A High Efficiency, Modular Pre-combustion Capture System for 21st Century Power Plant Poly-generation Process (Contract No. DE-FE0031926)

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Project Objectives

- **The objective is to demonstrate techno-economic viability of a modular coal-to-energy-and-chemicals process with a focus on syngas treatment and processing**
  - A high temperature PSA adsorbent/WGS process is used for CO_2 removal
  - A fixed-bed TSA based sulfur removal system will be used to remove H_2S
  - High temperature contaminant removal process to remove any contaminants
- **Project Tasks**
  - Design a fully-equipped slipstream test unit with 10 SCFM treatment capacity
  - Demonstrate the operation of the integrated system in achieving high CO_2 and contaminant removal efficiency
  - Detailed design of the integrated system
  - High fidelity process design and economic analysis

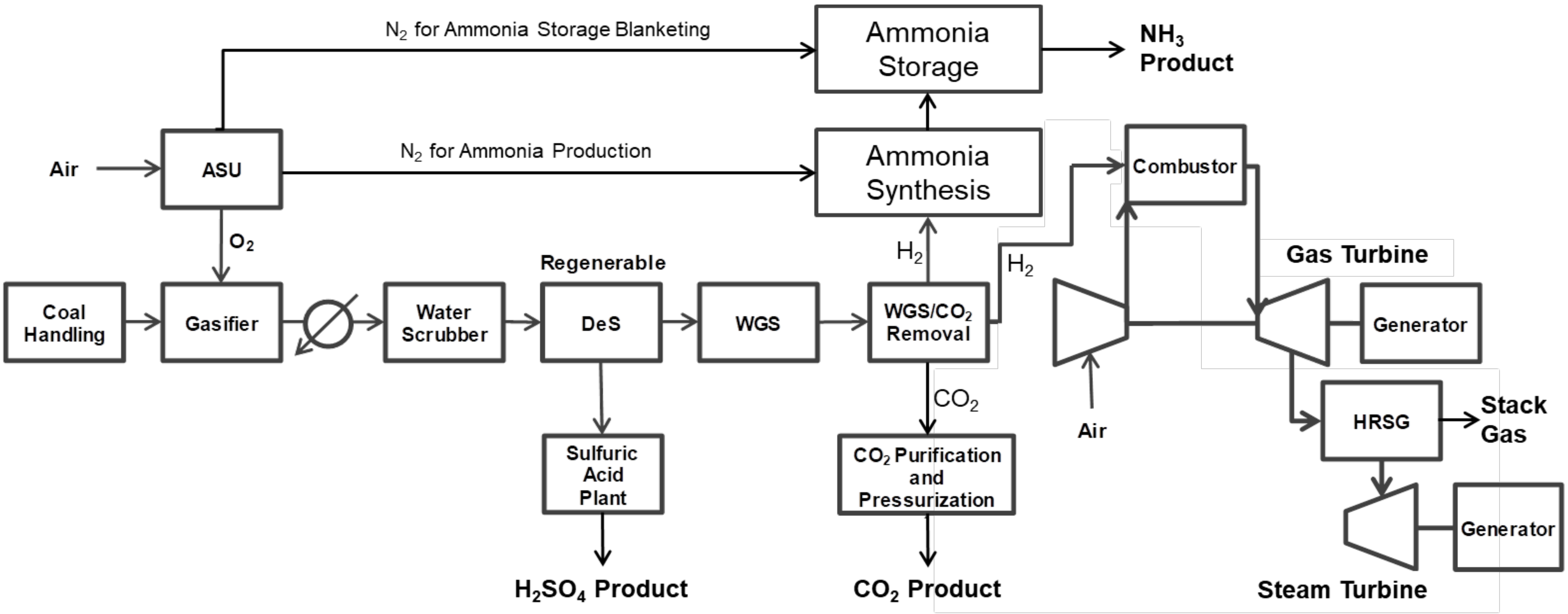
Project Duration

Start Date = October 1, 2020

End Date = September 30, 2025

	DOE Share	Cost Share	Total
BP 1	$886,187	$221,547	$1,107,734
BP 2	$792,419	$198,105	$990,524
BP 3	$1,321,394	$330,348	$1651,742
Total	$3,000,000	$750,000	$3,750,000

Process Schematic



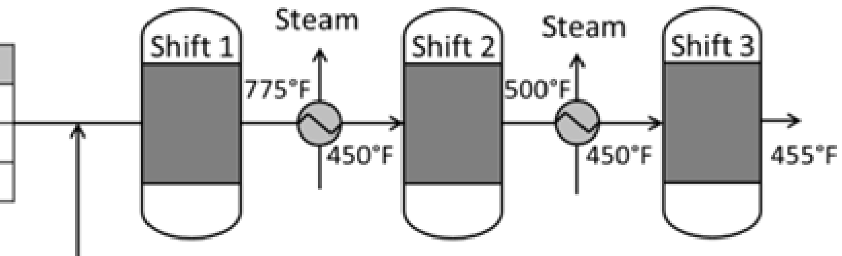
- **Warm gas removal of CO_2, sulfur and contaminants improve efficiency**
- **Reducing the use of excess steam improves power cycle efficiency**
  - Lower energy consumption to raise the steam
- **Process intensification could potentially reduce the number of hardware components and cost**

