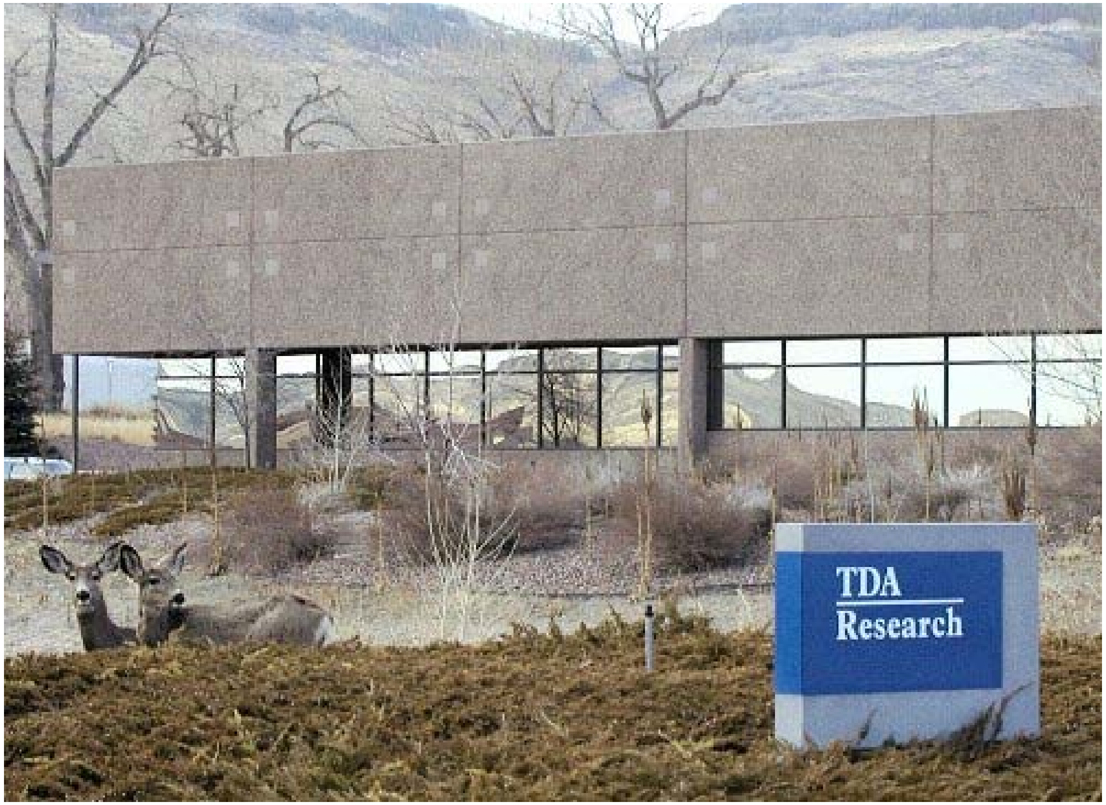
A Low Cost, High Capacity Regenerable Sorbent for Pre-Combustion CO_2 Capture

Contract No. DE-FE0000469
Project Briefing



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NETL CO_2 Capture Technology Meeting

Pittsburgh, PA

July 12, 2012

TDA Research Inc. • Wheat Ridge, CO 80033 • www.tda.com

Project Objective

- **The objective is to develop a new pre-combustion carbon capture technology and demonstrate its techno-economic viability**
- **A mesoporous carbon grafted with surface functional groups that remove CO_2 via physical adsorption above the dew point of the synthesis gas**

- **Budget Period 1**
  - Sorbent optimization and production scale-up
  - Bench-scale evaluations
  - Process design and optimization
- **Budget Period 2**
  - Demonstrate sorbent life for 10,000 cycles
  - Slipstream demonstration using actual synthesis gas
  - Conduct an economic analysis to estimate the cost of CO_2 capture

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Project Partners

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UNIVERSITY of CALIFORNIA · IRVINE

ConocoPhillips

SOUTHERN COMPANY

MWV MEADWESTVACO

Project Duration

- **Start Date = November 15, 2009**
- **End Date = September 30, 2012**

Budget

- **Project Budget = $2,500,000**
- **DOE Share = $2,000,000**
- **TDA/Partners Share = $500,000**

TDA's Approach

- **The sorbent consists of a carbon material modified with surface functional groups that remove CO_2 via strong physical adsorption**
  - **CO_2-surface interaction is strong enough to allow high T operation**
  - **Because there is no covalent bond, energy input for regeneration is low**

- **Heat of adsorption of CO_2 is 4.9 kcal per mol for TDA sorbent**
  - **Selexol ~4 kcal/mol**
  - **Amine solvents ~14.4 kcal/mol**
  - **Chemical absorbents 20-40 kcal/mol ($Na_2CO_3 \rightarrow NaHCO_3$ 30 kcal/mol)**
    - $Na_2CO_3 + CO_{2(g)} + H_2O_{(g)} \rightarrow 2NaHCO_3$ (ΔH = -30 kcal/mol)

- **Net energy loss in sorbent regeneration is similar to Selexol**
  - **A much better IGCC efficiency due to higher temperature CO_2 capture**
  - **Warm gas clean-up improves cycle efficiency 2 to 4%**
  - **Potential for even higher efficiency by integrating WGS/CO_2 removal processes (3 to 6% improved efficiency)**

