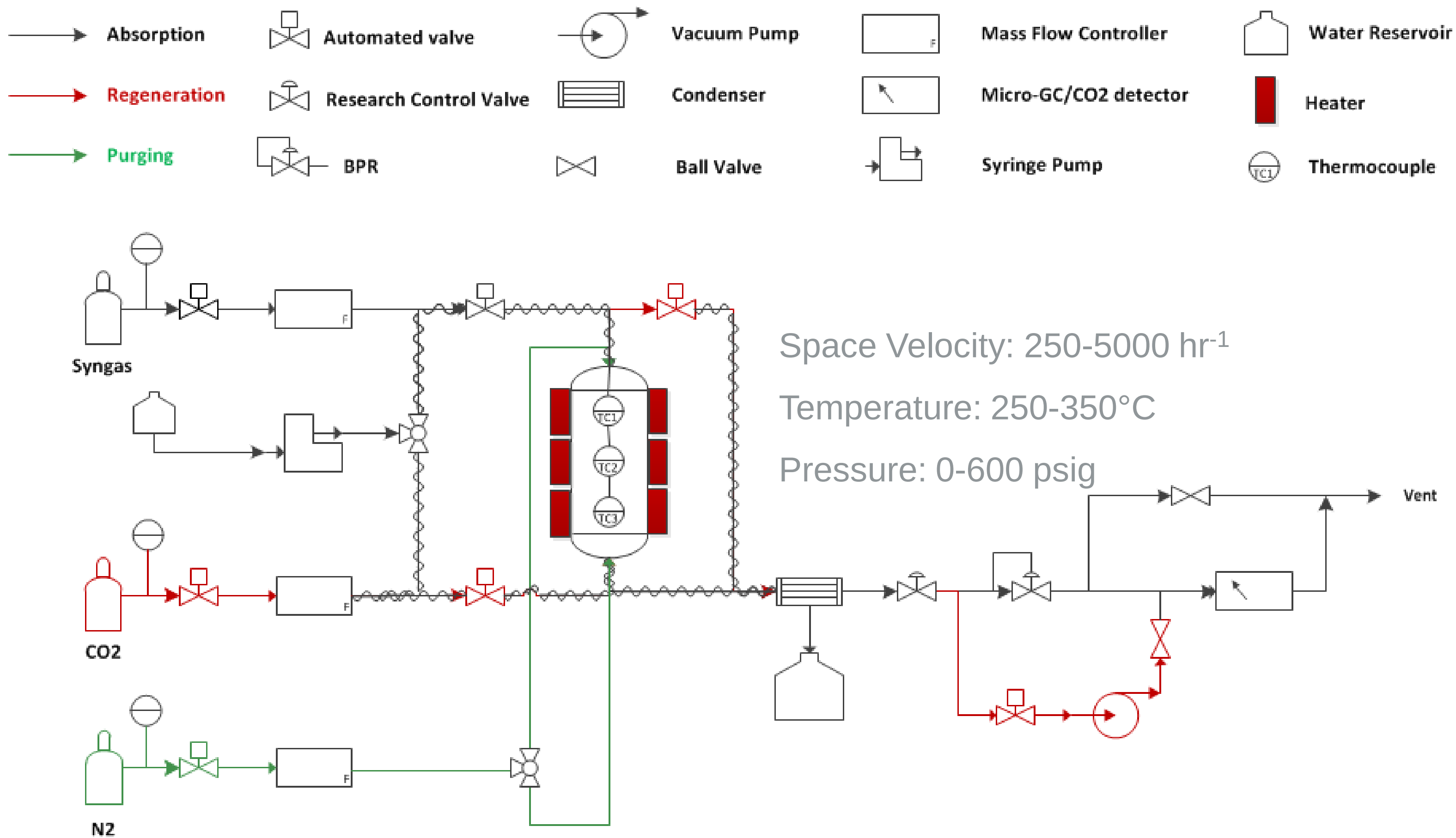
# Progress and Current Status

- 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 comparision
- Design, procurement, construction for lab-scale $CO_2$ 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



