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

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Presentation for
2016 NETL CO2 Capture Technology Project Review Meeting

Andrew Lucero, August Meng, Shen Zhao, and
Santosh Gangwal

DOE FPM: Isaac "Andy" Aurelio

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Agenda

- Project Overview
- Technology Background
- Technical Approach
- Progress and Current Status
- 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 that offers high levels of durability, simplicity, 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, 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

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/CO_2 Capture

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
- Process integration with IGCC
- Sorbent capacity, kinetics, and durability
- Large scale sorbent manufacture

Process Chemistry*

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

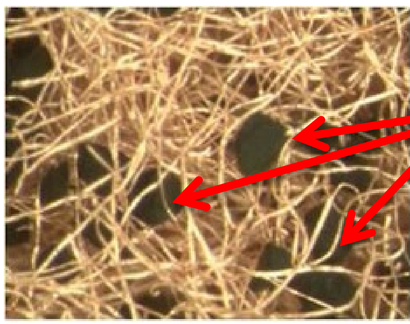
$$MgO\ (s) + H_2O\ (g) \leftrightarrow Mg(OH)_2\ (s);\ \Delta H = -81.1\ KJ/mol$$

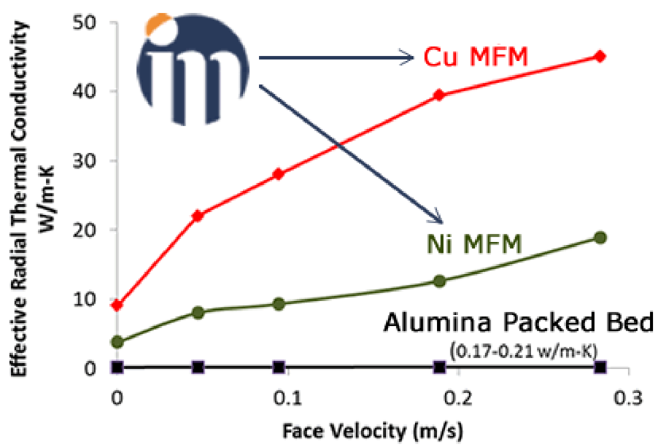
$$Mg(OH)_2\ (s) + CO_2\ (g) \leftrightarrow MgCO_3\ (s) + H_2O\ (g);\ \Delta H = -19.5\ KJ/mol$$

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

*298K

IntraMicron's Microfibrous Entrapped Catalysts (MFEC)



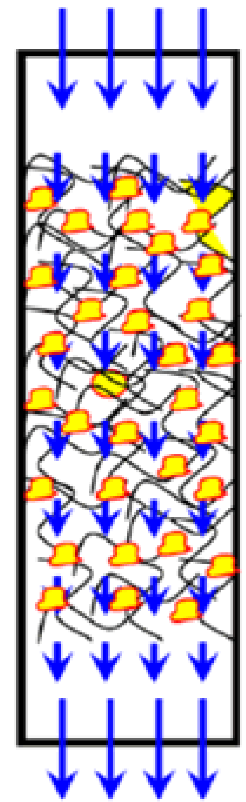


MFEC Allows

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

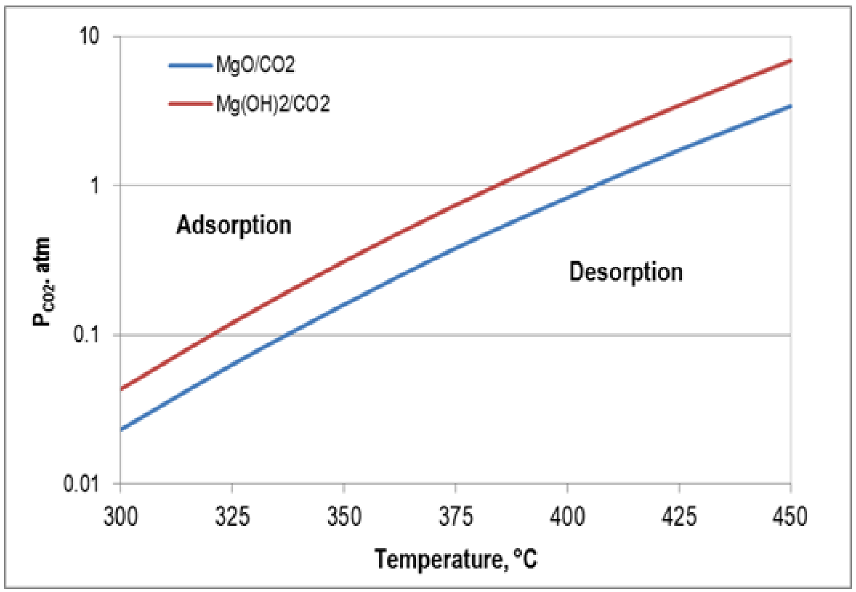
Resulting in

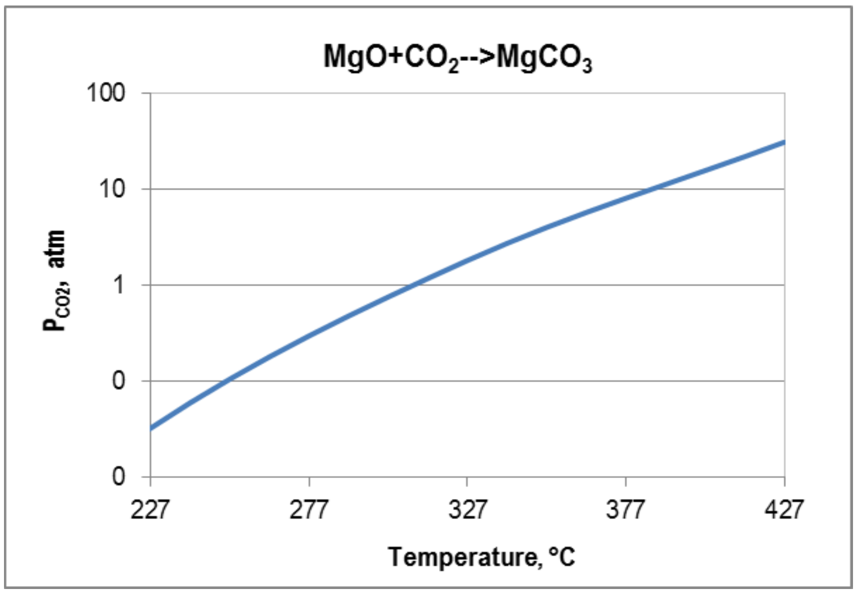
- **High productivity and selectivity**
- **Shorter and fewer tubes**
- **Reduced cost**



Images from http://www.intramicron.com

Comparison of Thermodynamic Predictions from Two Sources





Aspen

Barin and Knacke

SOUTHERN RESEARCH
Solving the world's hardest problems.