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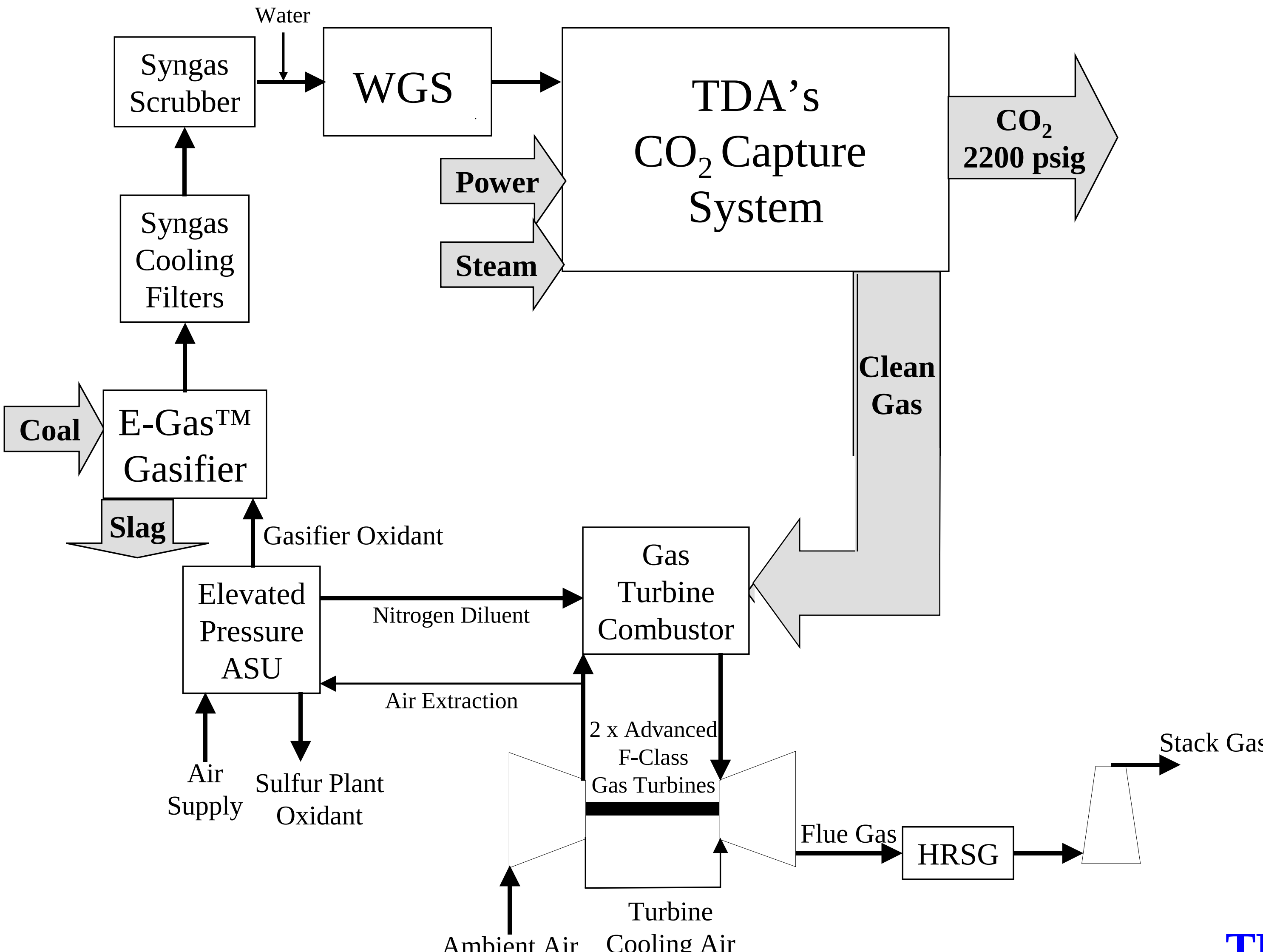
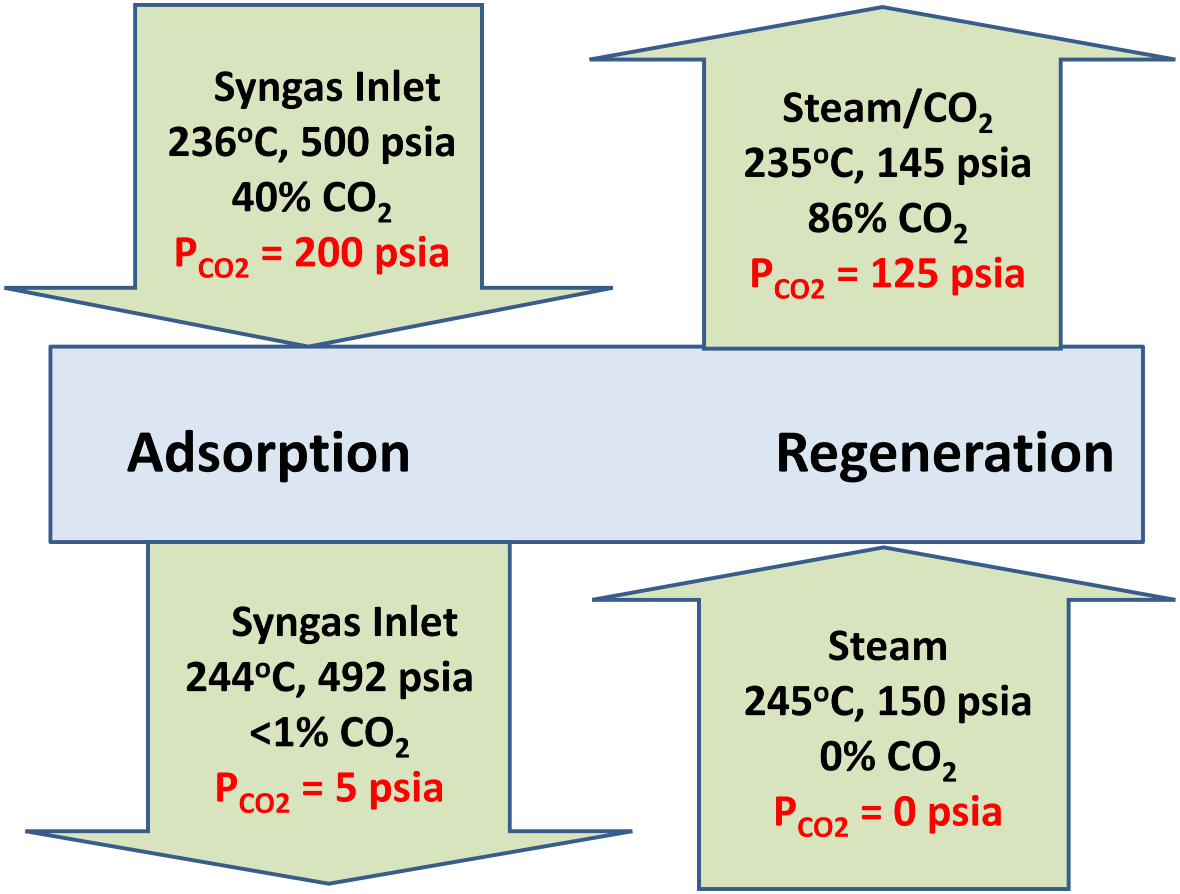
IGCC-Integrated CO_2 Capture System



Regeneration Options

- **Physical adsorbent provides flexibility in regeneration**
  - Temperature swing
  - Pressure swing
  - Concentration swing
  - Any combinations

