Evaluation of Dry Sorbent Technology for Pre-Combustion CO_2 Capture

(FE-0000465)

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URS Group

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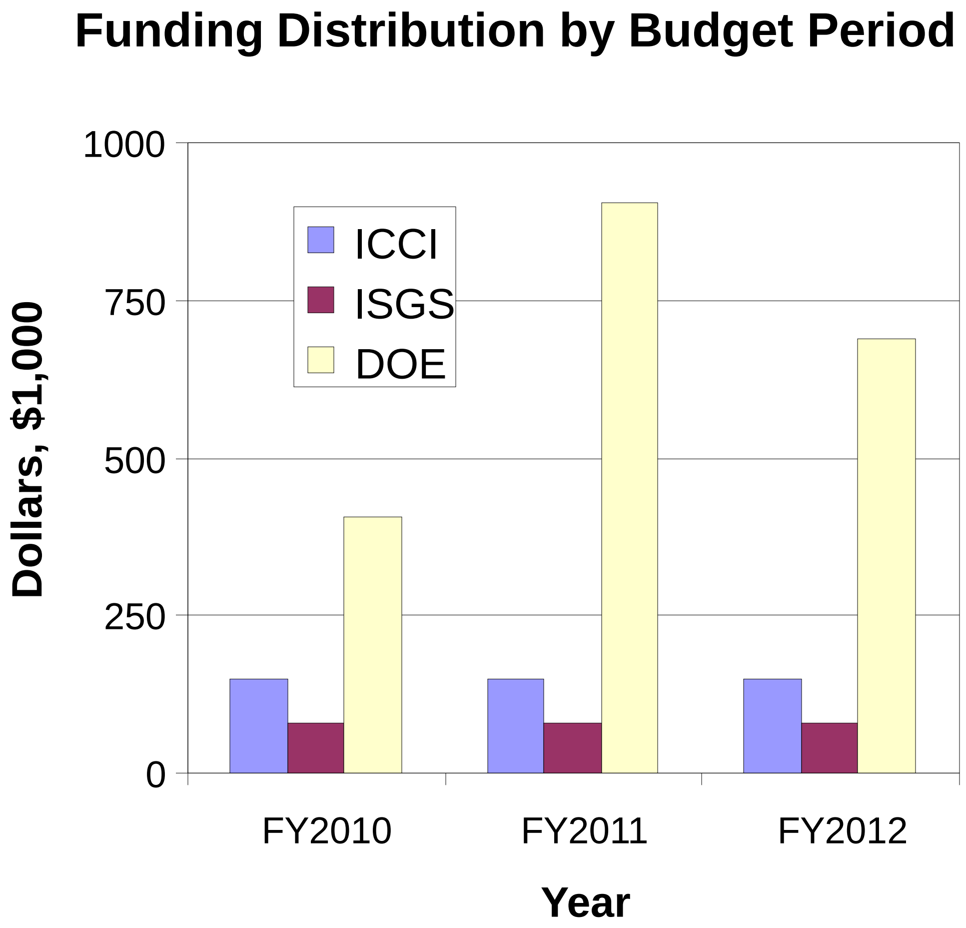
Project Funding & Performance Dates