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

SOUTHERN RESEARCH

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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

Progress and Current Status

- Revisited recent MgO sorbent literature
- Prepared SR-1.3 sorbent (promoted MgO) in powder and pellet form
- Based on literature review, selected a sorbent for comparison [US 2013/0195742]
- Spray dryer installed and commissioned to make larger quantities of sorbent particles
- 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

SOUTHERN RESEARCH
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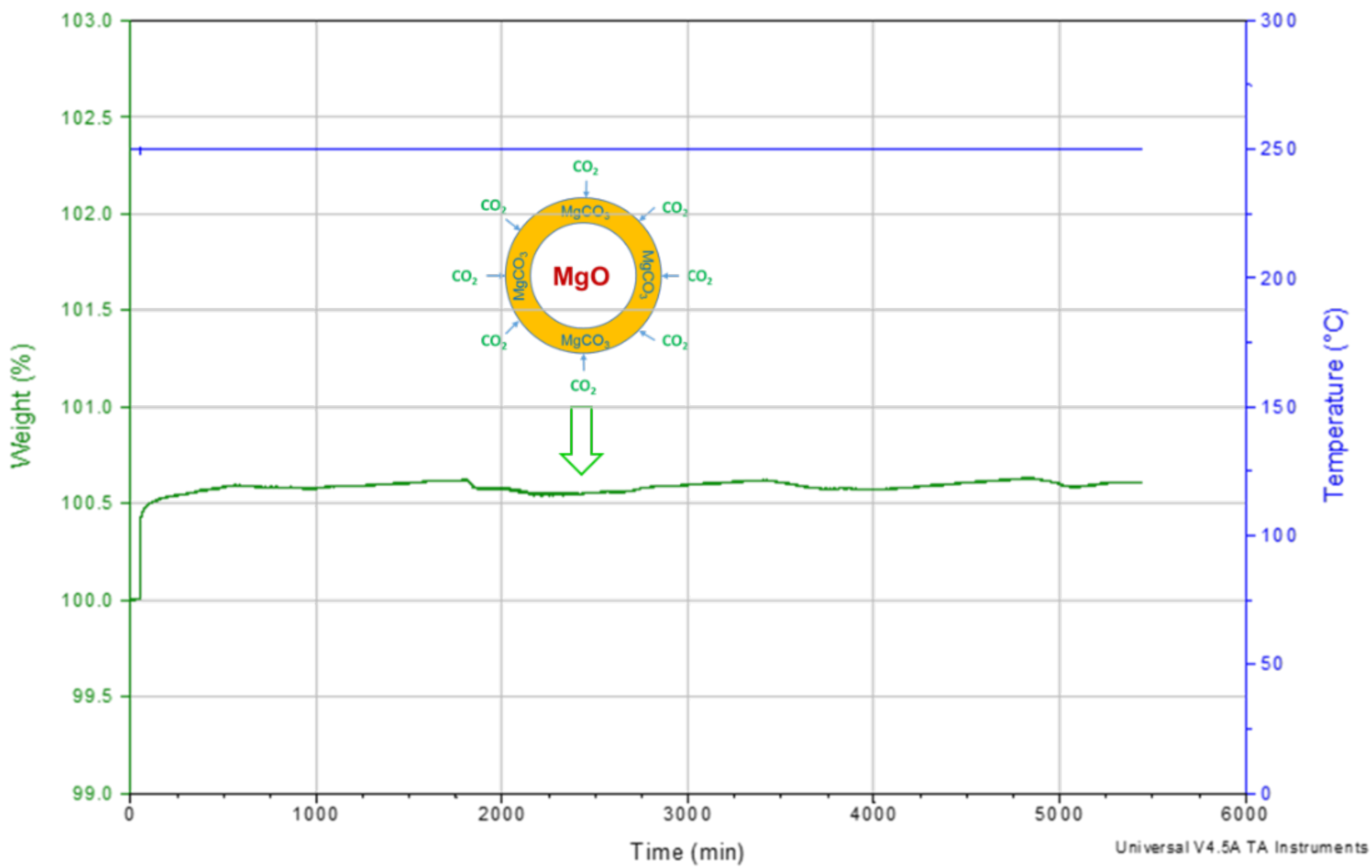
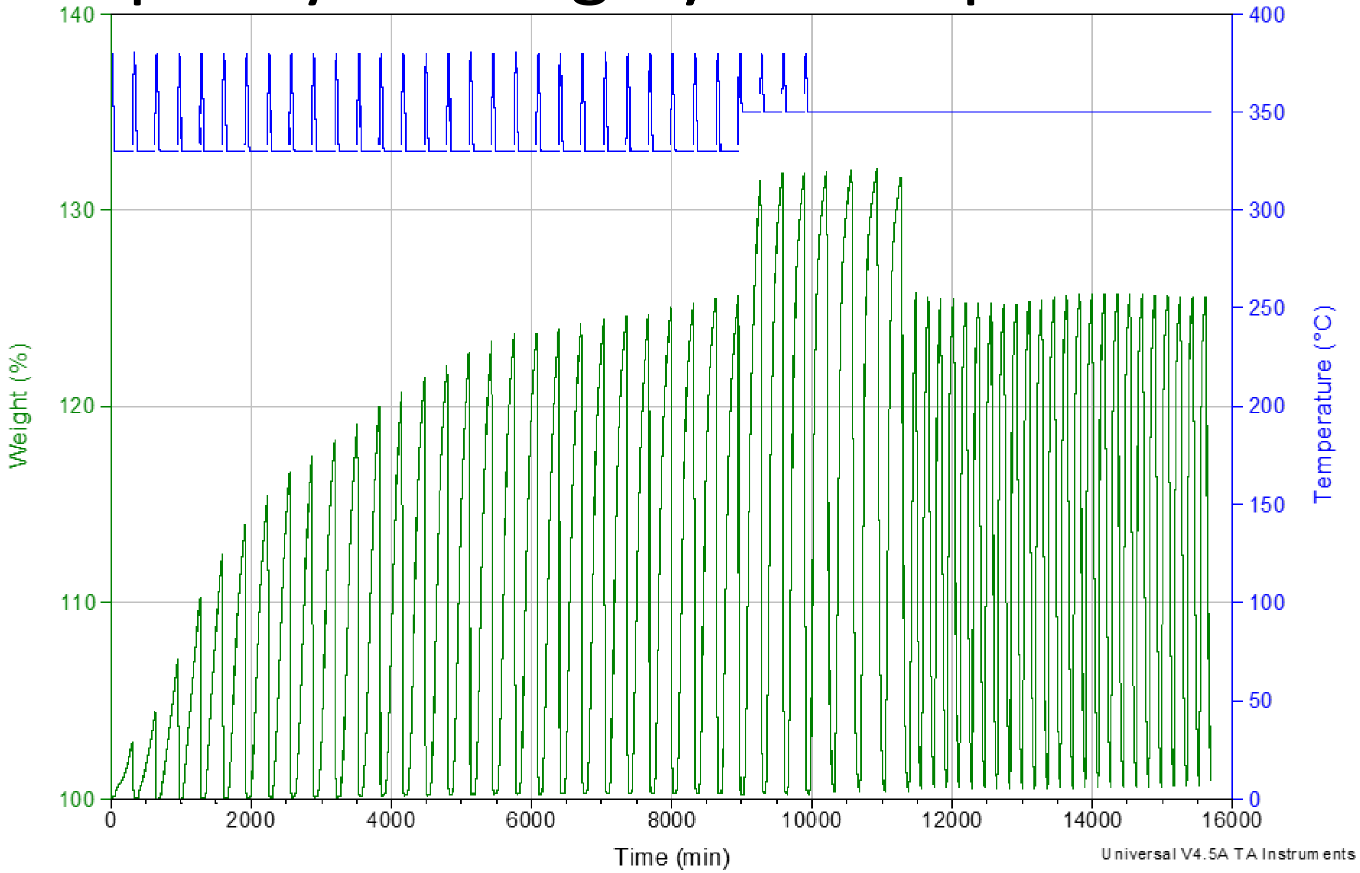
Several sorbents prepared and tested