TDA's Approach – Carbon Capture

- **In conventional coal-to-hydrogen or coal-to-power applications, a multi-stage WGS process with inter-stage cooling is used**
  - WGS is an equilibrium-limited exothermic reaction
- **Water is supplied at concentrations well above required by the reaction stoichiometry to completely shift the CO to CO_2**
- **Excess water is also used to suppress carbon formation**

H2O/CO Ratio[1]	
GE	1.3
E-Gas	0.4
Shell	1.5

[1]Prior to shift steam addition



	Relative HP Steam Flow	Steam Turbine Output (MW)
GE	1.0	275
E-Gas	2.4	230
Shell	0.9	230

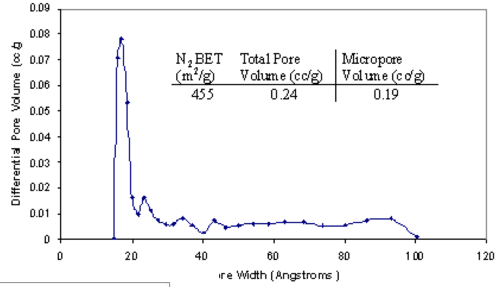
$H_2O + CO \leftrightarrow CO_2 + H_2$

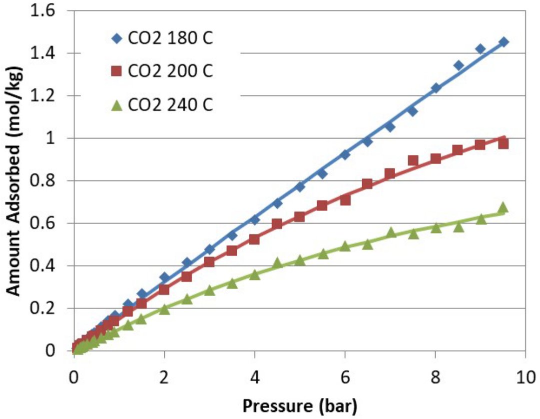
3-stage WGS unit as described in the DOE/NETL-2007/1281

- **In our process, the WGS catalyst is combined with a high temperature CO_2 adsorbent to achieve high CO conversion *at low steam:carbon ratios***
- **Reduced water addition increases process efficiency**

TDA’s Sorbent

- **TDA uses a mesoporous carbon with surface functional groups that remove CO_2 via strong physical adsorption**
  - CO_2-surface interaction is strong enough to allow operation at elevated temperatures
  - Because CO_2 is not bonded via a covalent bond, energy input for regeneration is low
- **Heat of CO_2 adsorption is 4.9 kcal/mol for TDA sorbent**
  - Net energy loss in sorbent regeneration is similar to Selexol; much higher IGCC efficiency can be achieved due to high temperature CO_2 capture
- **Favorable material properties**
  - Pore size is tuned to 10 to 100 A
  - Mesopores eliminates diffusion limitations





US Patent 9,120,079, Dietz, Alptekin, Jayaraman “High Capacity Carbon Dioxide Sorbent”, US 6,297,293; 6,737,445; 7,167,354
US Pat. Appl. 61790193, Alptekin, Jayaraman, Copeland “Pre-combustion CO_2 Capture System Using a Regenerable Sorbent”

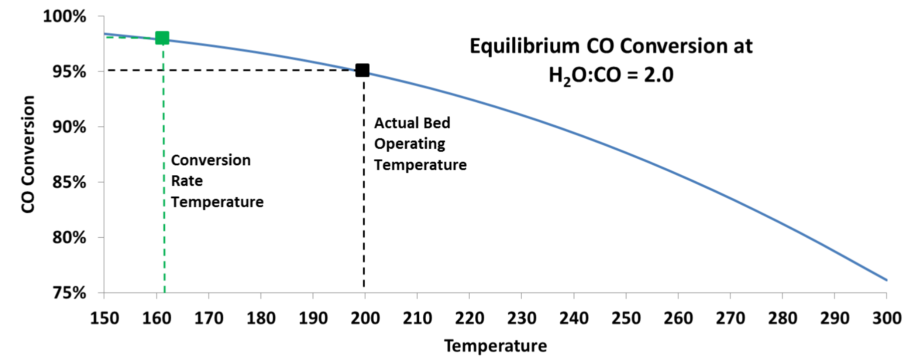
Sorbent Development Work

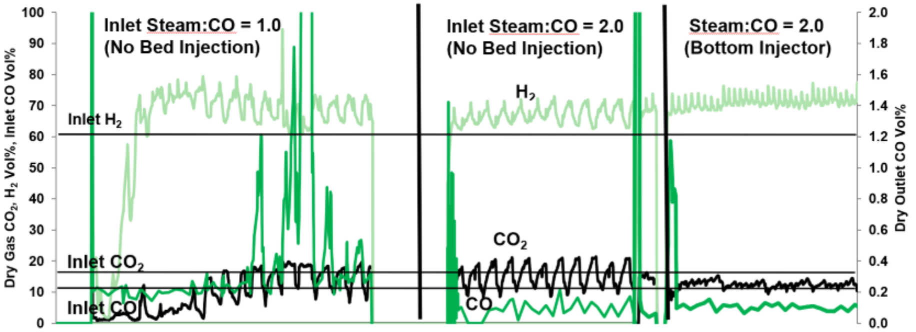
TDA 0.1 MW pre-combustion carbon capture unit installed at the National Carbon Capture Center