BP1: $ 633,669

BP2: $1,134,602

BP3: $ 916,123

Total: $2,684,394



- Cost Share is 25%
- POP is September 2009 through September 2013

Project Objectives and Scope of Work

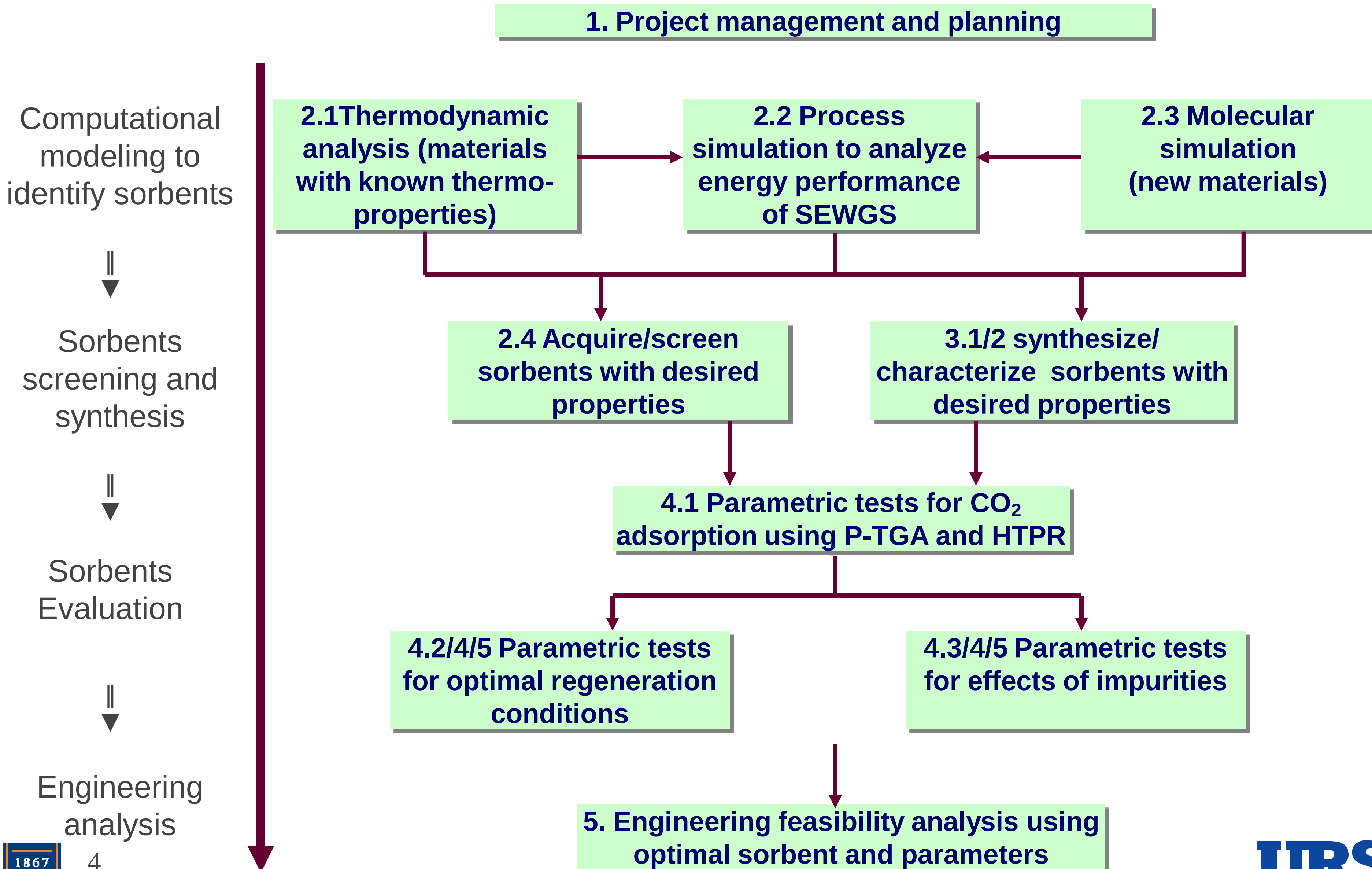
Objective

- **Identify, develop, and optimize engineered sorbents for a process that combines CO_2 capture with the water gas-shift (WGS) reaction**

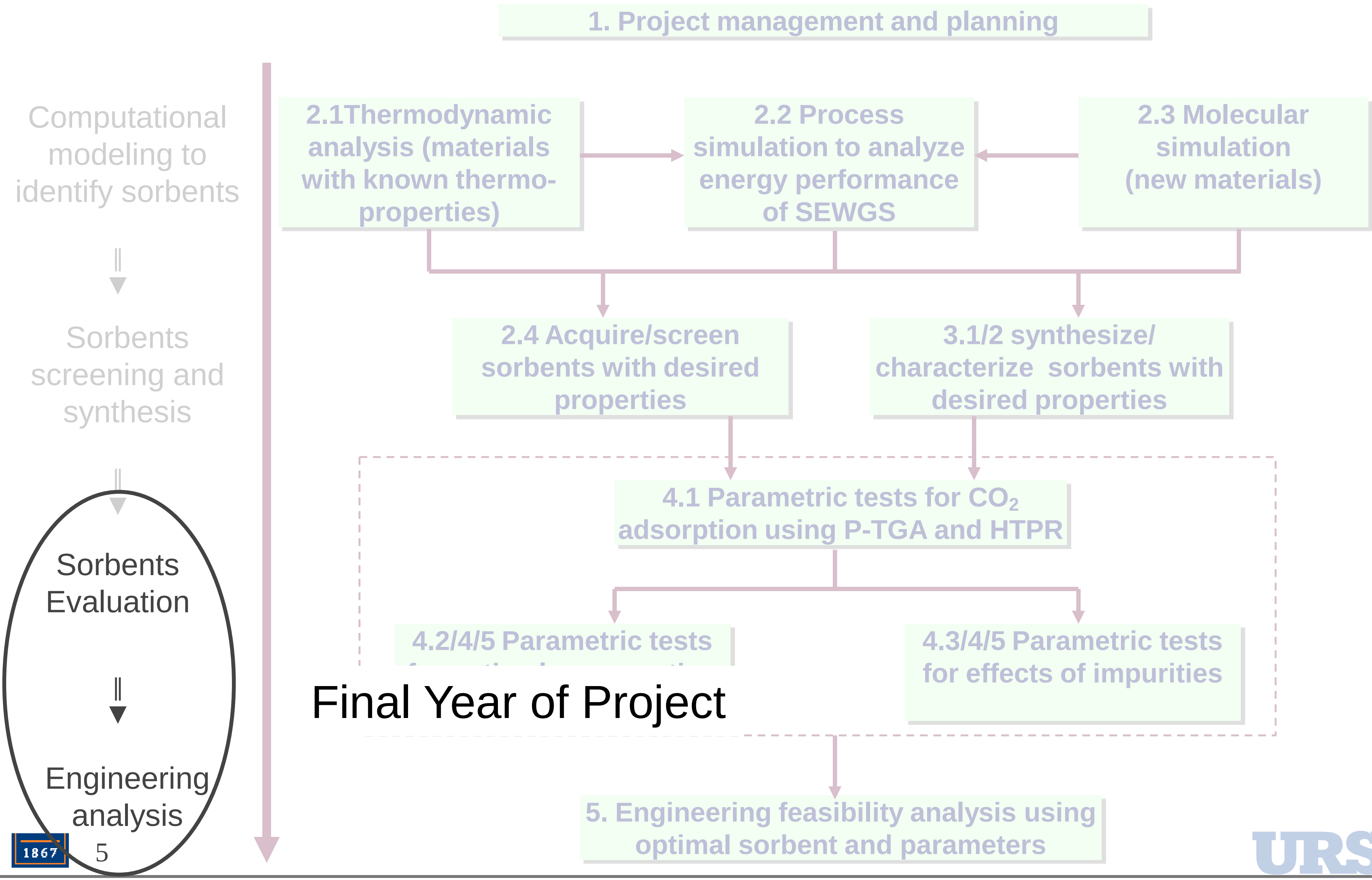
Scope of Work

- **Thermodynamic, molecular and process simulation modeling to identify/predict optimal sorbent properties and process operating conditions**
- **Synthesis and characterization of sorbents**
- **Experimental evaluation of sorbents for CO_2 adsorption and regeneration**
- **Techno-economic analysis**