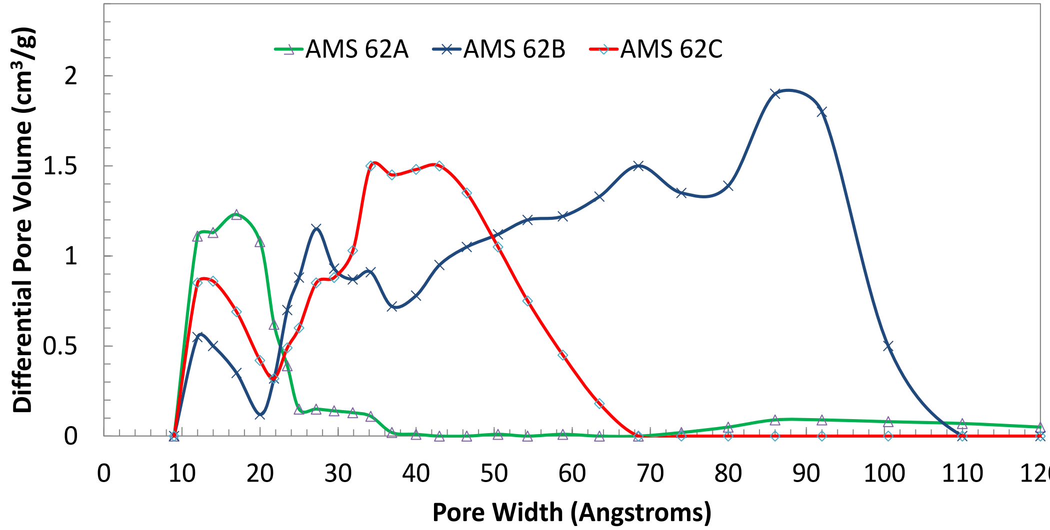


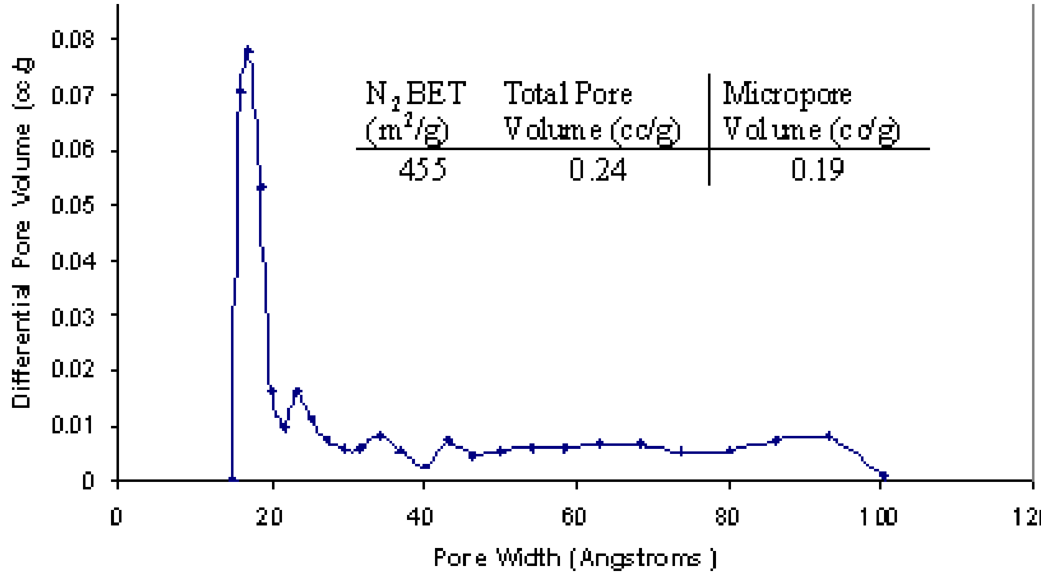
- **Isothermal operation is critical to eliminate heat/cool transitions which reduces cycle time and increases sorbent utilization**
- **Steam consumption can be reduced significantly if steam purge is carried out at low pressure**

TDA’s Sorbent

- **A mesoporous carbon is used to disperse the active sorbent phase**
- **The carbon support is previously developed for ultra-capacitors, large pores to achieve liquid transport**

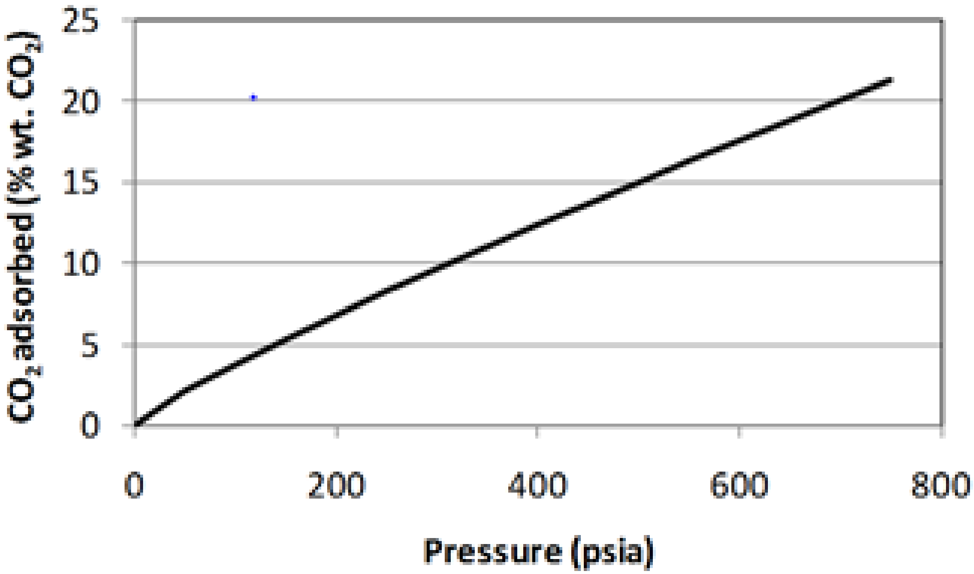
- **The preparation process enables us to introduce various surface groups active for removing different compounds**
- **Large pores accommodate different active groups**