- **0.1 MW_e test in a world class IGCC plant to demonstrate full benefits of the technology**
  - Field Test #1 at NCCC (2017)
  - Field Test #2 at Sinopec Yangtzi Petro-chemical Plant, Nanjing, Jiangsu Province, China (2019)
- **Full operation scheme**
  - 8 reactors and all accumulators
  - Utilize product/inert gas purges
  - H_2 recovery/CO_2 purity

Yangtzi Petro-chemical Plant

Integrated WGS/CO_2 Capture System



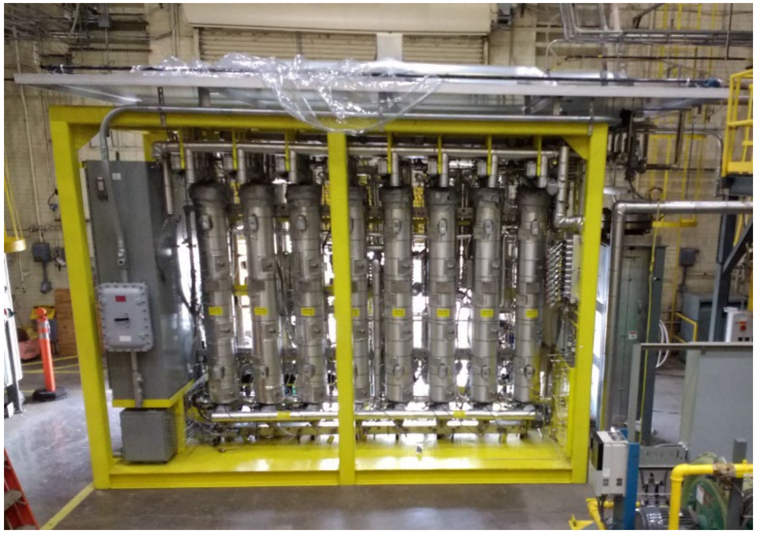


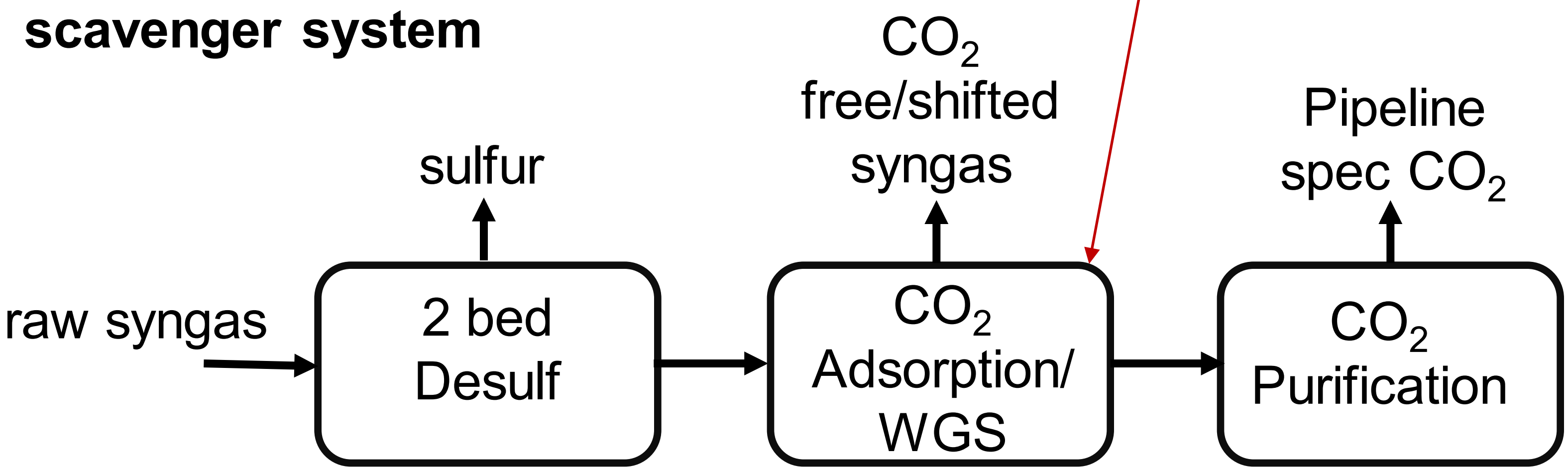
- **Following repurposing of the Wabash River IGCC plant and decommissioning of PSDF at NCCC, we identified Praxair R&D Center (Tonawanda, NY) as a test site**
  - Integrated with OTM on natural gas
- **Two test campaigns were completed at Praxair**

- **An overall CO conversion >98% was achieved**
- **By coupling the WGS with the CO_2 sorbent and water injection, we were able to operate the beds at 200ºC but achieve the equilibrium CO conversion of a 40ºC cooler bed**