Research Tasks



Research Tasks

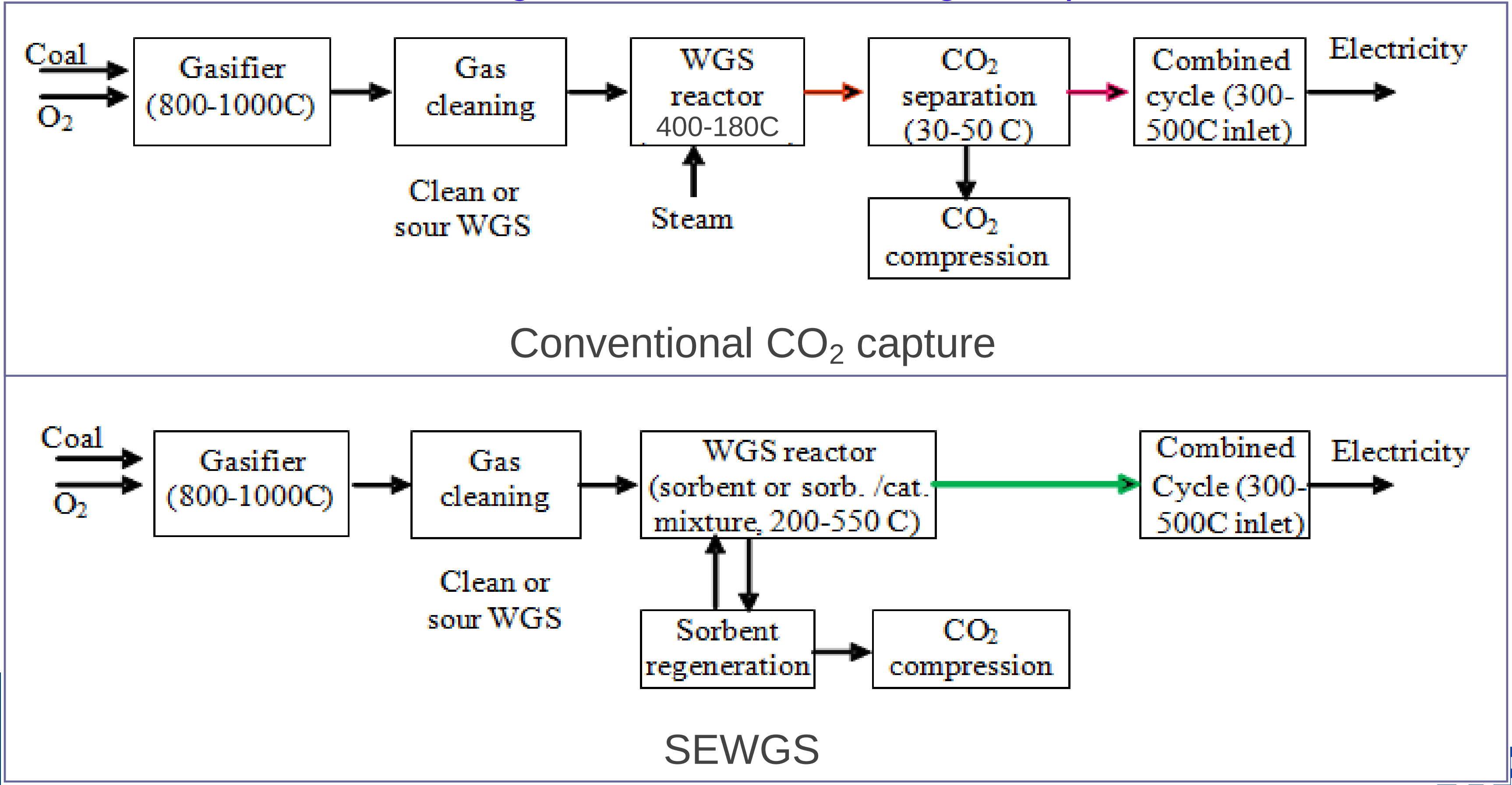


Technology Fundamentals/Background

IGCC + SEWGS vs. Conventional IGCC

$CO + H_2O = CO_2 + H_2$

- Exothermic reaction
- Kinetically limited at low temperatures, multiple stages / temperatures required
- SEWGS can achieve high CO conversion at high temperature