# $CO_2$ Capture Reactor Design




Space Velocity: 250-5000 $hr^{-1}$

Temperature: 250-350°C

Pressure: 0-600 psig

- 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

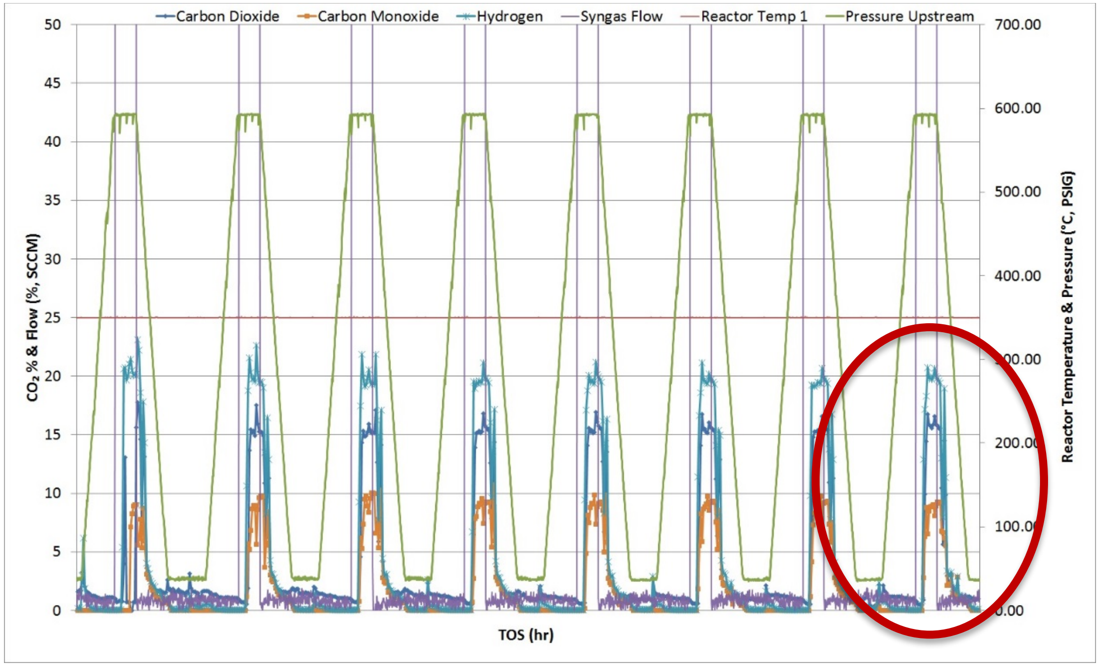
# Laboratory Scale $CO_2$ Capture Skid

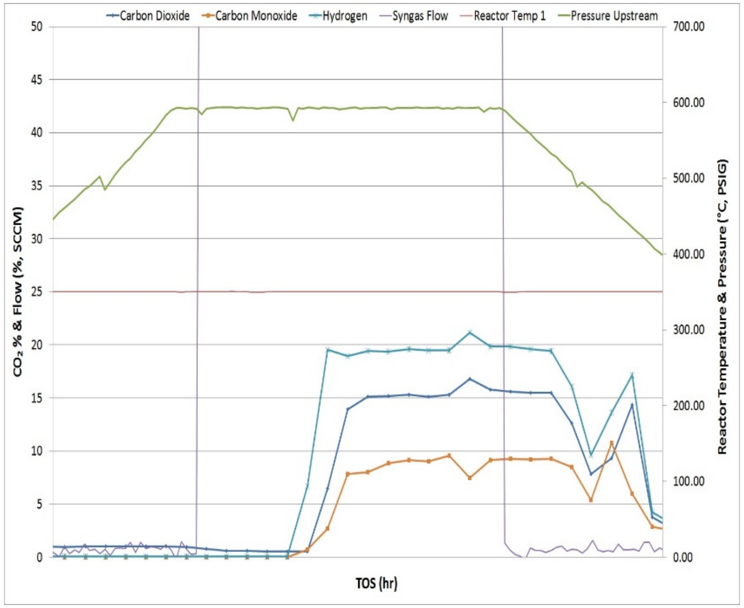
# Major Syngas Components*

| | GE (Oxygen Blown) | TRIG (Air Blown) |
|---|---|---|
| $H_2$ | 34.2% | 11.7% |
| CO | 35.8% | 17.5% |
| $CO_2$ | 13.7% | 8.5% |
| $CH_4$ | 0.12% | 2.6% |
| $N_2$ | 0.8% | 50.5% |