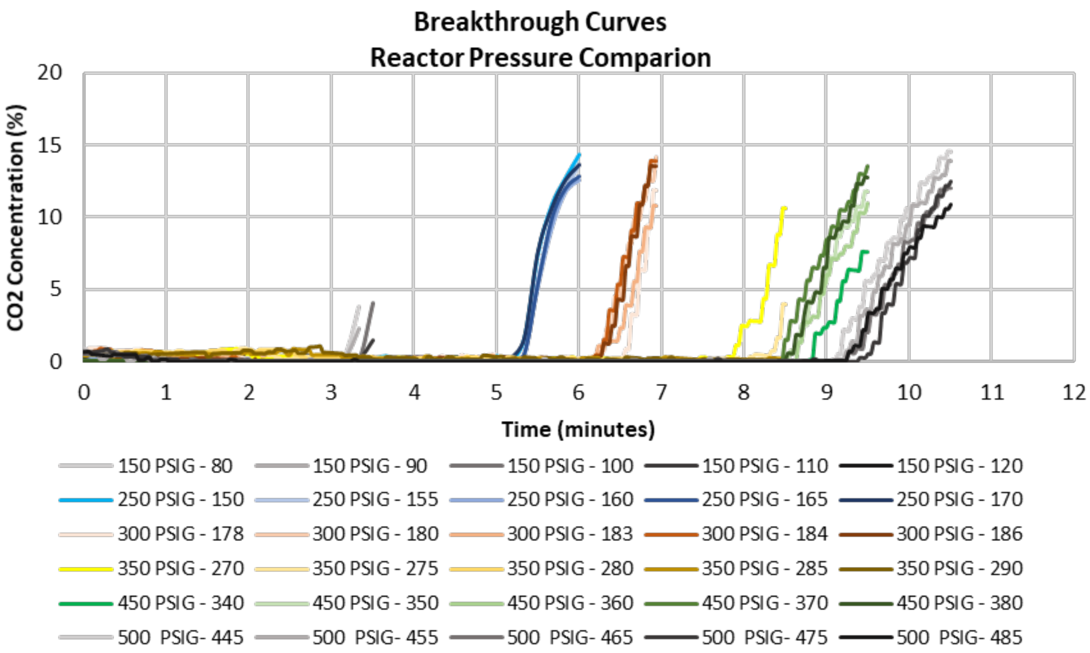
Integrated WGS/CO_2 Field Test System

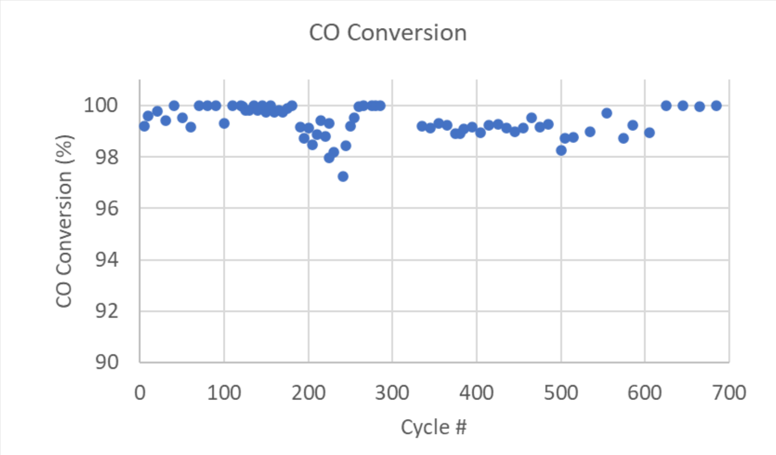
- **Regenerable sulfur sorbent skid will be upstream of the other two skids to desulfurize the syngas**
- **CO_2 PSA will shift the CO and selectively remove CO_2**
- **CO_2 from the PSA will be purified using TDA's catalytic oxidation and oxygen scavenger system**