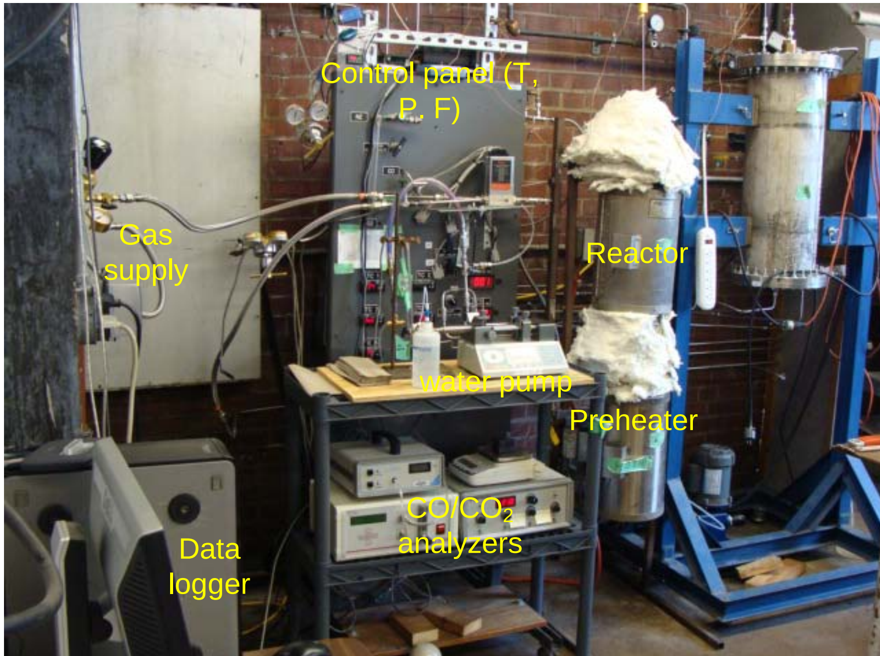


Progress and Current Status

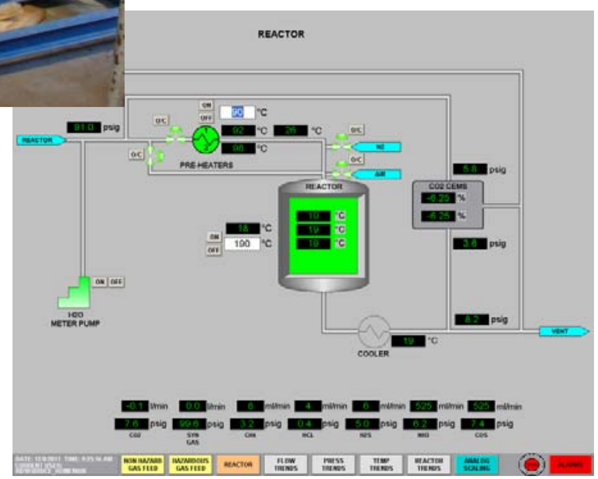
Current Status Overview

- Computational Modeling
  - Thermodynamic Modeling, Process and Molecular Simulations
  - Helped down-selected from ‘optimal’ sorbents
- Sorbent Preparation
  - Goal is to synthesize sorbents per computational modeling and with high capacity, WGS reactivity, long cycle life, etc.
  - Ultrasonic Spray Pyrolysis, Flame Spray Pyrolysis, and Molecular Alloying
- Sorbent Evaluation
  - Analytical Characterization and TGA for screening
  - High Temperature, High Pressure Reactor Studies: laboratory simulated, closest to real world conditions short of pilot studies
- Techno-Economic Study
  - Evaluated different approaches to process
  - Identified keys to economic viability

High Temperature, High Pressure Reactor



- Up to 1000°C, 40 bar
- PLC Controlled
- CO/CO_2 monitoring



- Syngas, CO_2/N_2, steam introduced as water
- Corrosive / toxic environment (*e.g.*, NH_3, H_2S, HCl)

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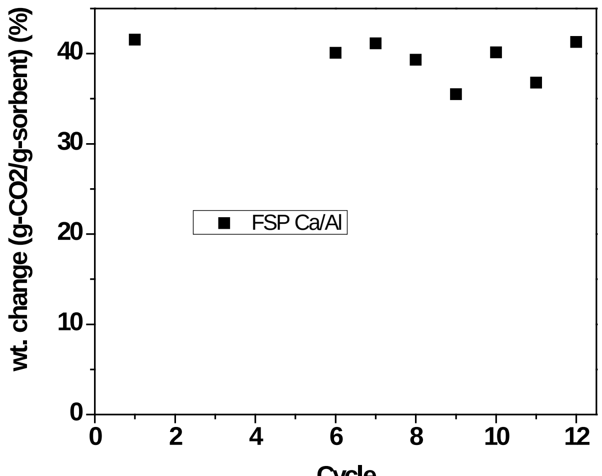
CO_2 Adsorption / Desorption Tests

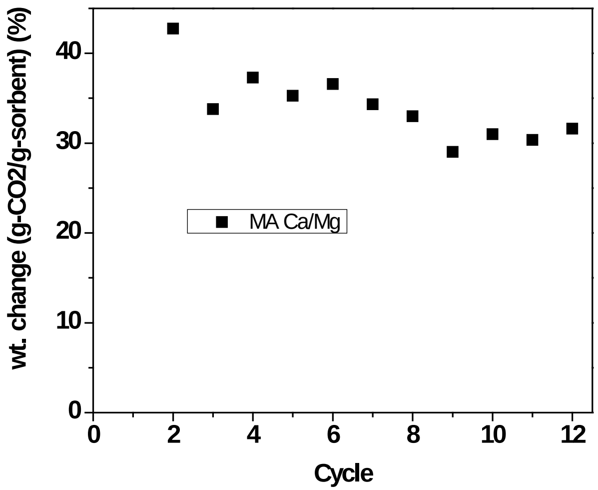
- Adsorption in CO_2/N_2 and desorption in N_2

	Temperature, °C	Time, min	P_{CO2}, bar	P_{total}, bar
Adsorption	650	12*	4	12
Regeneration	650 ~ 830	~90	0	12

*30 min CO_2 adsorption in Cycle 12.



Sorbent FSP32



Sorbent MA63

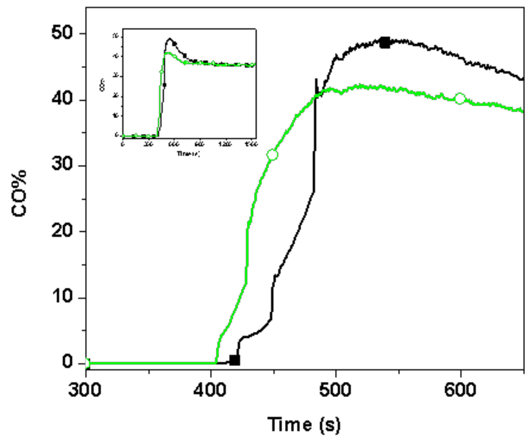
- Capacity of the sorbents: 0.3 – 0.4 $g_{CO2}/g_{sorbent}$ (70-80% of theoretical)
- Comparison between cycle 12 and cycles 1-11 indicated CO_2 adsorption completed in ≤12 min

SEWGS Performance Tests

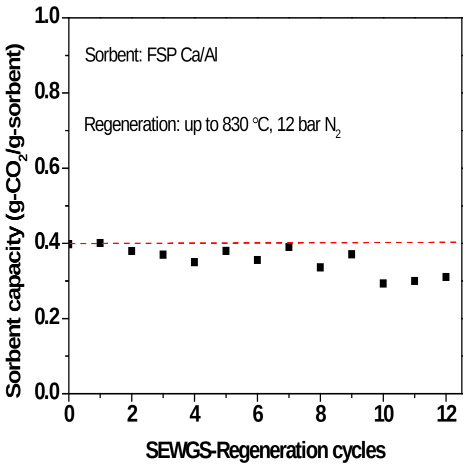
- CO_2 adsorption/WGS (SEWGS) in syngas and desorption in N_2 or N_2/H_2O