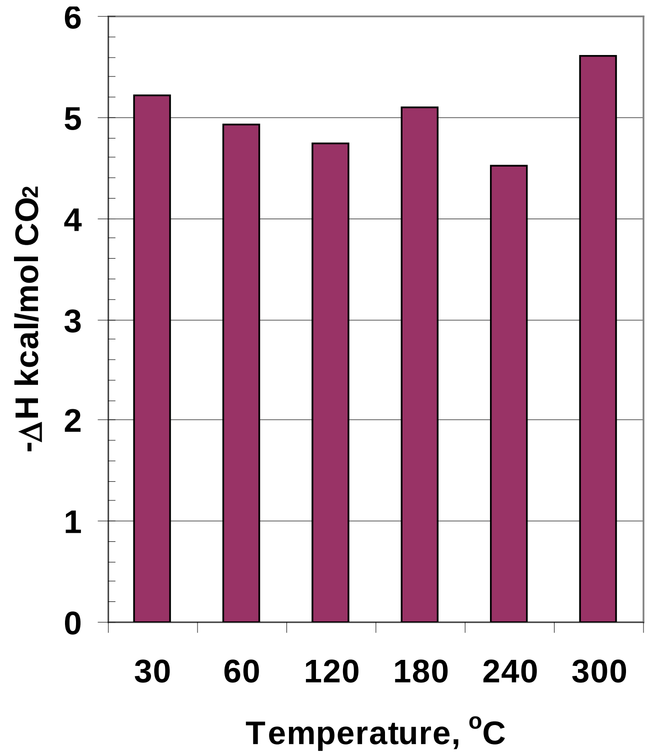
CO_2 Isotherm and Heat of Adsorption

CO_2 isotherm at 240°C



Langmuir Coefficient (q_s)	386.4 mmol/g
Langmuir Coefficient (B)	4.15E-04 1/atm
Langmuir Coefficient (n)	0.869
Diffusion Coefficient (D/R^2)	1.32E-03 1/s
Reference Temperature for B	240 °C
Heat of Adsorption (ΔH)	4.8 kcal/mol

Calorimetry Measurements



$-\Delta H_{ads} = 4.9 \quad 0.4$ kcal/mol

- **Isosteric heat of adsorption calculations and DSC experiments confirm the low heat of adsorption**

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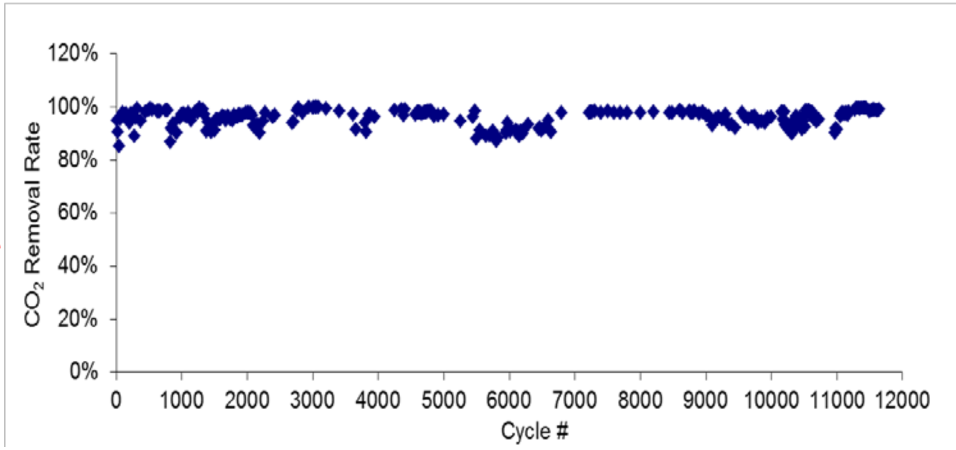
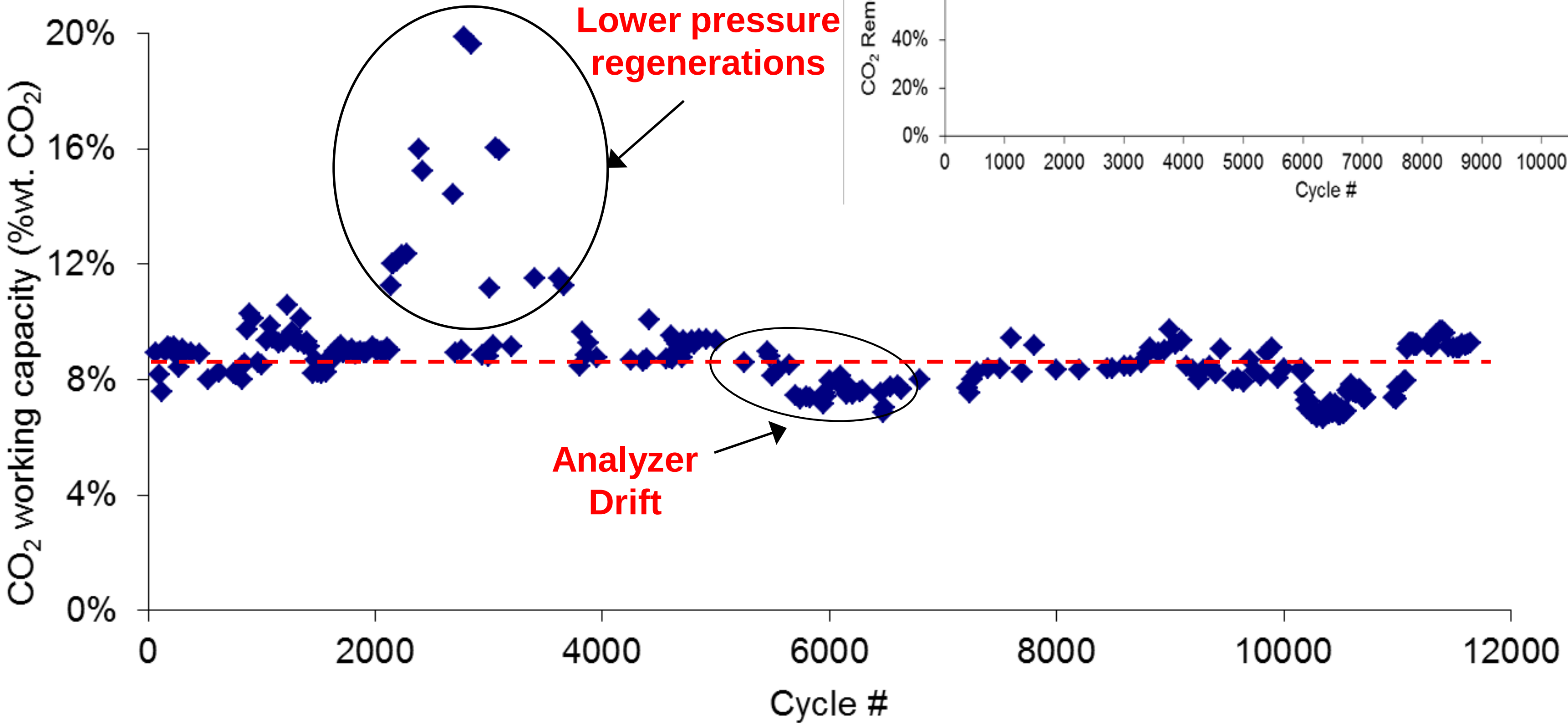
Multiple Cycle Tests