Sorbent Code	Short Description	BET Surface Area (m^2/g)	Pore Size (nm)	Pore Volume (cm^3/g)
Group I				
SR-1.1	MgO (pure, mesoporous)	94.7	17.1	0.36
SR-1.2	MgO (US 2013/0195742)	6.5	12.1	0.02
SR-1.3	MgO (promoted, MgO from SR-1.1)	59.8	20.3	0.42
SR-1.4	MgO (promoted, MgO from SR-1.1)	41.6	15.0	0.21
SR-1.5	MgO (promoted, MgO from SR-1.1)	39.8	16.0	0.22
SR-1.6	MgO (C4Mg4O12·H2MgO2·xH2O calcination)	244.5	4.6	0.40
SR-1.7	MgO (promoted, MgO from SR-1.6)	49.7	19.6	0.36
Group II				
SR-11.1	MgO-inert Support A	101.0	12.4	0.75
SR-11.2	MgO-inert Support A	91.0	11.9	0.67
SR-11.3	MgO (with inert support B)	35.9	8.8	0.37
SR-11.4	MgO (with inert support B)	31.6	7.7	0.35
SR-11.5	MgO (with inert support B)	36.8	6.8	0.38
SR-11.6	MgO- inert Support A	2.8	11.8	0.04
SR-11.7	MgO (inert support B), promoted)	17.7	16.9	0.25
SR-11.8	MgO (inert support B), promoted)	NA	NA	NA
SR-11.9	MgO (inert support B), promoted)	NA	NA	NA
SR-11.10	MgO (MgO from SR-11.5, promoted)	NA	NA	NA

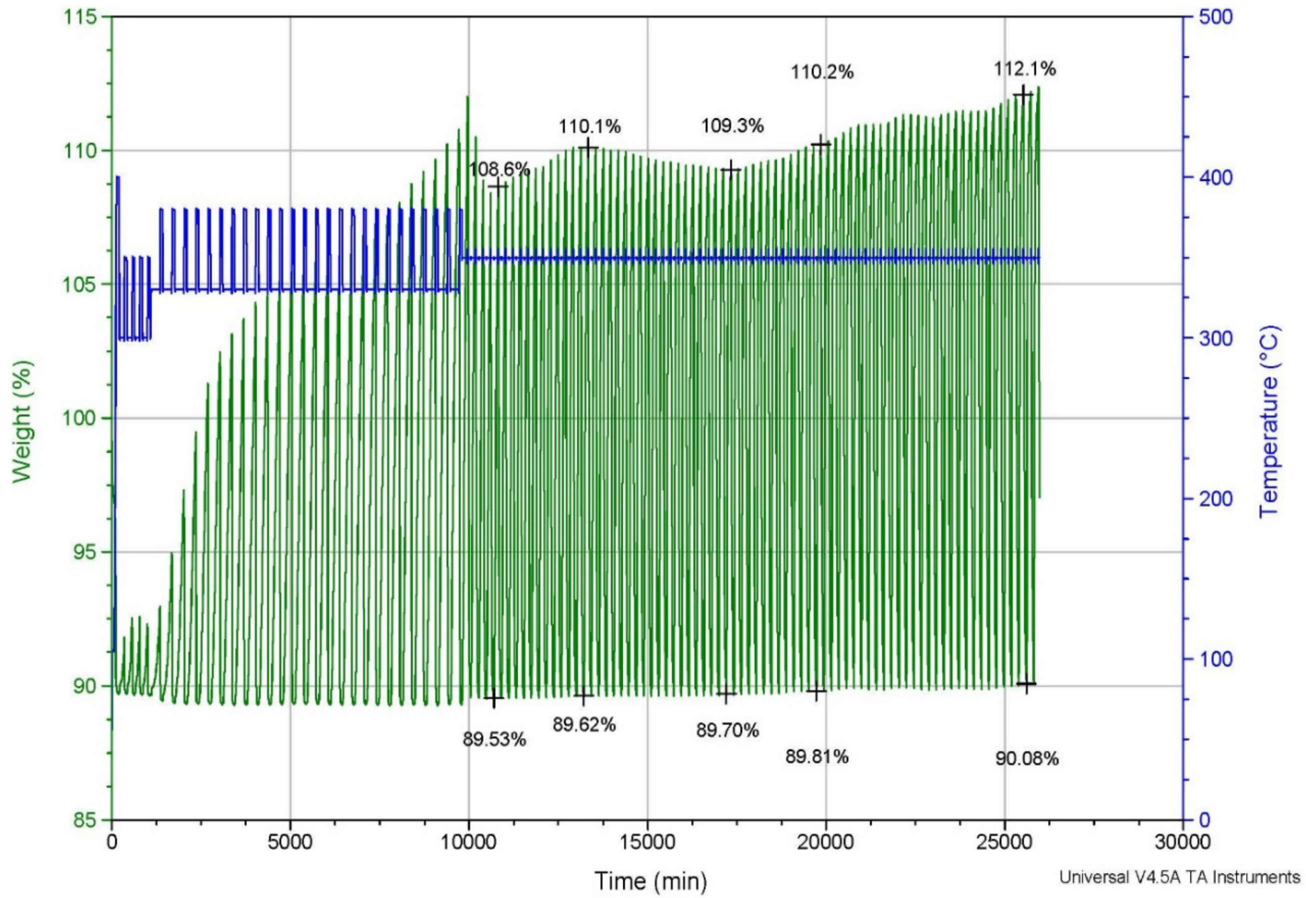
Un-promoted MgO had Poor Capacity



TGA results SR-1.3 promoted sorbent had induction period but high ultimate capacity and highly stable performance