* $H_2O$ (steam) as necessary for WGS

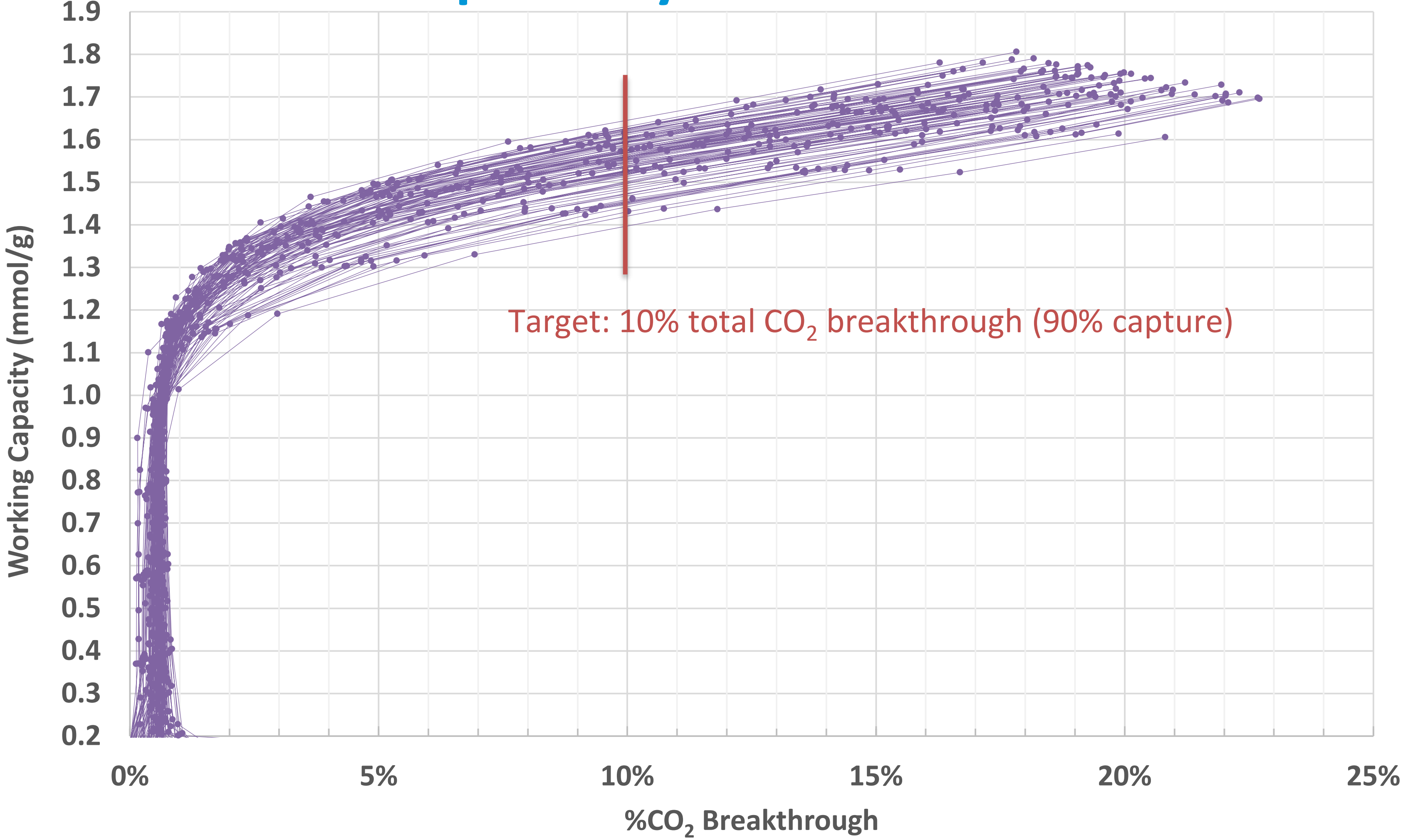
# Combined $CO_2$ Capture/WGS Test without Temp. Swing