H_2=32%, CO_2=40%, N_2=3%, CO=1%,H_2O=24%; T= 240°C; P_{ads}= 500 psig; P_{des} = 50-300 psig





- **Sorbent maintained its CO_2 capacity (8+%wt.) for ~12,000 cycles**

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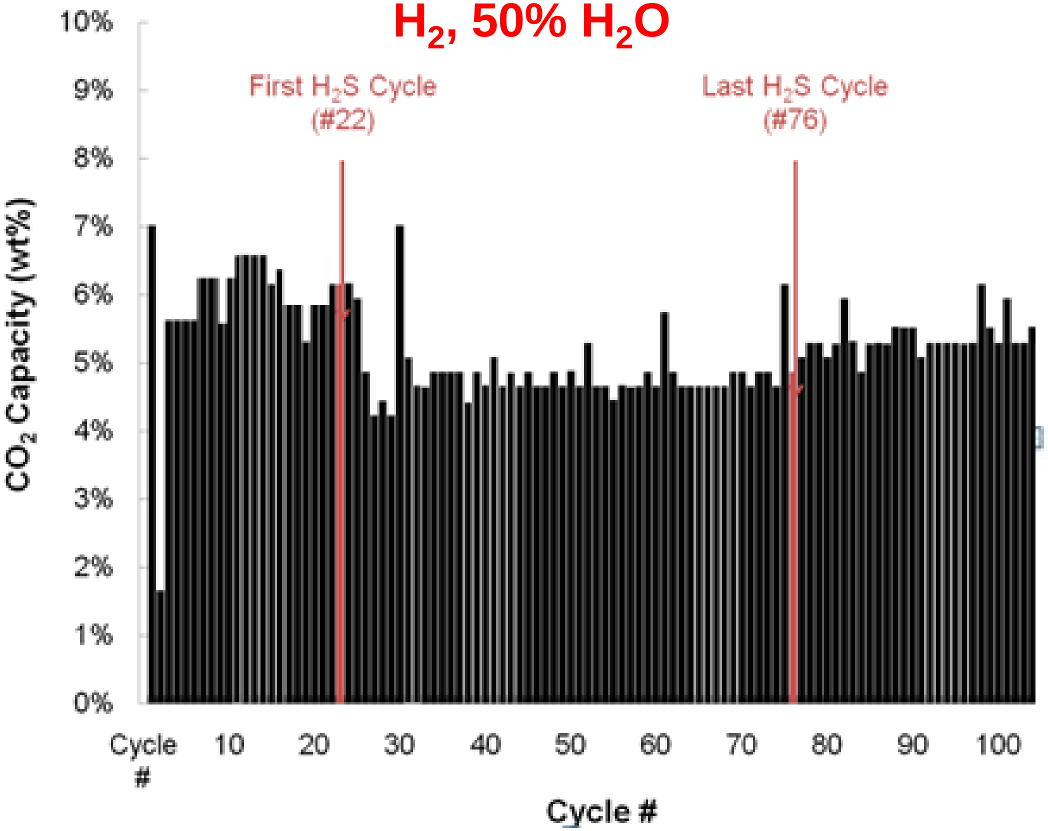
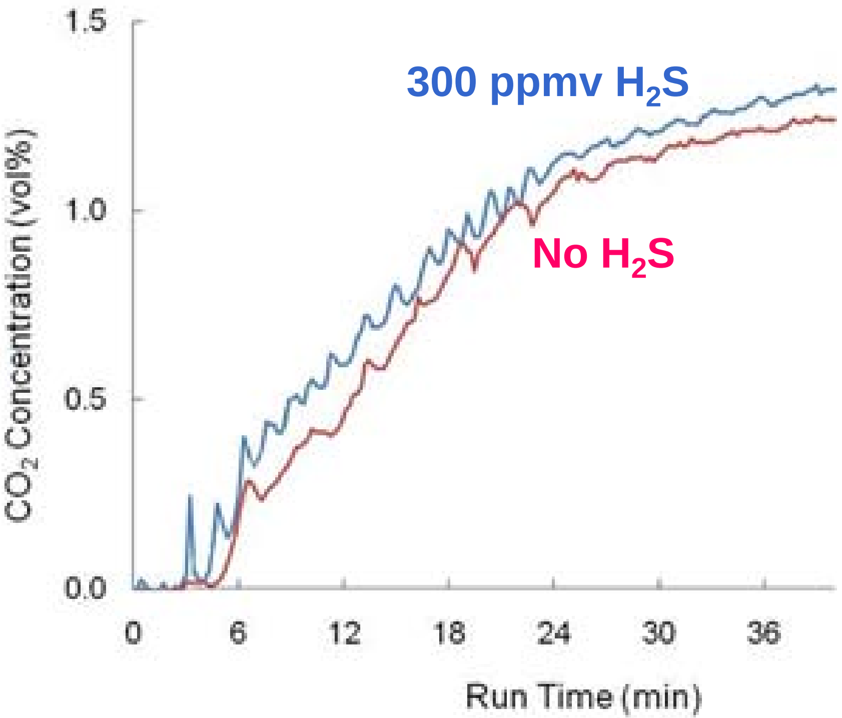
Impact of Sulfur

T= 240°C, P= 500 psig, 10 ppmv H_2S, 44% CO_2, 20% H_2, 36% H_2O; Purge Gas: 50% H_2, 50% H_2O