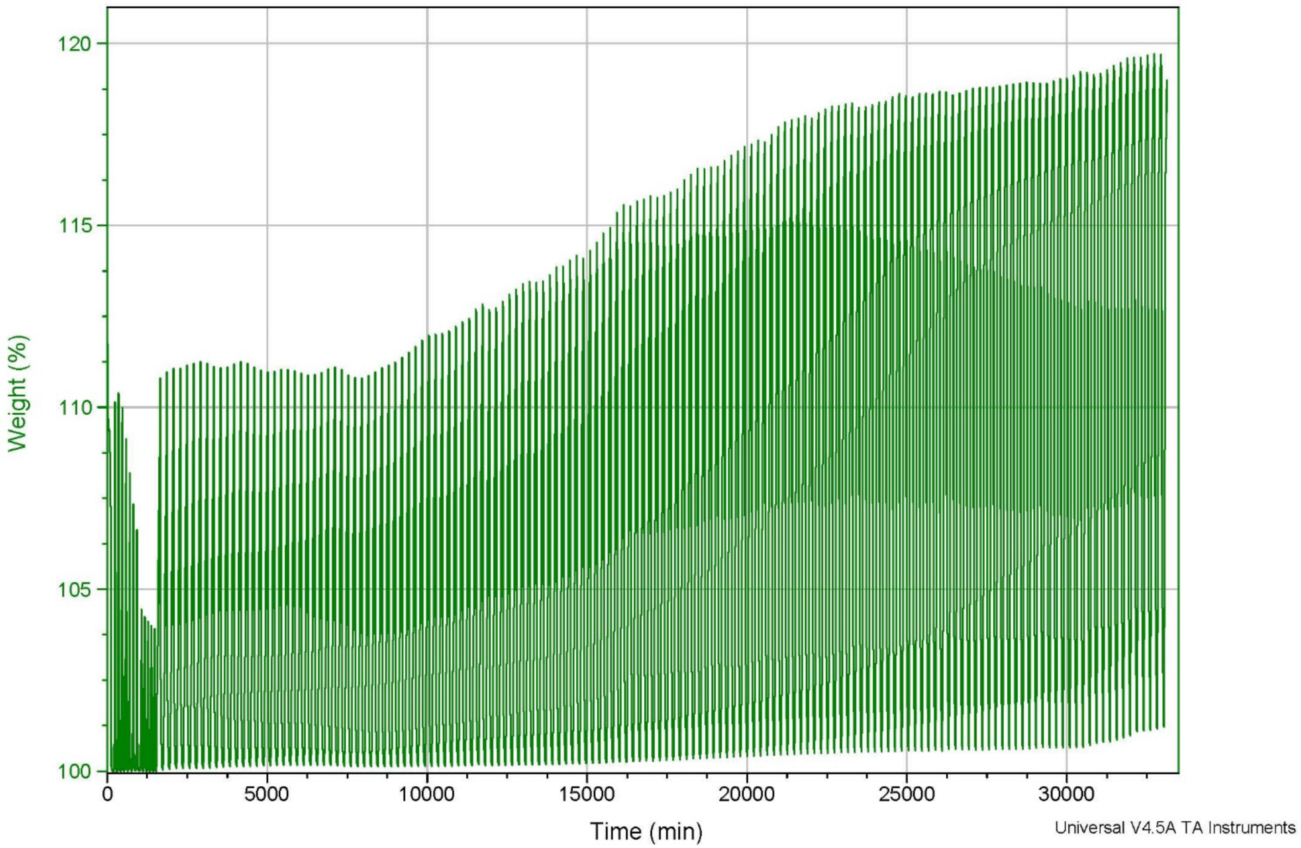


Results duplicated in separate batch of same sorbent

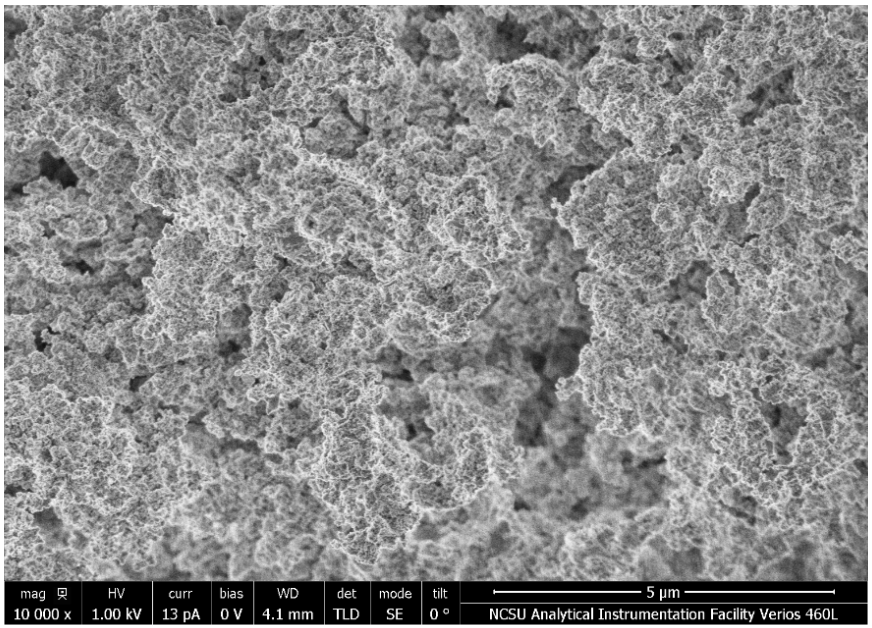


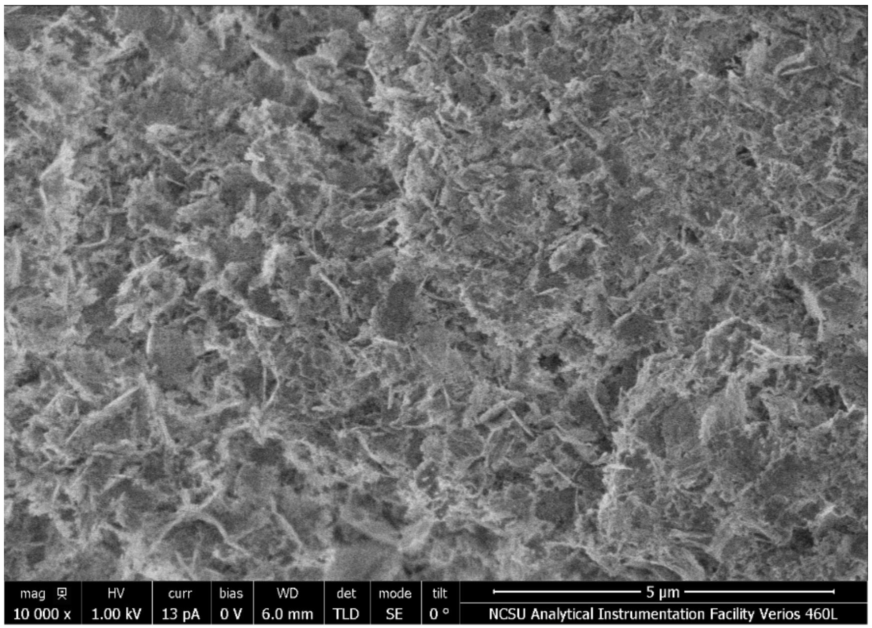
Sorbent formula 1.3 converted to pellets