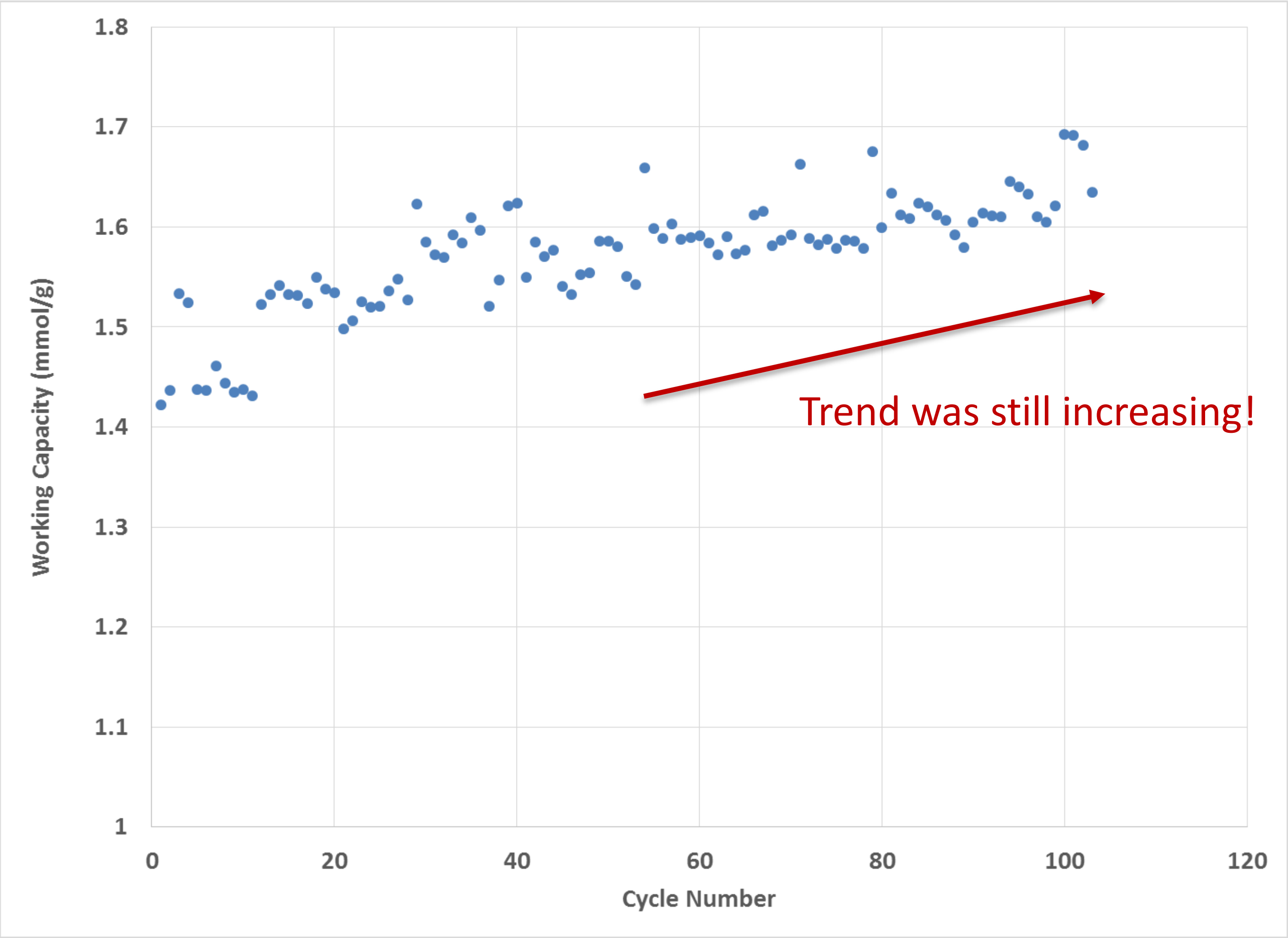

- **Simulated TRIG Feed**
- **CO conversion close to 100% before the $CO_2$ breakthrough**
- **Working capacity similar to the previous separate tests (1.5 mmol/g)**