300 ppmv H_2S, T= 240°C, P= 500 psig



- **Presence of H_2S did not have a significant impact on sorbent performance**

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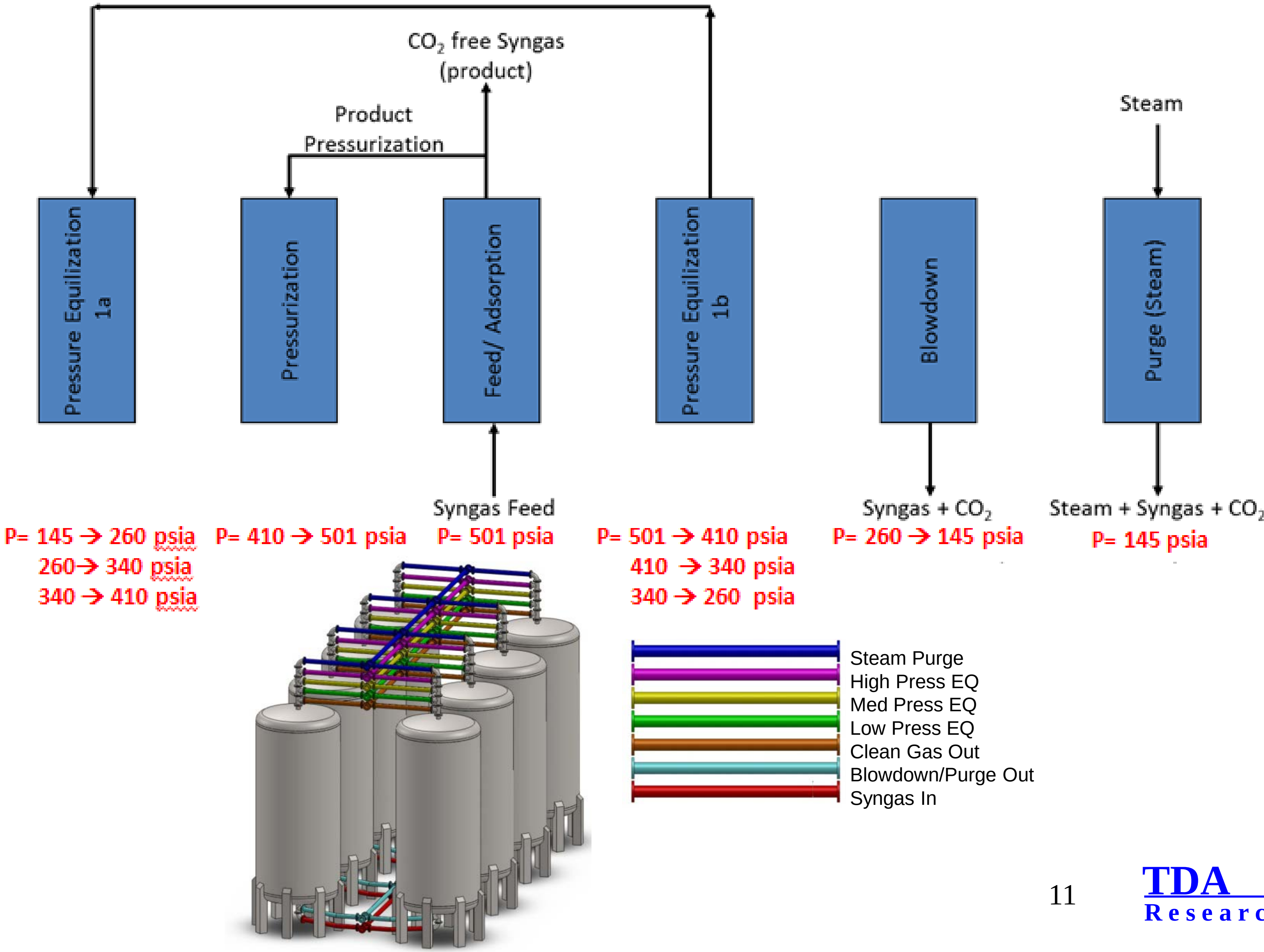
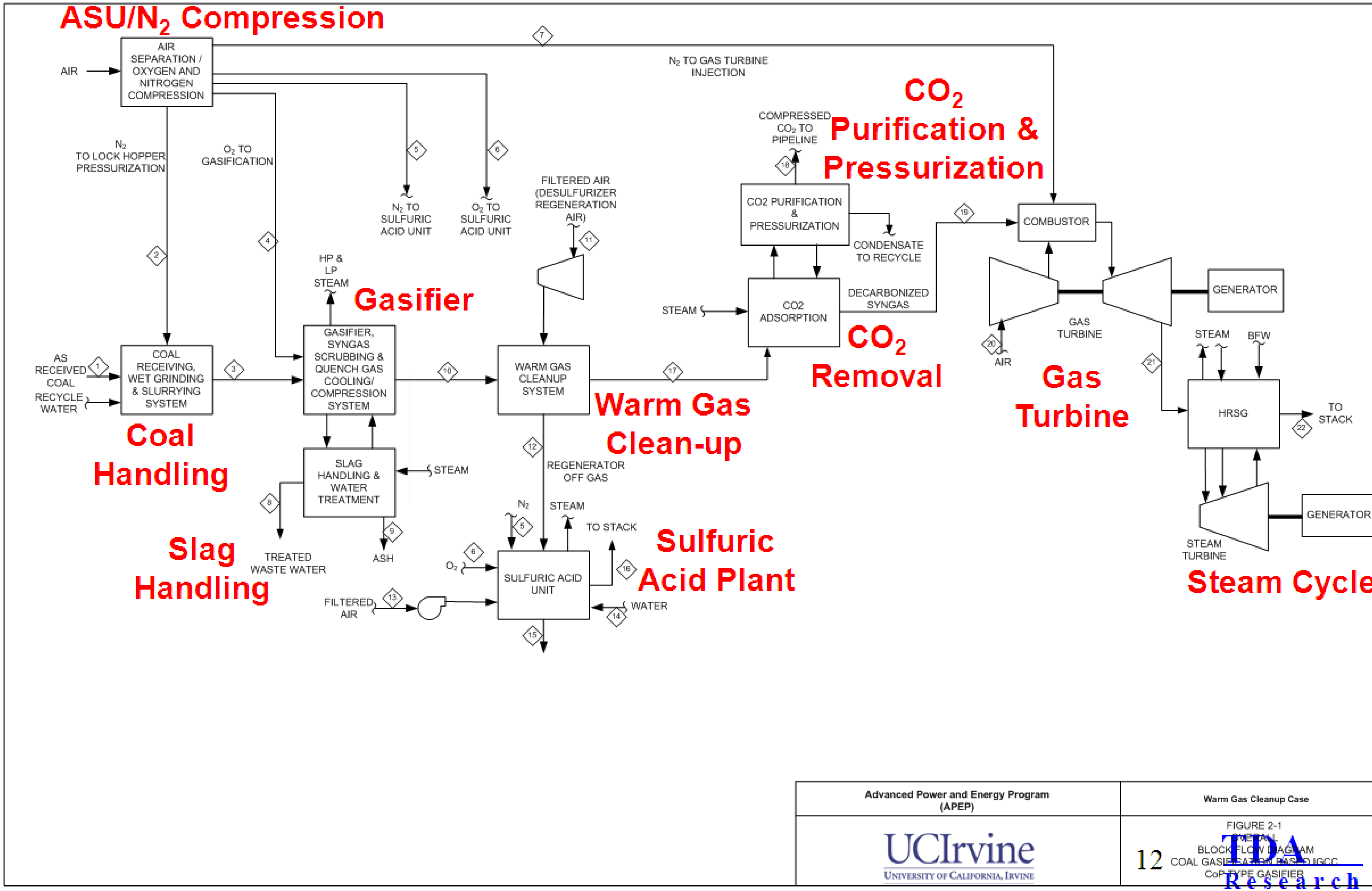
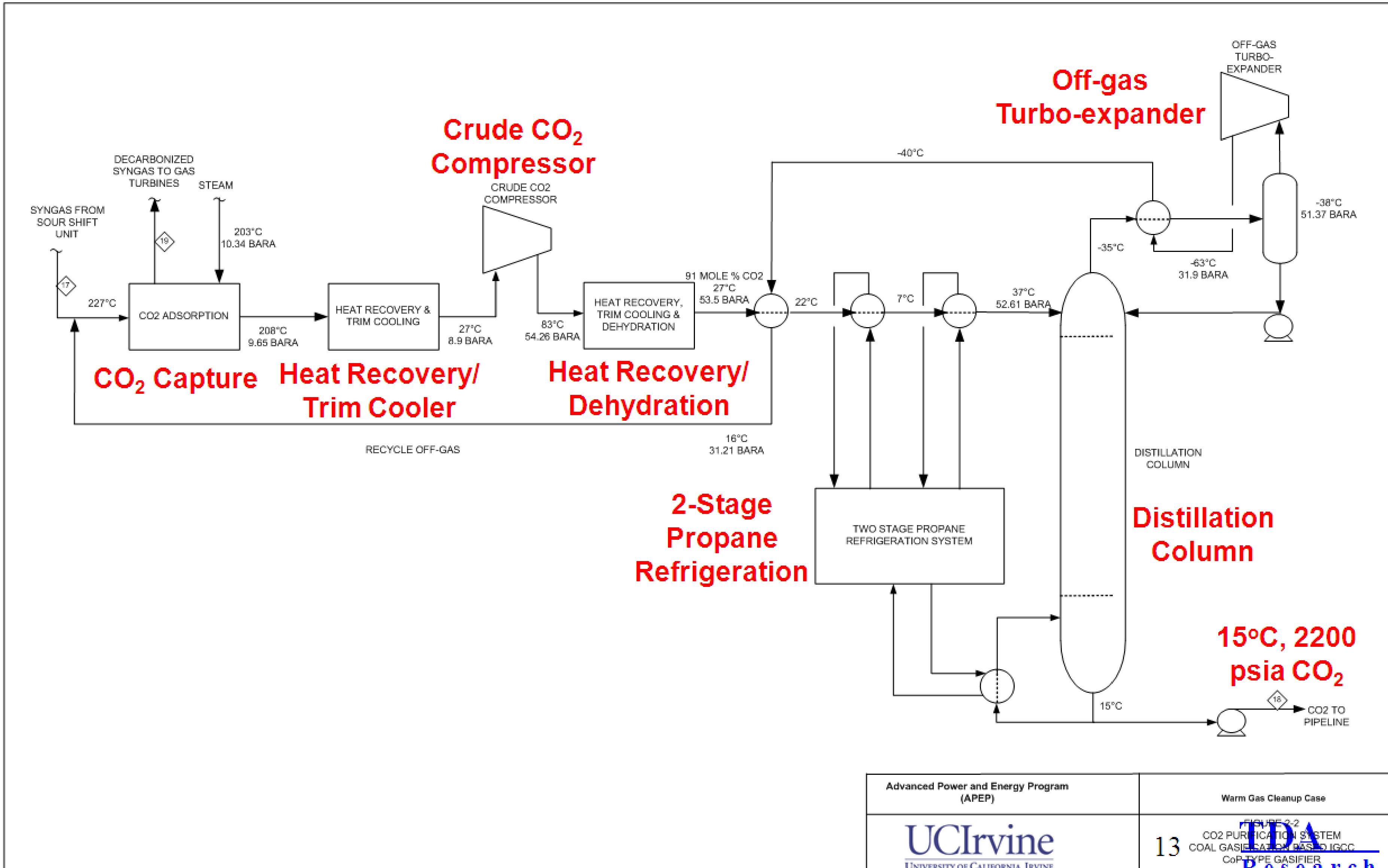
PSA Cycle Design