Pellets made of SR-1.3 stable for over 150 cycles



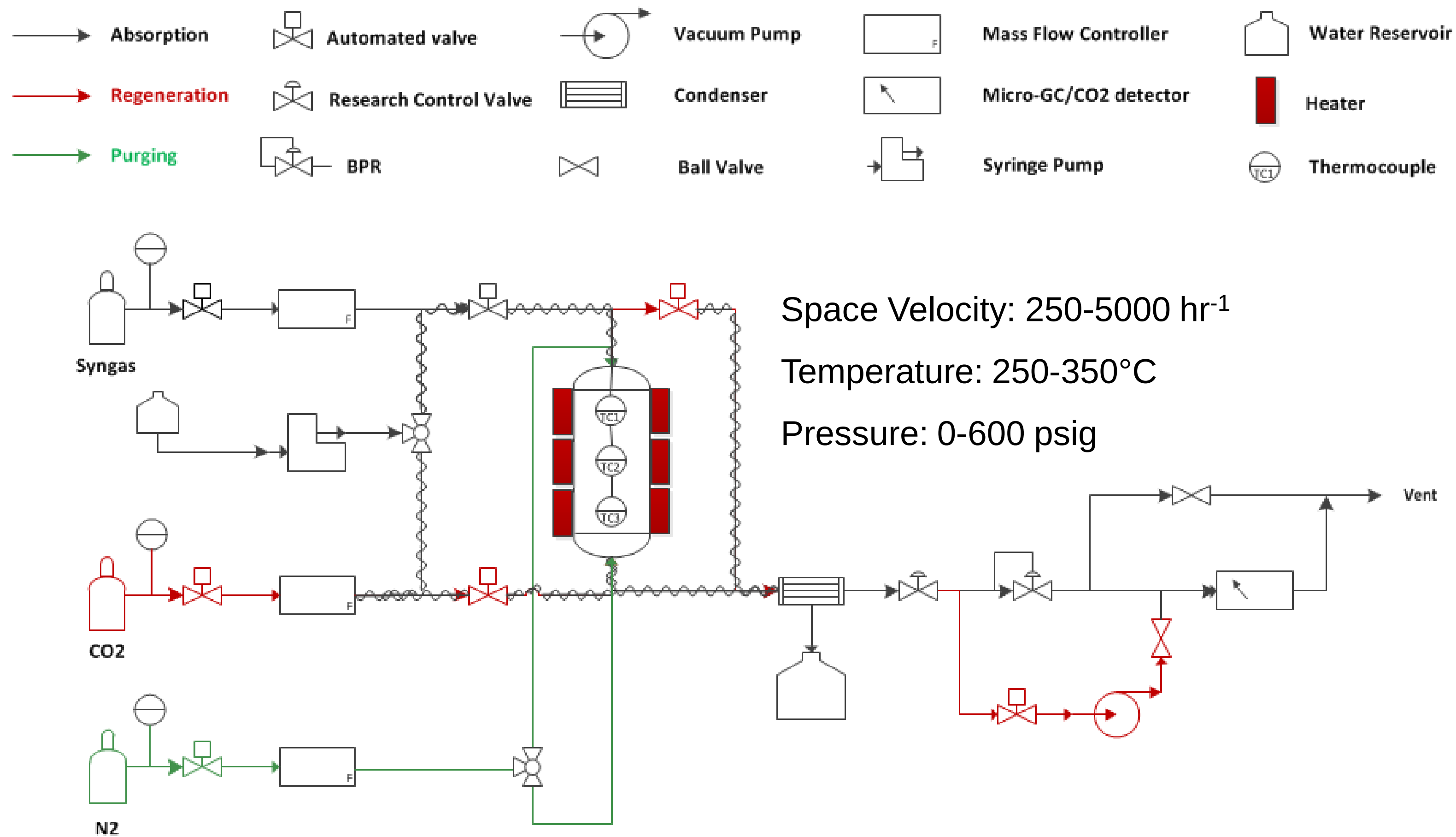
SEM images of MgO (left) and promoted MgO (right)





Additional XRD, ICP, SEM and SEM/EDS characterizations ongoing for cycled, carbonated, and regenerated sorbents to assist in developing improved sorbents