	Temperature, °C	Time, min	P_{CO}, bar	P_{H2O}, bar	P_{N2}, bar	P_{total}, bar
SEWGS	650	20	4	8	0	12
Regeneration	650-830	~90	0	0	12	12
Regeneration*	650-830	~90	0	2	10	12

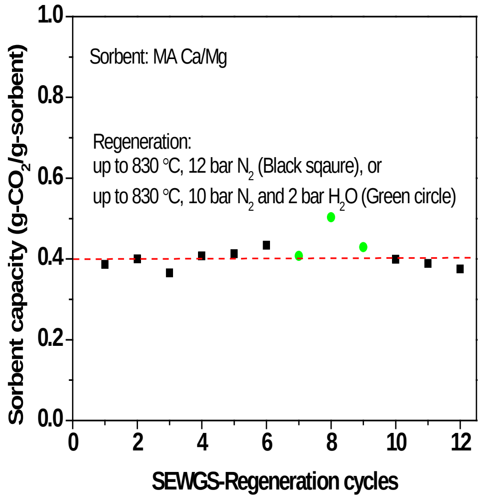
*Regeneration conditions used for Sorbent MA63 in Cycles 7-9.



An example of CO and CO_2 concentration profiles (Sorbent MA63)



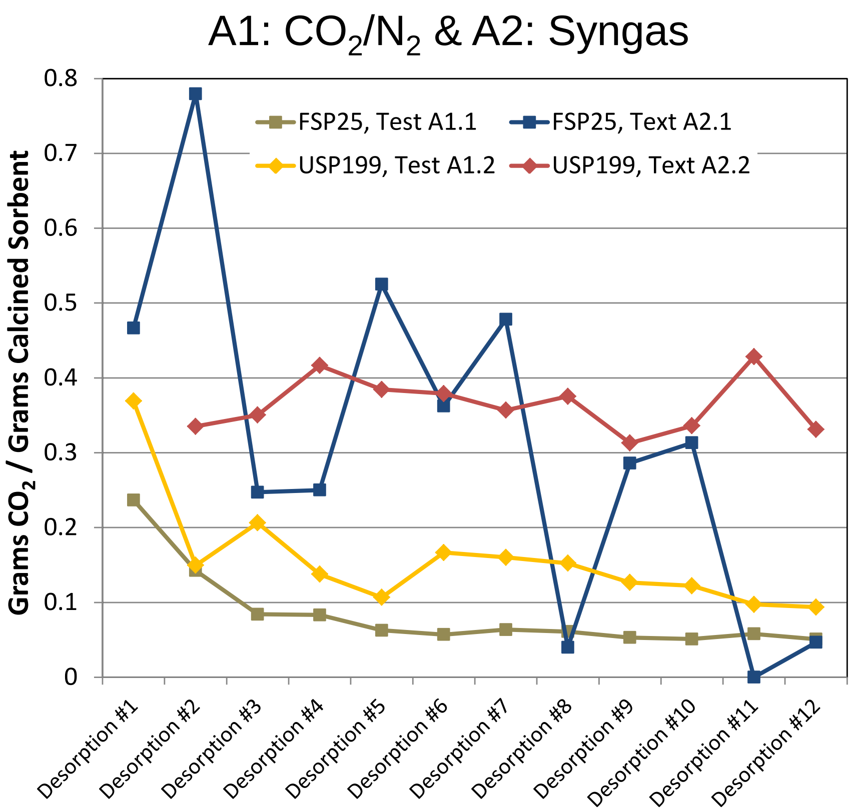
Sorbent FSP32

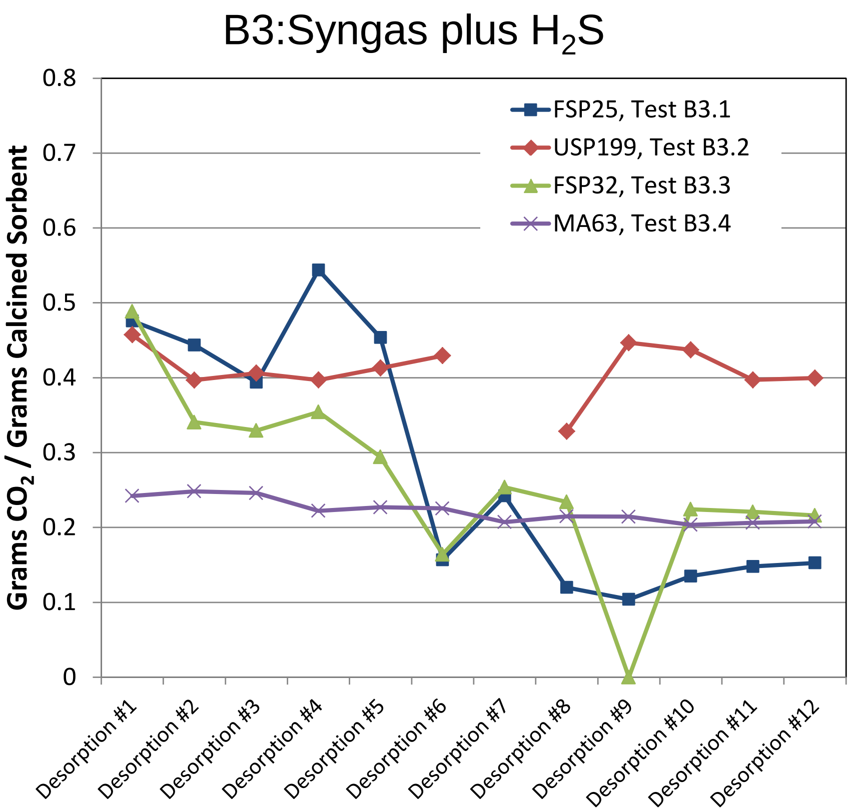


Sorbent MA63

- CO conversion increased from 47% to ~100% with sorbent (equilibrium CO conversion 77% at tested conditions without sorbent)
- Improved sorbent performance in syngas (w/ water vapor)