Process Design and Modeling



CO_2 Purification & Compression



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System Analysis Results

E-Gas Gasifier	IGCC - Selexol Calibration Case	IGCC - Selexol 90% Capture	IGCC -TDA WGC 90% Capture
CO_2 Capture	88.2	90	90
Gross Power Generated, kWe	696,770	691,624	711,083
Net Power, kWe	524,772	516,126	572,398
Net Plant Efficiency, % HHV	**32.1%**	**31.6%**	**33.5%**
COE, mills/kWh		98.6	91.0
COE (inc. TS&M), mills/kWh		**103.9**	**96.0**

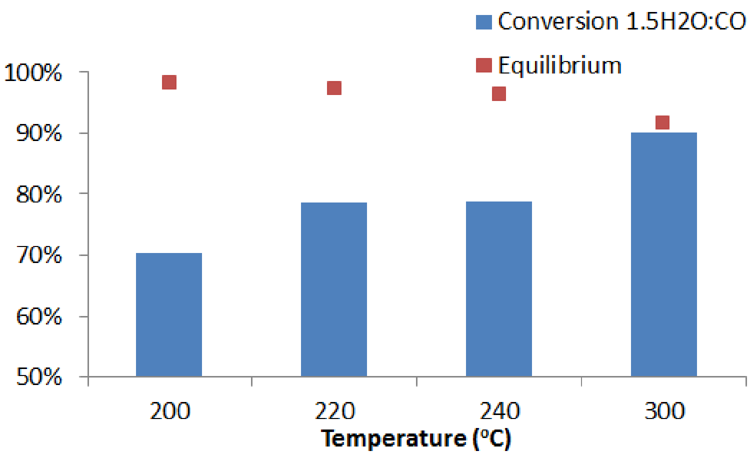
Model results validated based on DOE/NETL 2007/1281

- **IGCC plant with TDA's CO_2 capture technology system achieves higher efficiency than IGCC-Selexol**
  - **33.5% vs. 31.6% for E-Gas gasifier**
  - **34.2% vs. 32.4% for GE gasifier**
- **Cost of electricity with IGCC-TDA-WGC is ~8 mills/kWh lower than that of IGCC-Selexol**