CO_2 Capture Reactor Design



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

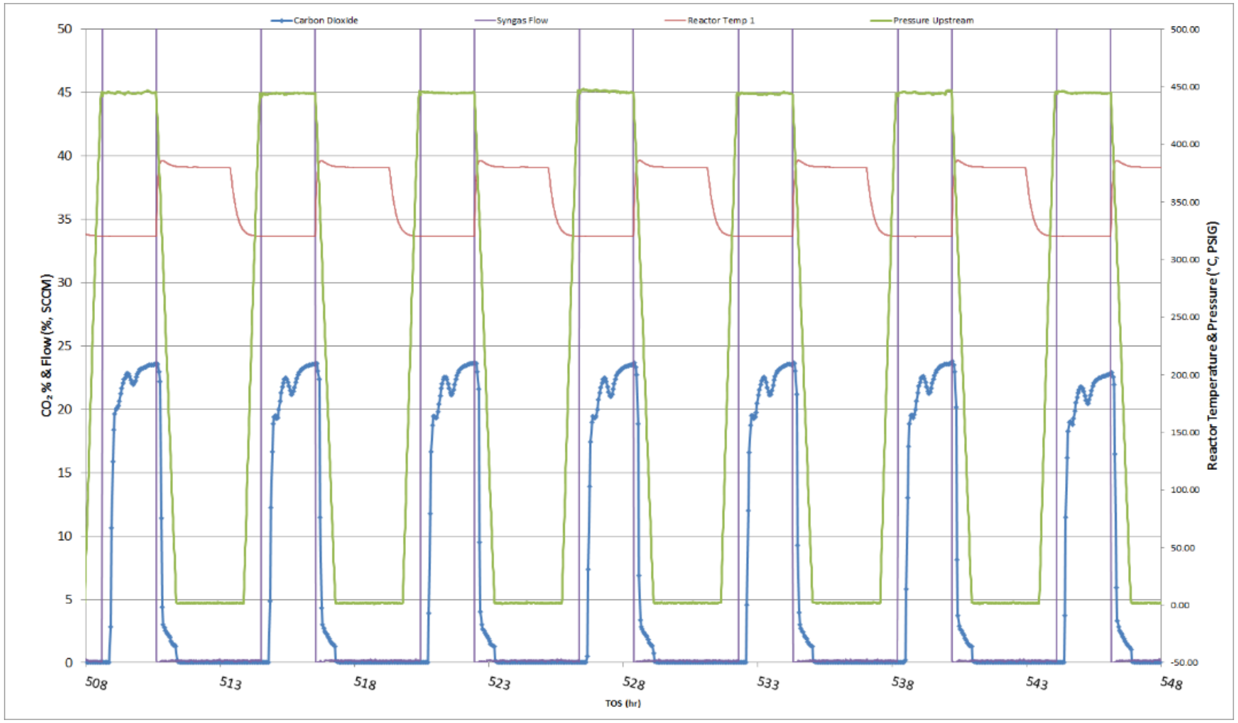
Temperature: 250-350°C

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
- Feed based on TRIG and GE Gasifier Syngas

Laboratory Scale CO_2 Capture Skid

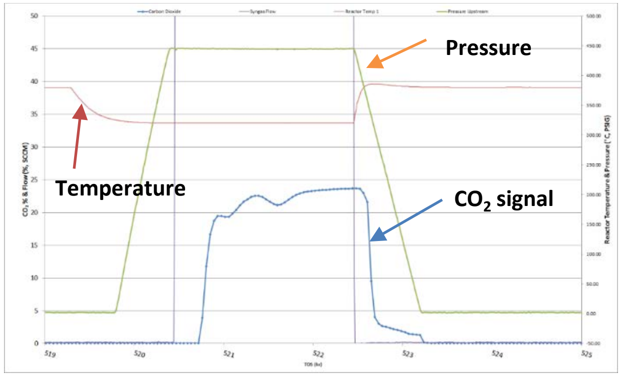
Skid Test: Blank test for dead volume under 450 – 1 psi with pressure swing under 25% CO_2 in N_2



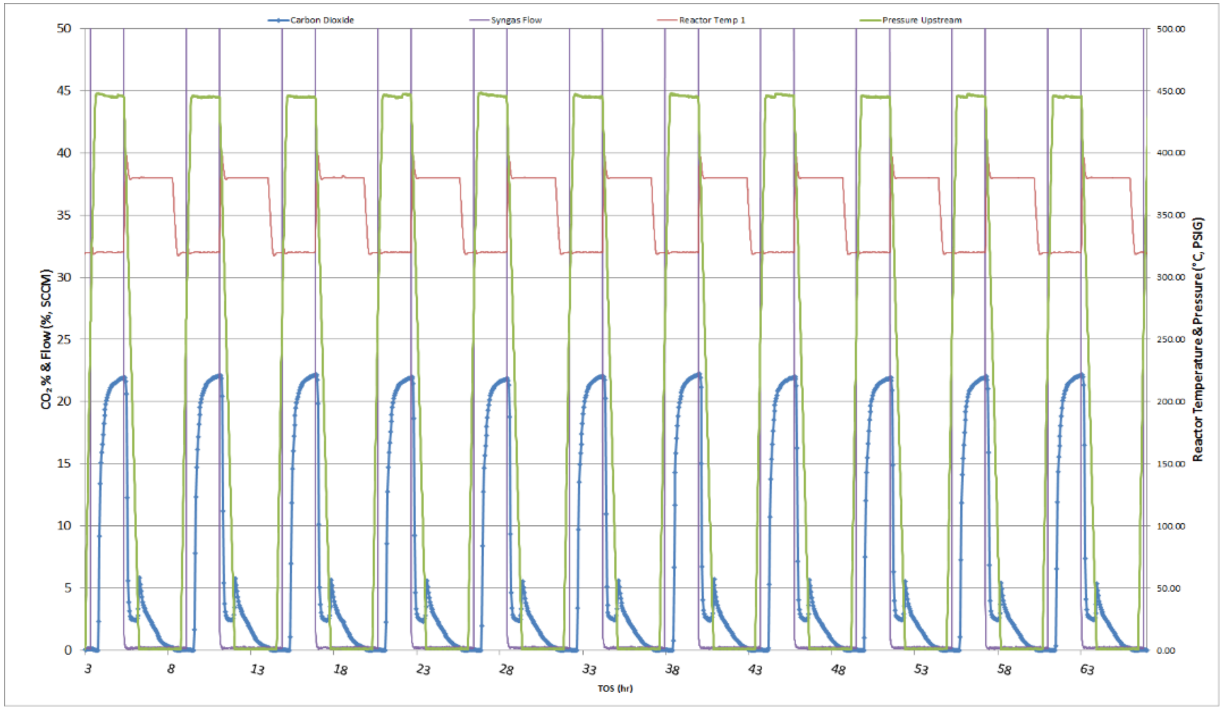
Space velocity: 1000

Pressure: 450 - 1 psig pressure swing

Breakthrough time for purging through the lab skid dead volume: 16.1 min



Skid Test: SR-1.2 sorbent test for CO_2 capacity under 450 – 1 psi with pressure swing under 25% CO_2 in N_2