Test Results: Working Capacity and Impact of H_2S





FSP25	44:56 wt% $CaZrO_3$:CaO (FSP)
USP199	25:75 wt% Meyenite:CaO (USP)
FSP32	1:4 Al:Ca at% (FSP)
MA63	23:77 wt% MgO:CaO (MA)

- Sorbents perform better in syngas
- USP199 seems to perform better
- Low impact of H2S

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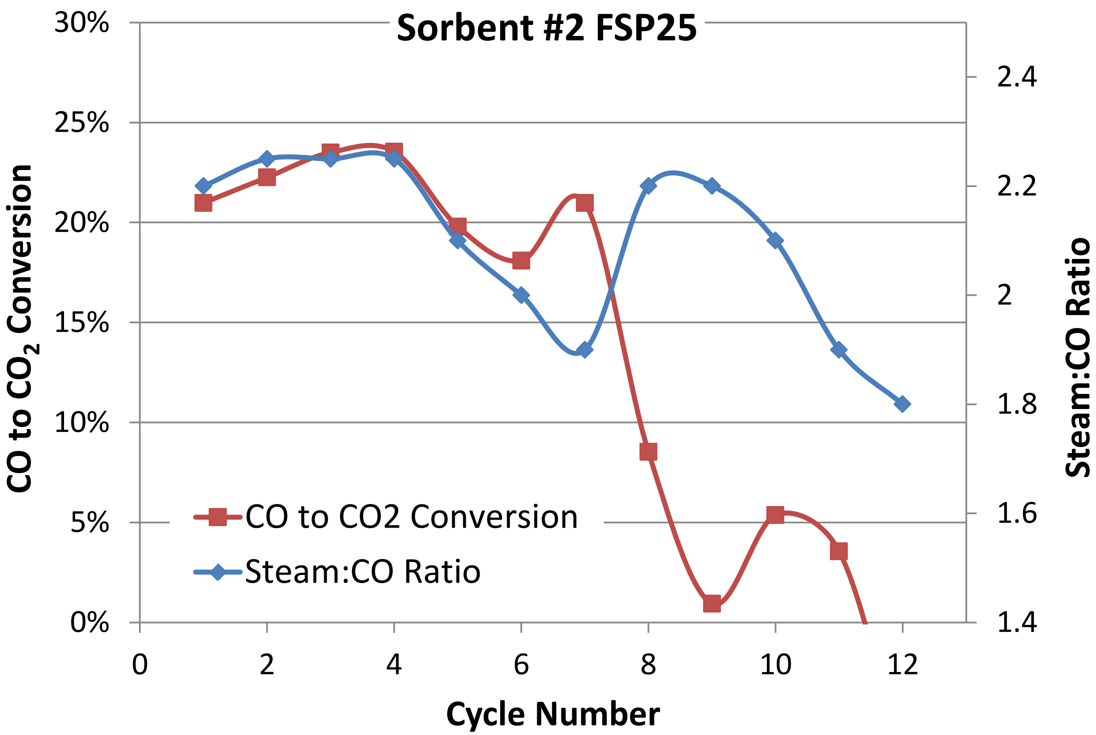
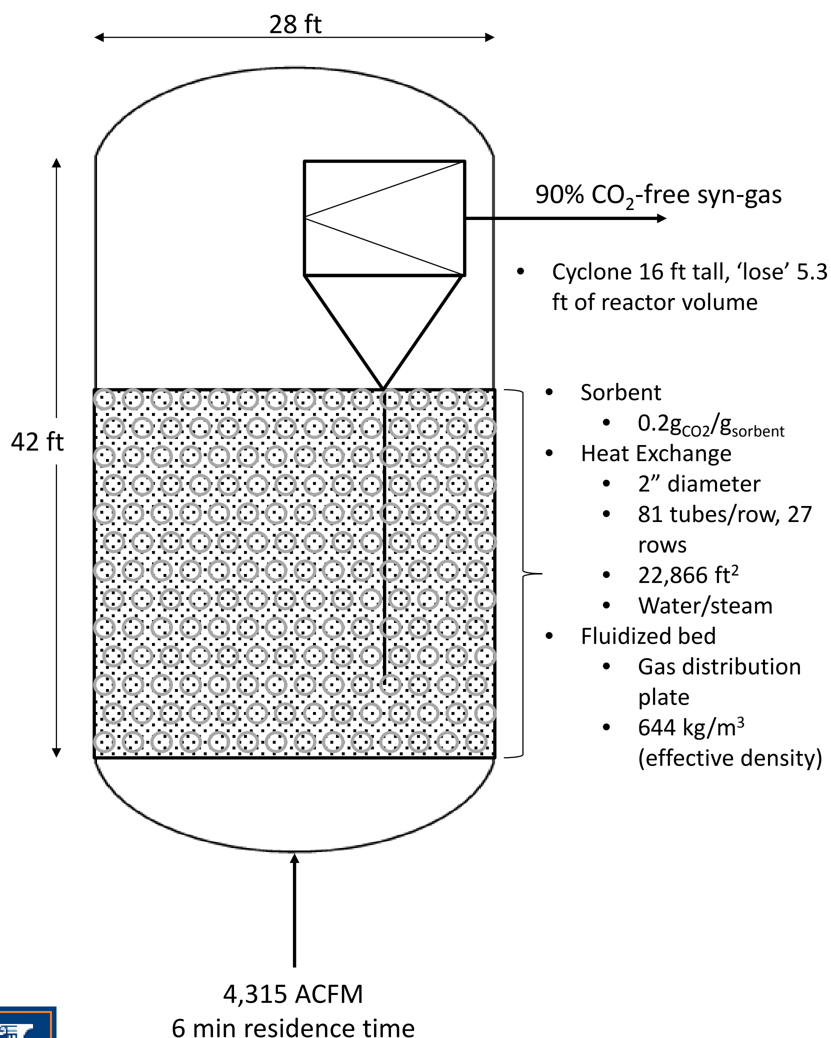
HTPR Results: Impact of Steam:CO Ratio on FSP25