# Sorbent Capacity



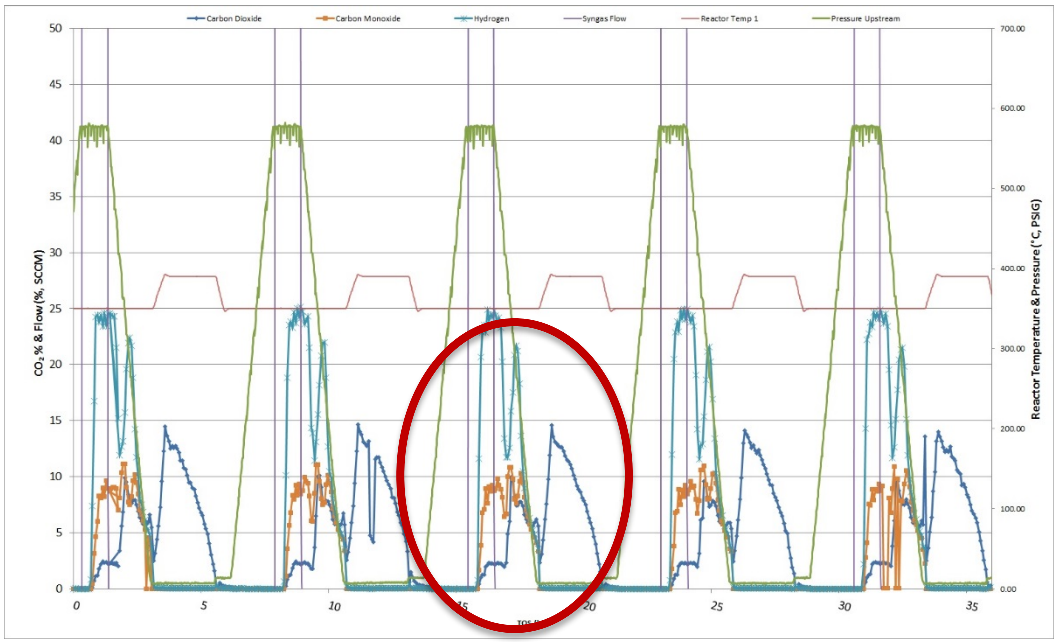

**Working capacity experiments for >100 cycles regenerating with pressure-swing (without temperature swing)**

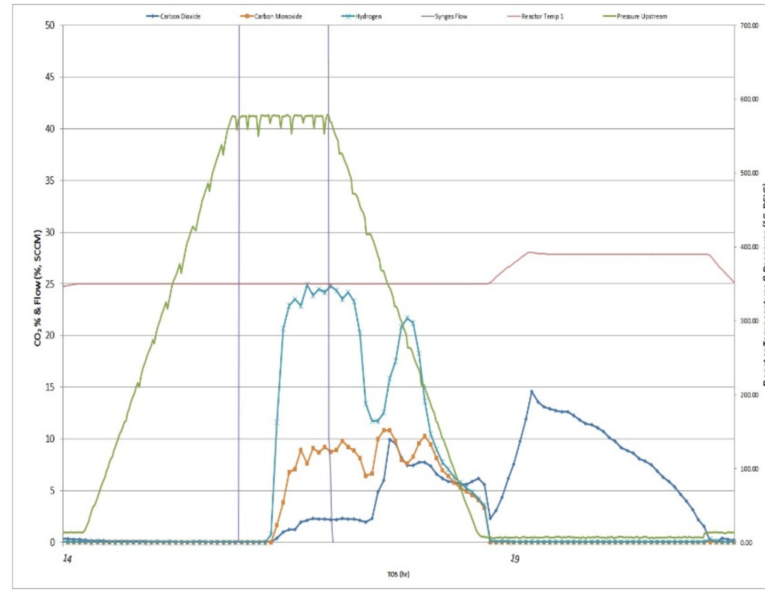
# Sorbent Stability




Working capacity at 10% $CO_2$ breakthrough versus cycle number for syngas feed and downflow regeneration.

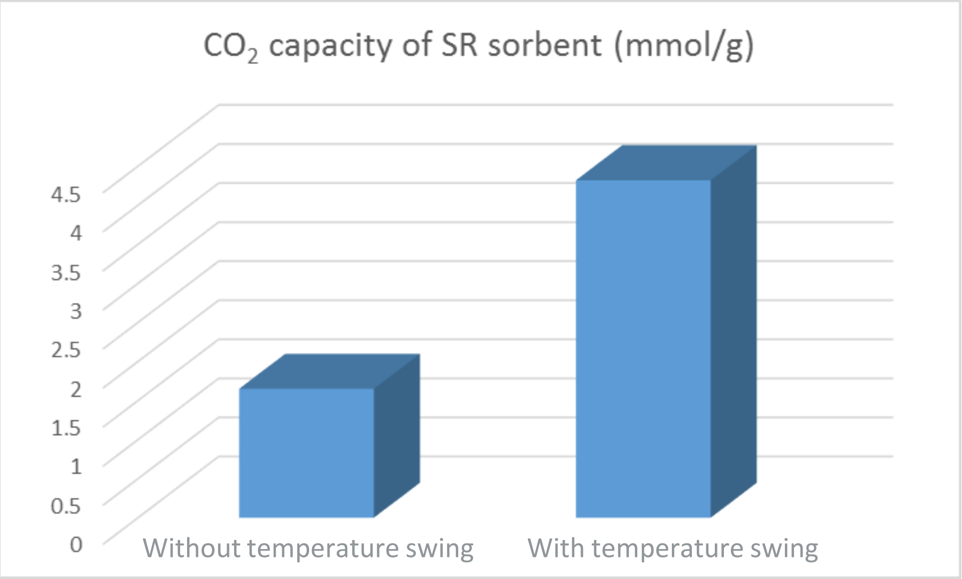
# Combined $CO_2$ Capture/WGS Test with Temp. Swing