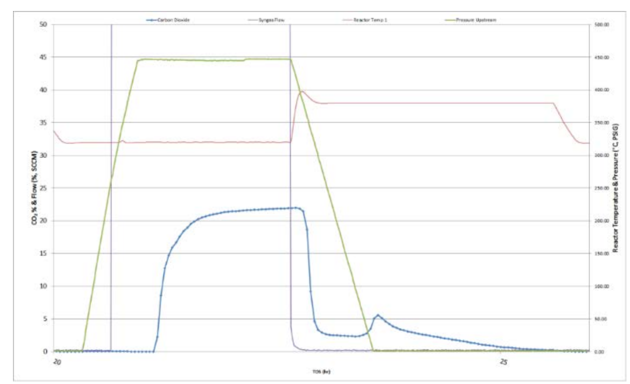


Space velocity: 1000

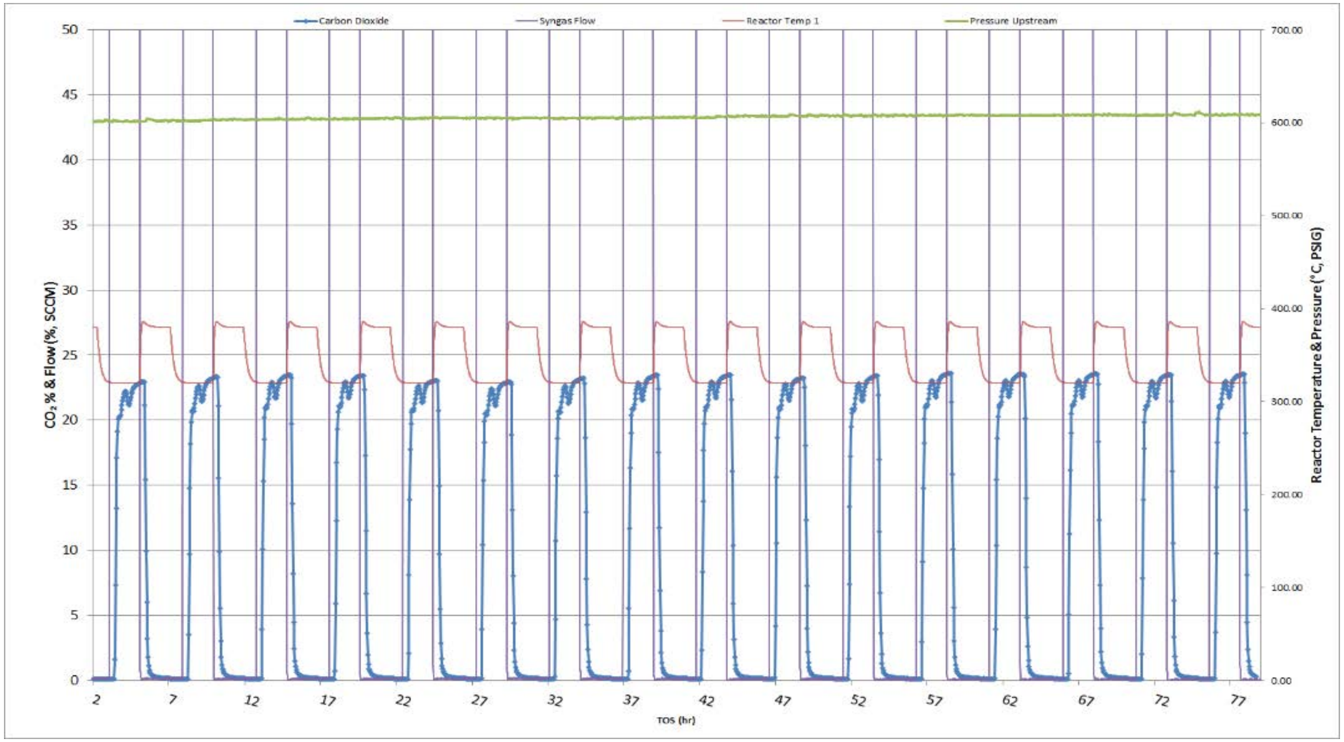
Pressure: 450 - 1 psig pressure swing

Breakthrough time: 28.8 min

Sorbent working capacity for CO_2 capture: 0.012065 mol or 2.74 mmol/g



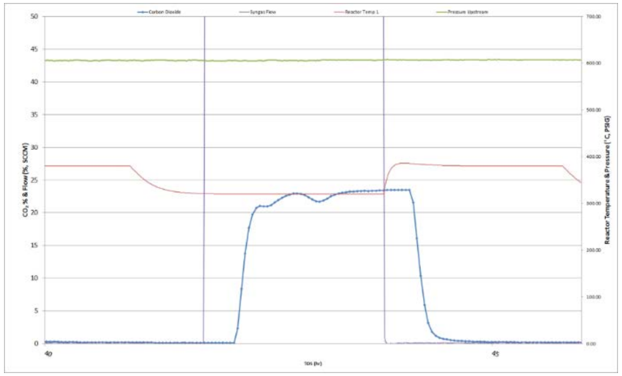
Skid Test: Blank test for dead volume under 600 psi without pressure swing under 25% CO_2 in N_2



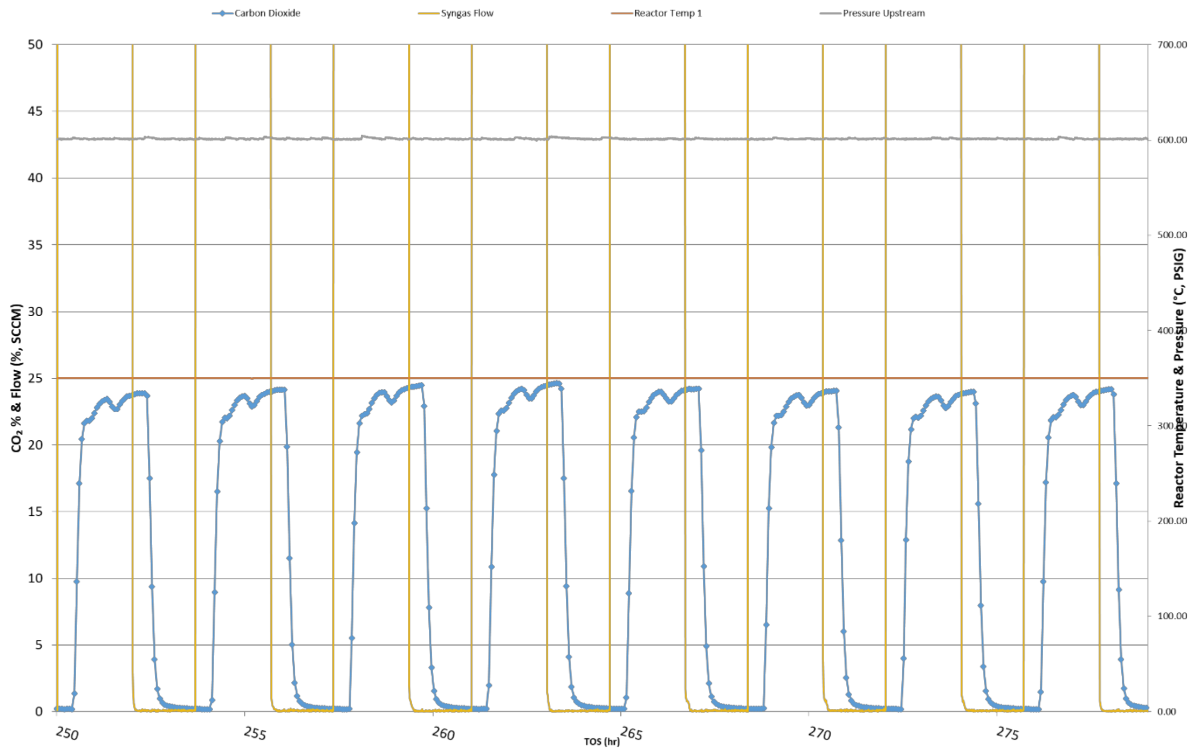
Space velocity: 1000

Pressure: 600 psig with no pressure swing

Breakthrough time for purging through the lab skid dead volume: 19.8 min



Skid Test: SR 1.3 test for CO_2 capacity under 600 psi without pressure swing under 25% CO_2 in N_2