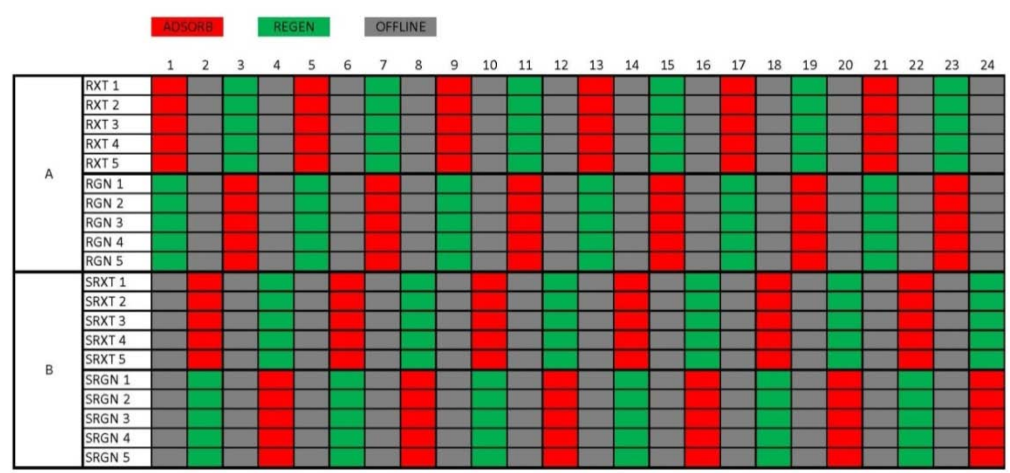


- Steam:CO ratio difficult to control (parametric conditions not always achieved)
- Apparent trend with decreasing ratio of CO conversion
- Conversion lower than observed by ISGS
- Hybrid sorbents may be necessary; could include WGS catalyst usage

Technoeconomic Assessment, Initial Approach



- Reactors switching between adsorption and regeneration
- Heat of adsorption removed by water
- Steam generated superheated to regenerate
- Resulted in long cycle times, many reactors, many heat exchange tubes
- Failed to take advantage of benefits of SEWGS