- **Simulated TRIG Feed**
- **Almost no breakthrough of $CO_2$**
- **High working capacity (>5.0 mmol/g)**

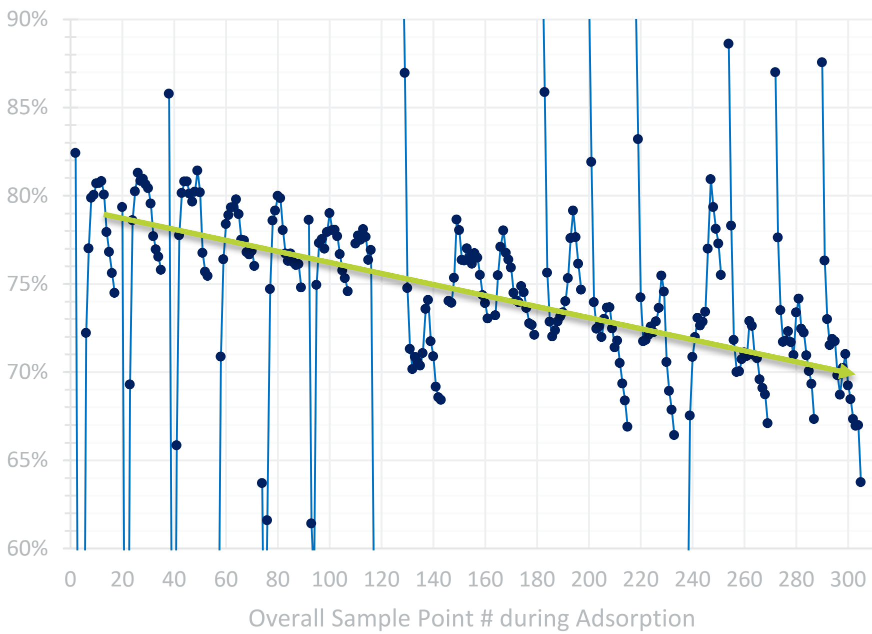
# Sorbent Capacity Increase



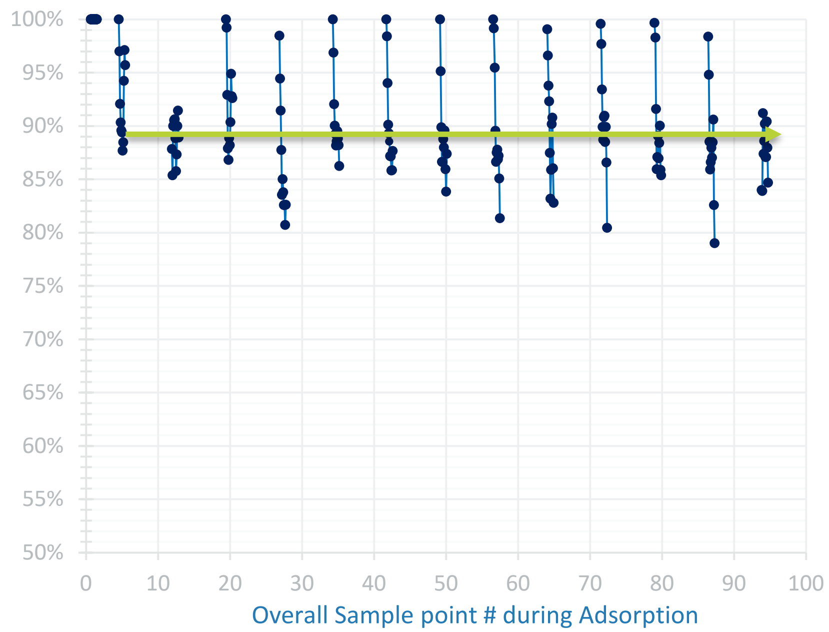

3+ times the capacity with 40 °C temperature swing

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

# WGS Catalyst Stability



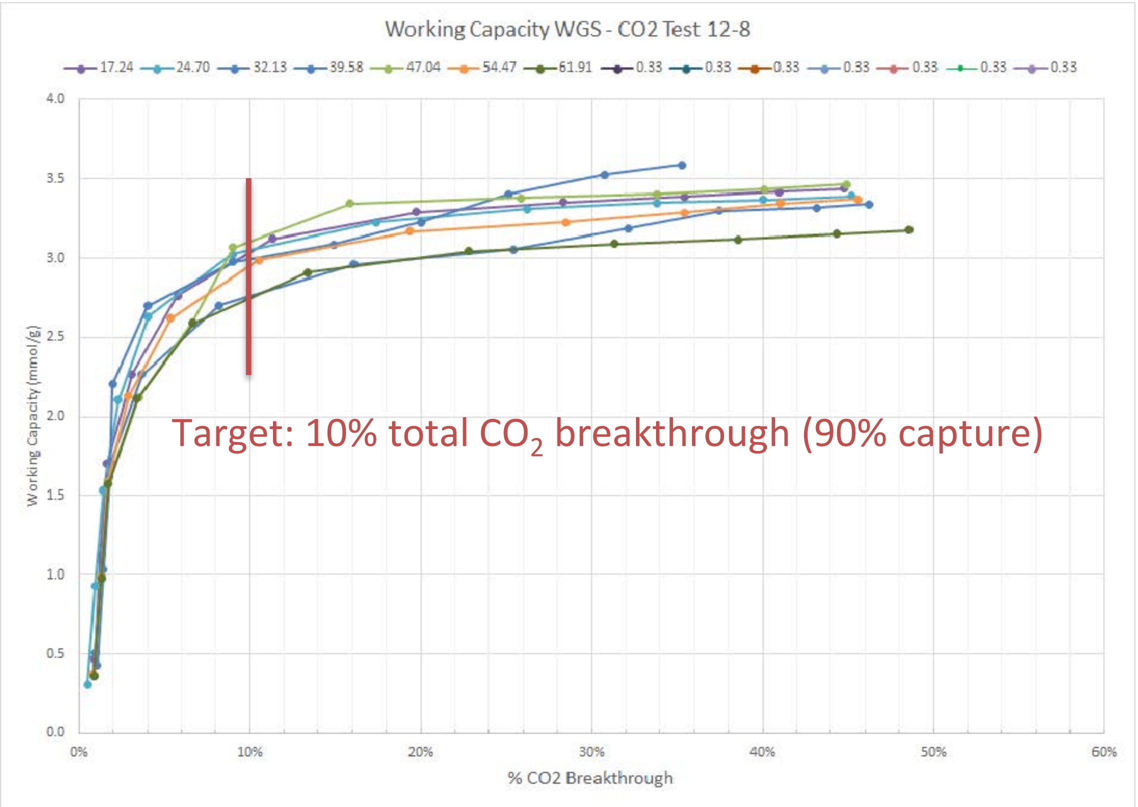

Regen. method 1




Regen. method 3

Regeneration methods can increase the sorbent capacity but reduce WGS catalyst performance

# Balanced experimental conditions




| Regen Method | Catalyst CO conversion (%) | Sorbent capacity (mmol/g) |
|---|---|---|
| Method 1 | 75 (decreasing over cycles) | 6.0 |
| Method 2 | 87 (stable) | 4 |
| Method 3 | 90 (stable) | 3 |

# SUMMARY

- A novel hybrid $CO_2$ 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 $CO_2$ 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

# Acknowledgements


- Funding provided by US Department of Energy National Energy Technology Laboratory and Southern Research under co-operative Agreement # DE-FE0026388
- Isaac "Andy" Aurelio DOE/NETL
- Intramicron:  Paul Dimick
- Southern Research E&E Department senior staff, engineers, and chemists

# Questions?

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