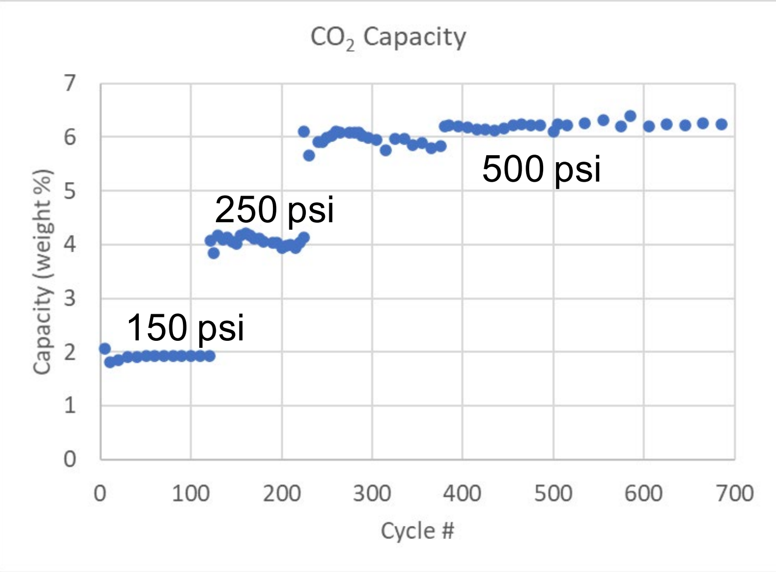




CO_2 Sorbent/WGS Catalyst Multiple Cycle Tests





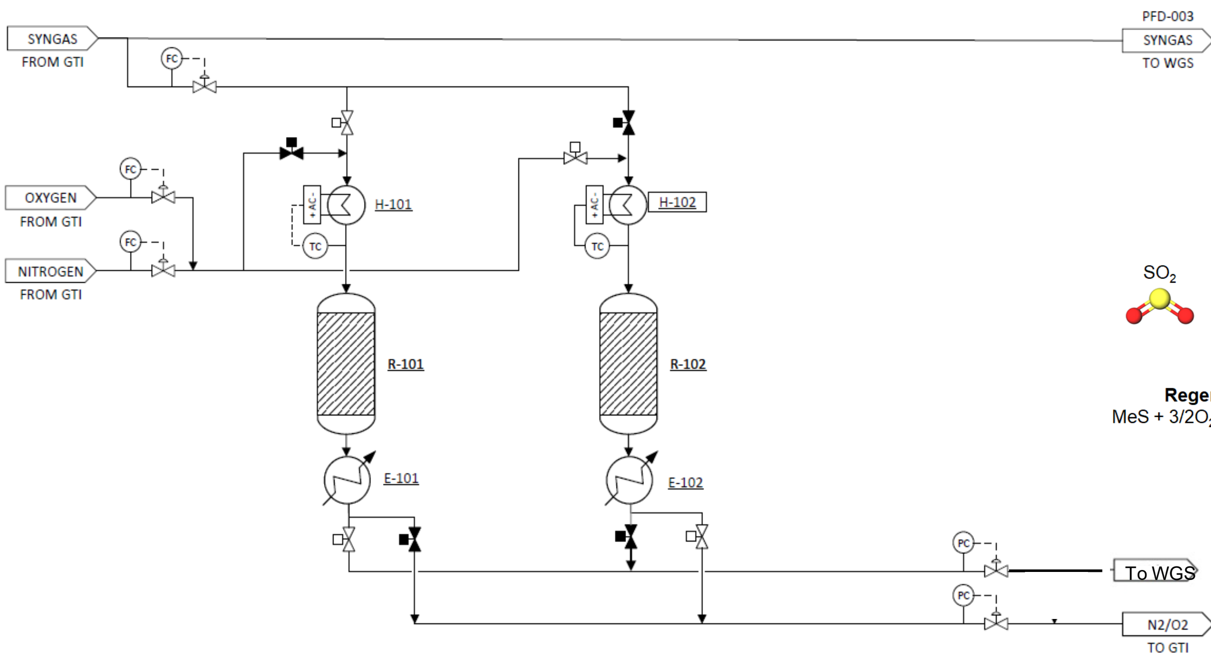


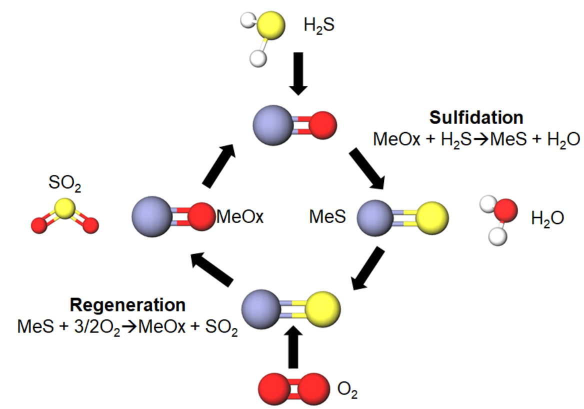
- **At 500 psi, the WGS/CO_2 sorbent bed achieved 6.2 % wt. CO_2 capacity and 99% CO conversion (far exceeding our Milestone M1.1 target of 4% wt. CO_2 capacity at 500 psi)**
- **We completed over 700 adsorption/ desorption cycles with the integrated WGS/CO_2 capture bed**
- **Previously we had demonstrated life over 32,000 cycles with stable performance**

CO_2 Sorbent/WGS Catalyst Test System

- **We replaced the sorbent/WGS catalyst in all 8 beds**
- **Utilized a new sorbent/spring retention system to help stabilize the sorbent and prevent movement**
- **System was powered up and ready for testing**