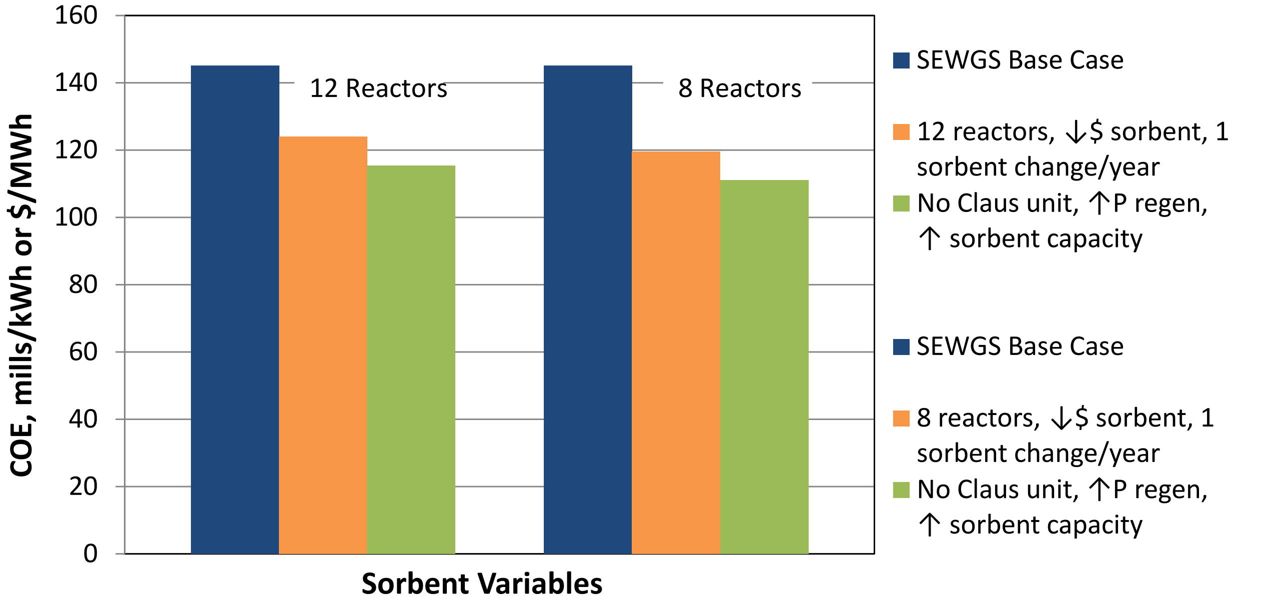


Techno-economic Assessment, Initial Approach

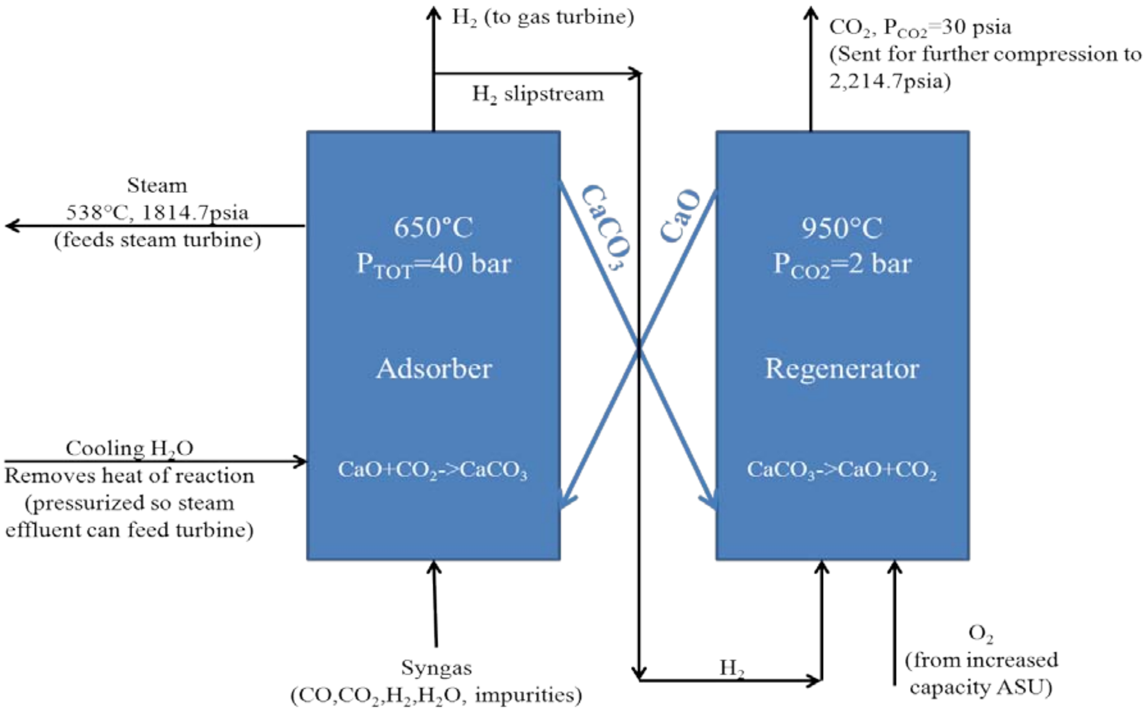
CO_2 Capture Scenario	TOC ($M)	COE (mills/kWh or $/MWh)
Case 6 (DOE Report)	1,940	119.4
SEWGS – Base Case	2,208	145.1
SEWGS – Fewer reactors (1/2)	2,031	136.4
SEWGS – Fewer reactors (1/3)	1,933	131.9

Base case for SEWGS not competitive, so assumed fewer reactors, still not competitive….

Even with all optimistic assumptions using initial approach, SEWGS can't compete with Case 6



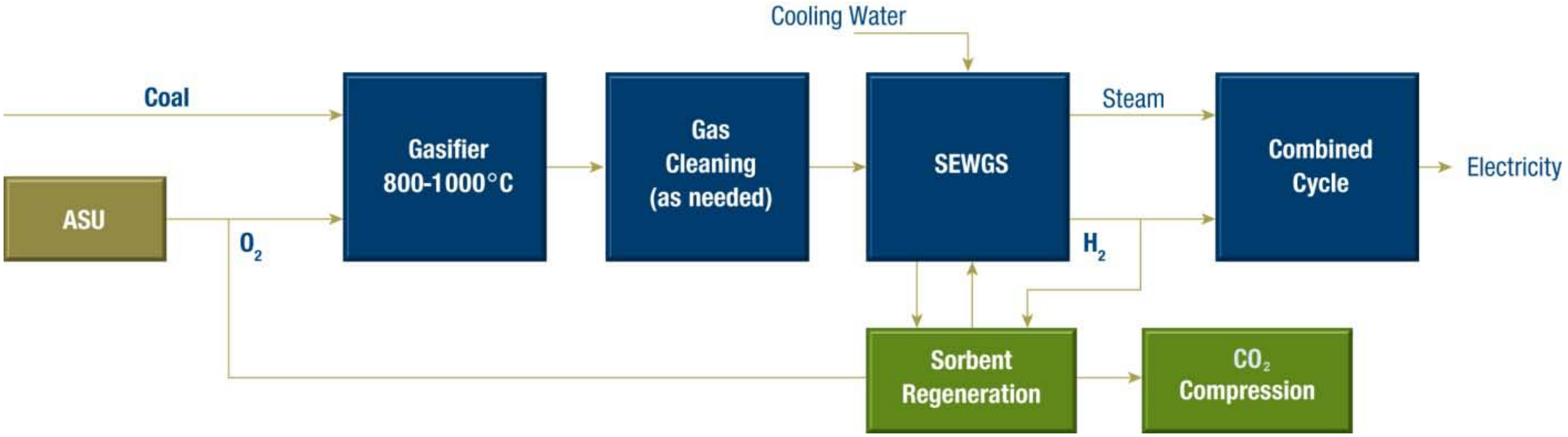
Techno-economic Assessment, Alternative Approach



- Dedicated adsorbers and regenerators
  - <u>Result</u>: Reduced the number and size of reactors (24 to 12)
- Combust H_2 with O_2 to generate the heat for regeneration
  - <u>Result</u>: Need another ASU and parasitic losses increase, but more efficiently generate pure CO_2
- Design process such that the water used to remove the heat of the adsorption can feed a steam turbine
  - <u>Result</u>: Need another steam turbine, but gain MWe capacity

Techno-economic Assessment, Alternative Approach

Case	ASU Penalty, MW	CO_2 Comp Penalty, MW	Regen Penalty, MW	Energy Gen. from H_2, MW	Energy Gen. from Adsorption, MW	Net MW	COE, $/MWh
Case 6	-60	-30	-19	464	-0-	497	119
SEWGS, Regen @ 1165°C	-107	-6	-213	251	419	594	128
SEWGS, Regen @ 950°C	-81	-30	-93	371	419	774	98



SEWGS becomes viable, but technological hurdles remain

Summary

- Four nano-engineered sorbents chosen for HTPR testing
- Capacities approaching 0.4 $g_{CO_2}/g_{sorbent}$
- Performance improved in syngas / water vapor
- No significant impacts of H_2S observed (other impurity studies ongoing)
- Steam:CO ratio still under investigation
- Techno-economics
  - Traditional process approach not competitive
  - More technically challenging approach
    - Creating turbine quality steam from heat of adsorption
    - Moving sorbent from dedicated sorption reactor to regenerator
    - Combusting H_2 slip with O_2 from ASU
    - Economically competitive, but technical challenges remain

Plans for Future Work

- Complete parametric tests with all impurities
  - (H_2S, NH_3, HCl, COS)
- Long-term tests on select sorbents (USP199)
- Revise Techno-economic Assessment
- Final Report

<u>Next Phase</u>

- Determine WGS viability / CO to CO_2 conversion of different sorbents
- Evaluate sorbents in more accurate regeneration environment
- Engineering challenges: reactor design, moving sorbent at operating conditions

Acknowledgments

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