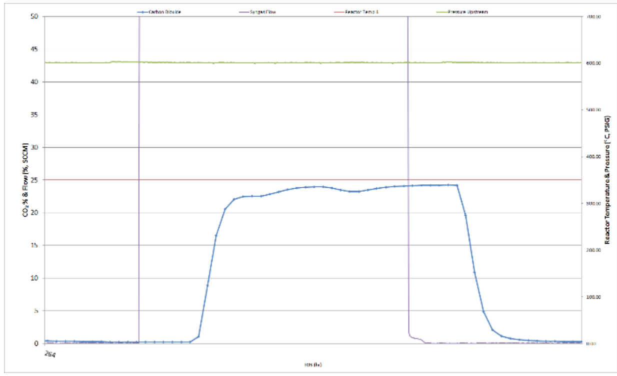


Space velocity: 1000

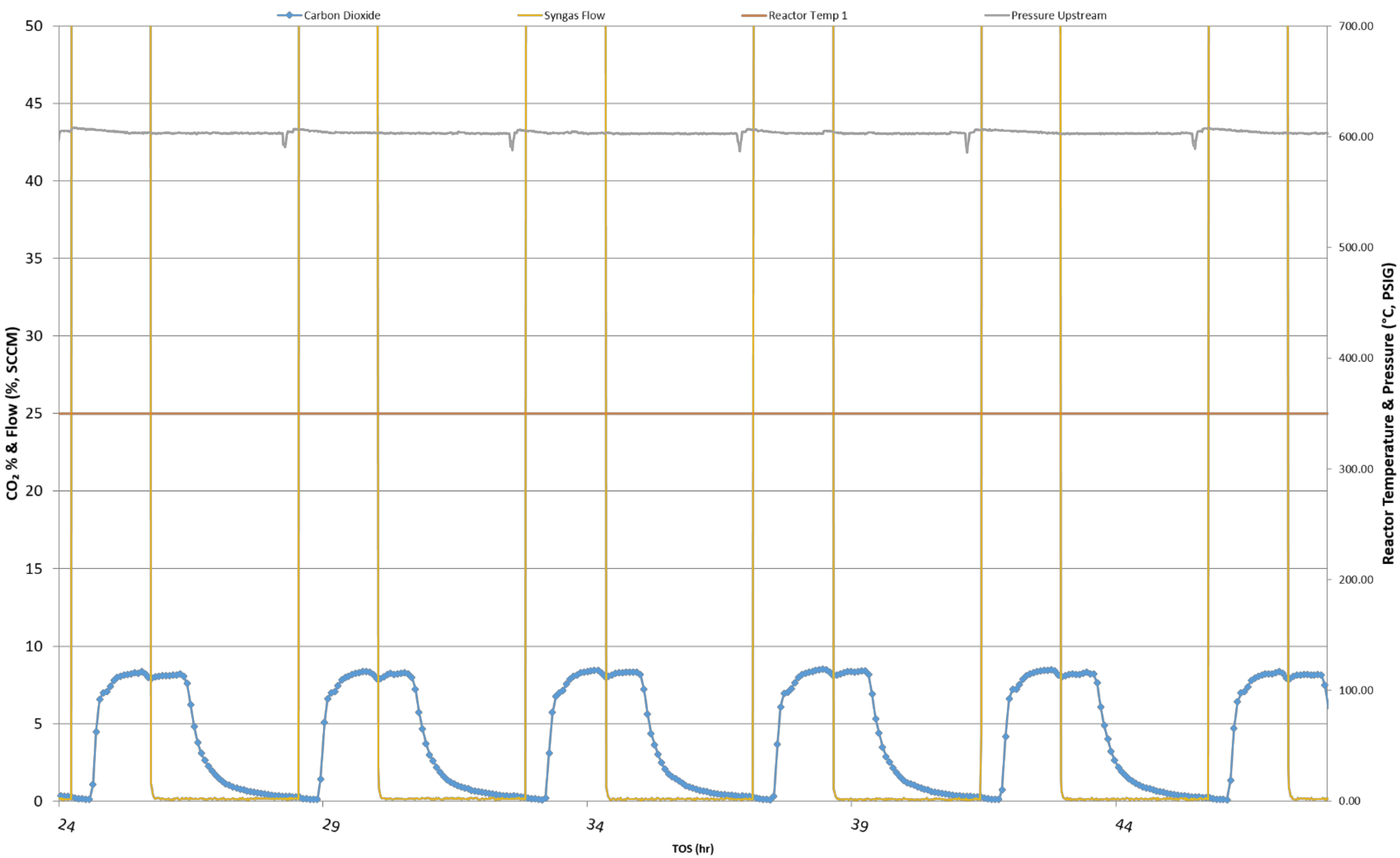
Pressure: 600 psig with no pressure swing

Breakthrough time: 30 min

Sorbent working capacity for CO_2 capture: 0.0095 mol or 2.16 mmol/g



Skid Test: SR 1.3 test for CO_2 capacity under 600 psi without pressure swing feeding simulated syngas. Data currently being evaluated.



Milestone Performance

- 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
    - Milestone met; Average 4.5 mmol/g increasing over 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
    - 90% CO_2 capture demonstrated in bench reactor
    - Commercial high activity WGS catalyst obtained

Summary

- Southern is developing a novel hybrid CO_2 capture/WGS reactor with integrated heat management
- Promising sorbents exceeded capacity and durability targets in powder and pellet form
- Several characterization techniques utilized including XRD, ICP, BET, SEM/EDS
- TGA experiments repeatedly confirmed CO_2 capacity in excess of targets for >100 cycles for powders and pellets
- Laboratory skid experiments confirmed CO_2 capture performance in excess of targets with no degradation several experimental conditions
- Successful completion of the project will develop technology ready for closed-loop testing at the bench-scale (TRL 5) with actual coal-derived syngas.
- Data and modeling tasks planned to confirm that technology has potential to meet DOE energy performance goals of 90% CO_2 capture, 95% CO_2 purity, and potential for 30% reduction in cost of electricity compared to baseline CO_2 capture approaches.

Future Plans

- Complete sorbent tests with simulated syngas (BP1)
- WGS catalyst performance confirmation (BP1)
- Integrated CO_2 capture/WGS experiments (BP2, BP3)
- Economic feasibility study (BP1, BP2, BP3)
- Scale-up and test on coal-derived syngas for technology development after project completion

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Questions?