Design of Regenerable Sulfur Sorbent System

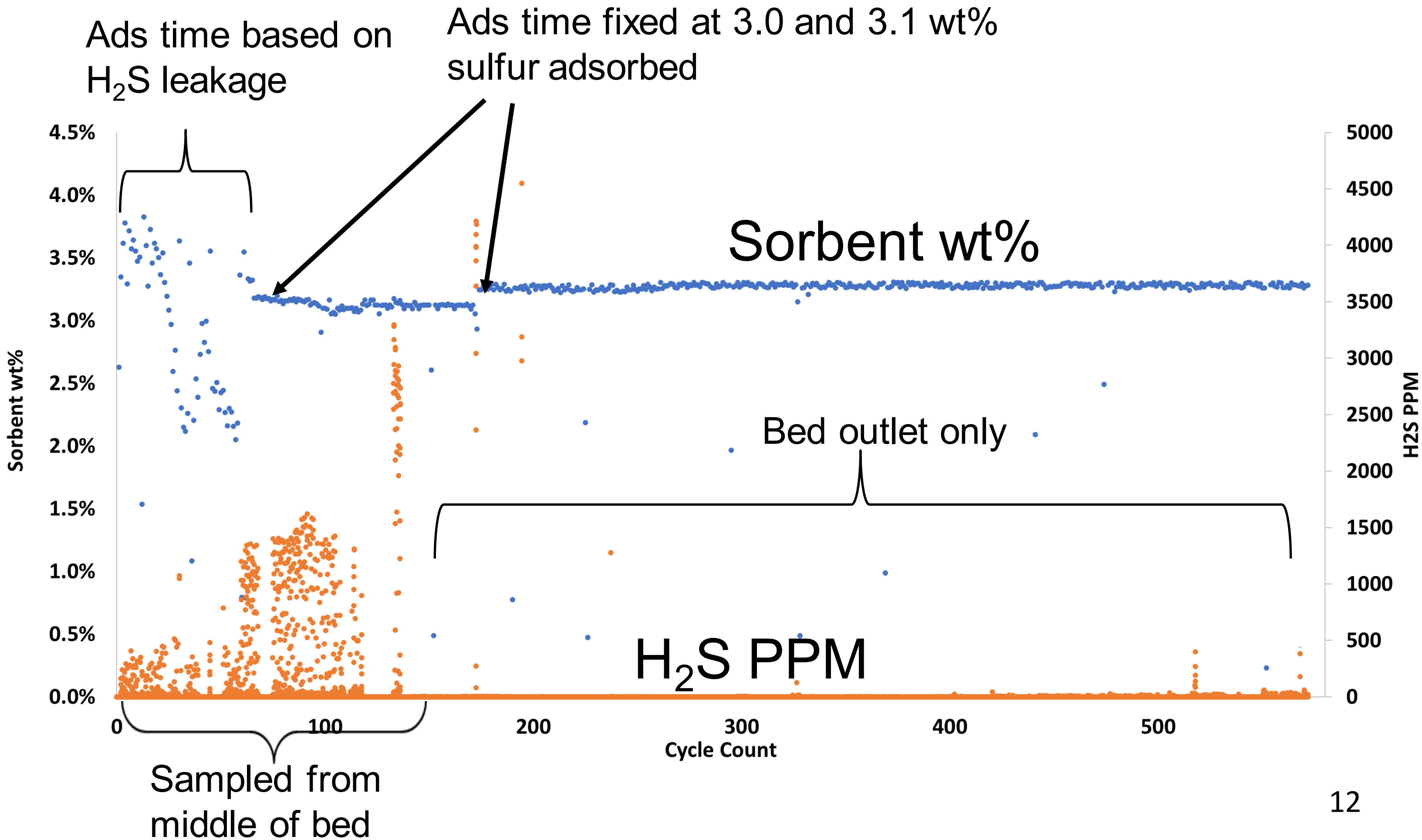




- **2 bed system**
  - One is adsorbing while the other is regenerating
  - H_2S is removed during adsorption by reacting with metal oxides to form metal sulfides
  - Regeneration occurs by reacting O_2 with metal sulfides to form SO_2
- **Electric heaters on inlet gas to achieve required adsorption and regeneration operating temperatures**
- **Deliver a constant stream of desulfurized syngas to the integrated CO_2/WGS system**

Manufacturing and Qualification of the Regenerable Sulfur Sorbent

- **Completed over 500 adsorption/regeneration cycles**
- **3.0 wt% was maintained throughout the test**



Regenerable Sulfur Sorbent Test System

- **Dual bed regenerable sulfur sorbent system is currently being lab tested as part of FAT**

- **Sulfur removal will be measured using a lead acetate tape analyzer**

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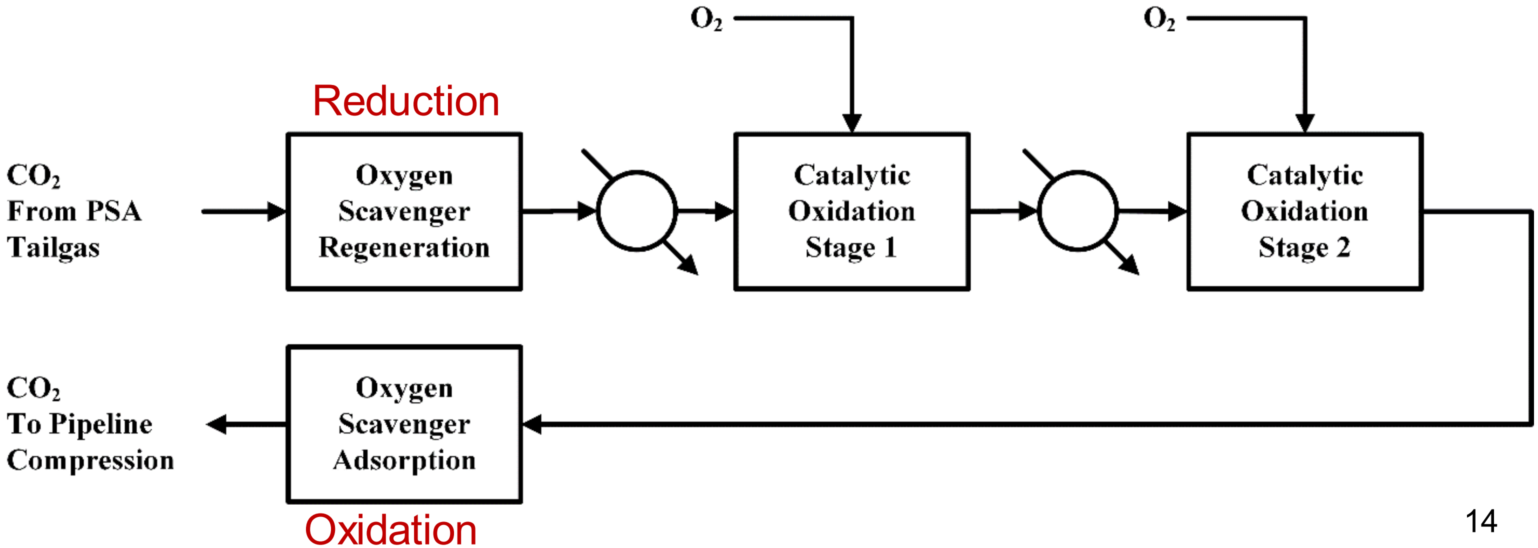
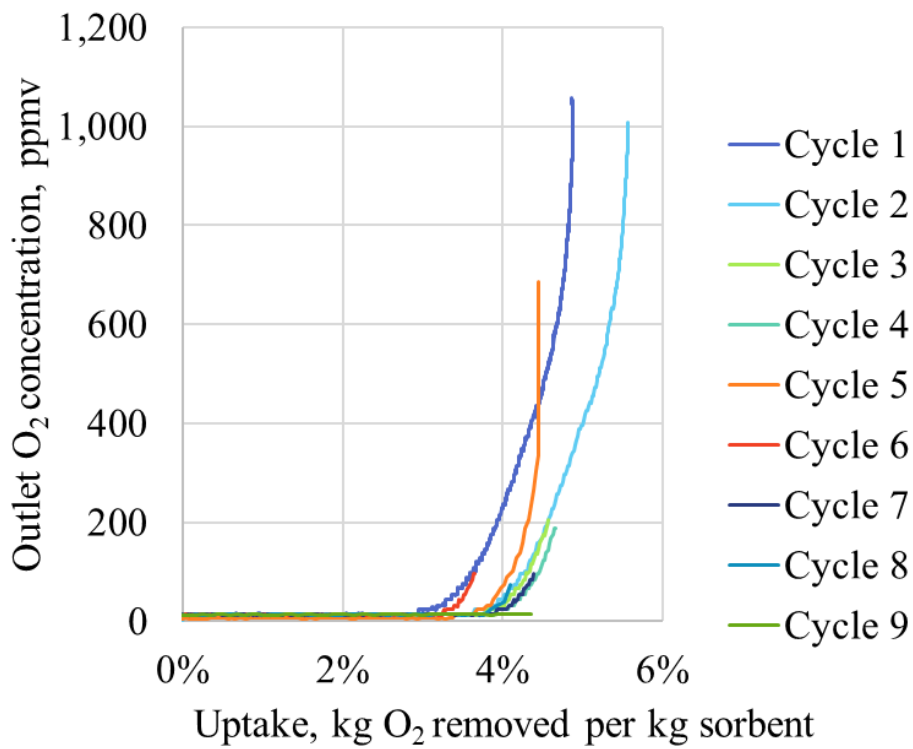
Design of CO_2 Purification System

- **CO_2 purification skid includes a catalytic oxidizer with a REDOX based oxygen scavenger to meet the CO_2 purity requirements**
- **Catalytic Oxidation removes hydrocarbons and other combustibles (e.g., CO, CH_4, H_2)**
  - Operates at slightest excess stoichiometric amounts of oxygen
  - Adiabatic, multi-staged design with intercoolers for heat management
- **Oxygen Scavenging system polishes excess O_2 to < 10 ppm**
  - Regenerable mixed metal oxide based chemical looping process
  - Oxidation step captures O_2 ; Reduction with inlet gas regenerates the sorbent
  - Oxygen sorbent will be regenerated using the H_2 in incoming CO_2



TDA's O_2 Scavenger Sorbent

- The oxygen scavenger was tested for nine cycles verifying consistent breakthrough capacity at <10 ppmv O_2 in the outlet
- Tested the effect of regen temperature, residence time, inlet oxygen concentration, presence of CO
- Uptake is 3.8%-w O_2 with a breakthrough time of 6.2 hours

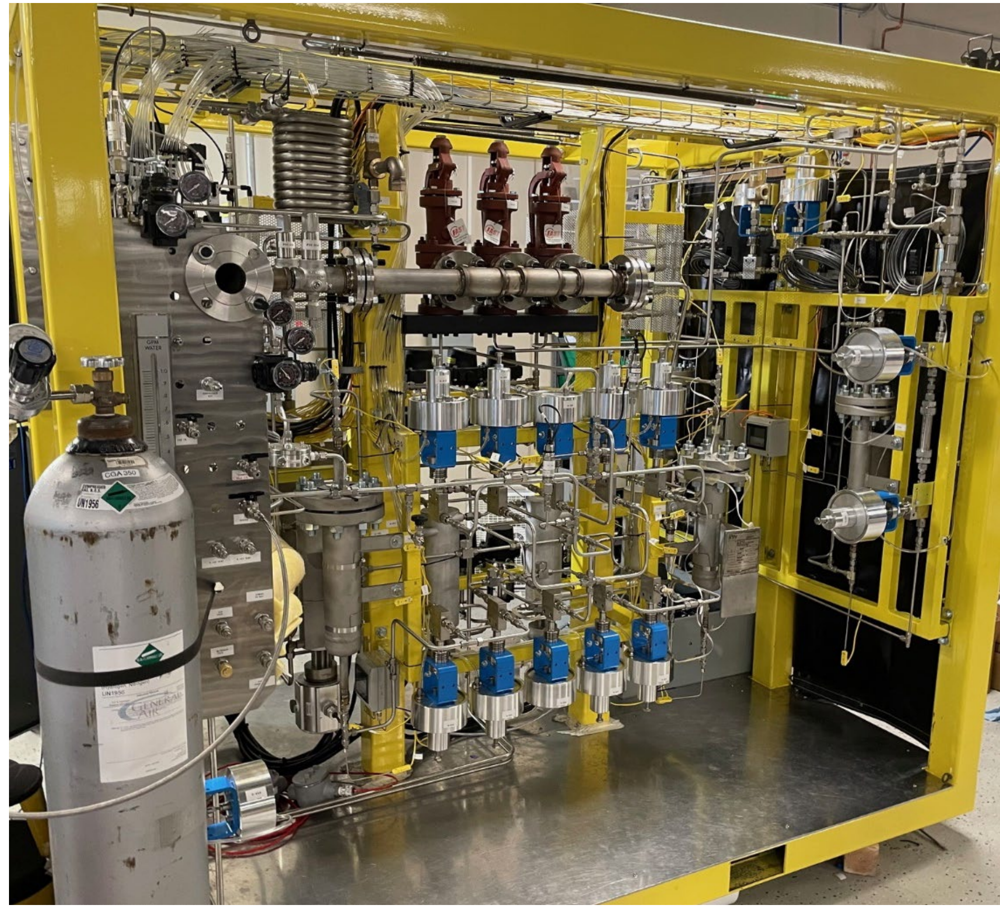


Oxygen Sorbent Design Conditions	
GHSV, 1/hr	3,000 – 6,300
Inlet O_2, ppmv	1,000 – 4,000
Inlet Temp, deg C	400 - 450
Bed L/D	2.7

CO_2 Purification Test System

- **System is currently being lab tested before shipment to GTI**

- **Trace O_2 in the CO2 product stream will be measured using an electrochemical analyzer**



Testing Schedule

- **We will be shipping the test systems in mid August to GTI is Des Plaines IL for testing using biomass derived syngas**

- **Testing is scheduled to start the beginning of September**

GTI ENERGY
solutions that transform

TDA RESEARCH

Process Design and System Analysis with Poly-generation Options

DOE Baseline Rev. 4 Study Basis

$2018 basis

Operating Scenario	**Max Power**	**Mid Power**	**Min Power**	**Mean over 24 hr day**
Operating Scenario as Fraction of 24 hr day	**0.25**	**0.5**	**0.25**	
Power Block Power as Fraction of Max Power	**1.00**	**0.80**	**0.65**	
Increase in CC Heat Rate over Max Power Scenario, Factor	**0**	**0.04**	**0.1**	
GROSS POWER GENERATED (AT GENERATOR TERMINALS),				
GAS TURBINE POWER	88,000	70,400	57,200	71,500
STEAM TURBINE POWER	66,657	53,326	43,327	54,159
SYNGAS EXPANDER POWER	1,644	1,315	1,069	1,336
CO2 VENT EXPANDER	-	-	-	-
TOTAL POWER	156,301	125,041	101,596	126,995
AUXILIARY LOAD SUMMARY, kWe				
TOTAL AUXIIARIES	73,763	75,520	76,693	75,374
NET POWER, kWe	**82,538**	**49,521**	**24,903**	**51,621**
COPRODUCT (NH_3)				
ST/D	959	1,096	1,191	1,085
TONNE/D	**869**	**994**	**1,080**	**984**
TOTAL (ELECTRIC + COPRODUCT) ENERGY, kW	308,866	308,214	306,135	307,857
ELECTRICITY / COPRODUCT ENERGY RATIO	0.365	0.191	0.089	0.201
NET PLANT EFFICACY, % HHV	**47**	**47**	**47**	**47**
THERMAL INPUT, kWt HHV	652,542	652,542	652,542	652,542
CARBON CAPTURED, %	95.8	95.8	95.8	95.8

Electricity Credit	$/MWh	64.5	71.7	78.9	107.2	152.3
NH3 RSP with CO_2 T&S	$/ST	884	870	855	798	708

Cost of CO_2 capture including T&S is $40.6/tonne CO_2

TDA RESEARCH

Acknowledgements

- NETL, Project Managers, Andrew Jones, Dr. Elliot Roth, Dr. Nicole Shamitko-Klingensmith (current)
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- Dr. Ashok Rao