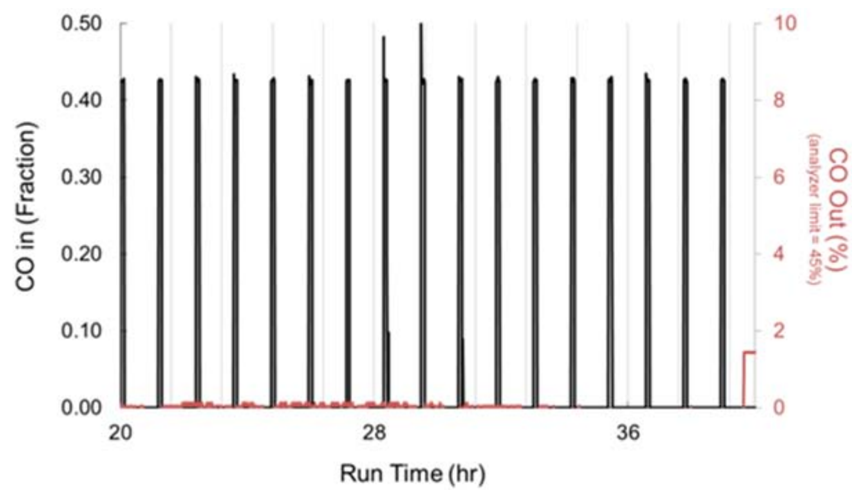
Process Design Modifications

<u>Integration of 3rd stage WGS with the warm gas carbon capture</u>

- **Commercial WGS catalyst (Shiftmax 230) co-located with the sorbent**
- **Cycle efficiency increase to 35+% due to reduced steam consumption**
- **Lower CAPEX**



gas	vol. %
CO_2	14
CO	37
H_2	26
N_2	8
H_2O	53
T = 240°C; P = 500 psig	



- **Promising performance data (Advanced Carbon Capture Concept for Low Rank Coals - DE-FE-0007966)**
- **7.82% wt. CO_2 loading (5.68% is from conversion of CO into CO_2)**

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Process Design Modifications (Cont'd)

Cycle optimization to increase H_2/syngas recovery (i.e., CO_2 purity)

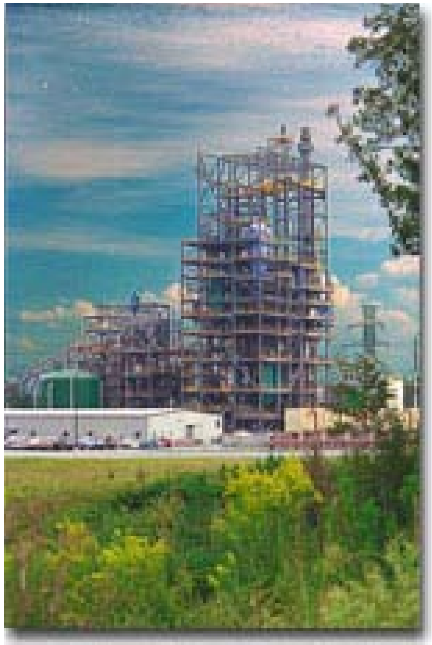
- **Baseline syngas recovery in the sorbent beds = 88%**
- **Target recovery = 95% (via product purging)**
- **Lower CAPEX due to reduced cost of purification system**

Slipstream Demonstrations

- **Two 3-week test campaigns for proof-of-concept demonstrations**

Wabash River IGCC Plant, Terre Haute, IN

- Largest single-train gasifier with 262 MW power output
- Oxy-blown E-Gas^{TM} Gasifier
- Operates on petcoke



National Carbon Capture Center, Wilsonville, AL

- Demonstration in November, 2011
- Pilot-scale gasifier
- Air-blown transport gasifier
- Operates on coals and lignites

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System Pictures – Prior to Insulation

Skid #1 - Synthesis gas pre-treatment skid

Skid #2 - CO_2 removal skid

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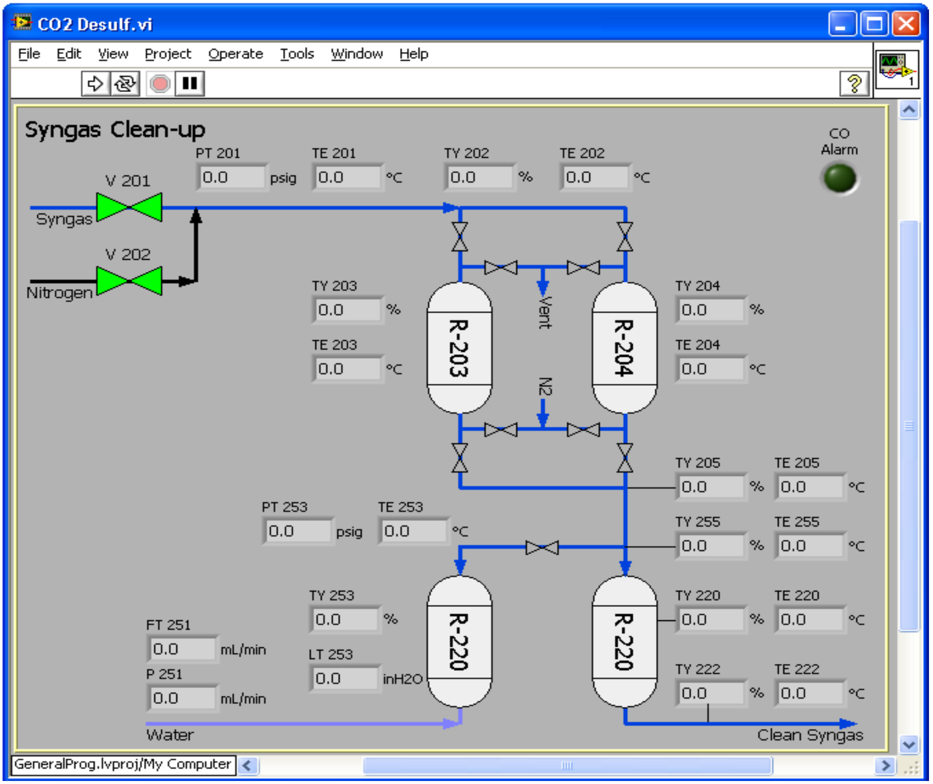
Test Units – In NEMA-Rated Enclosures

CO_2 Removal Skid

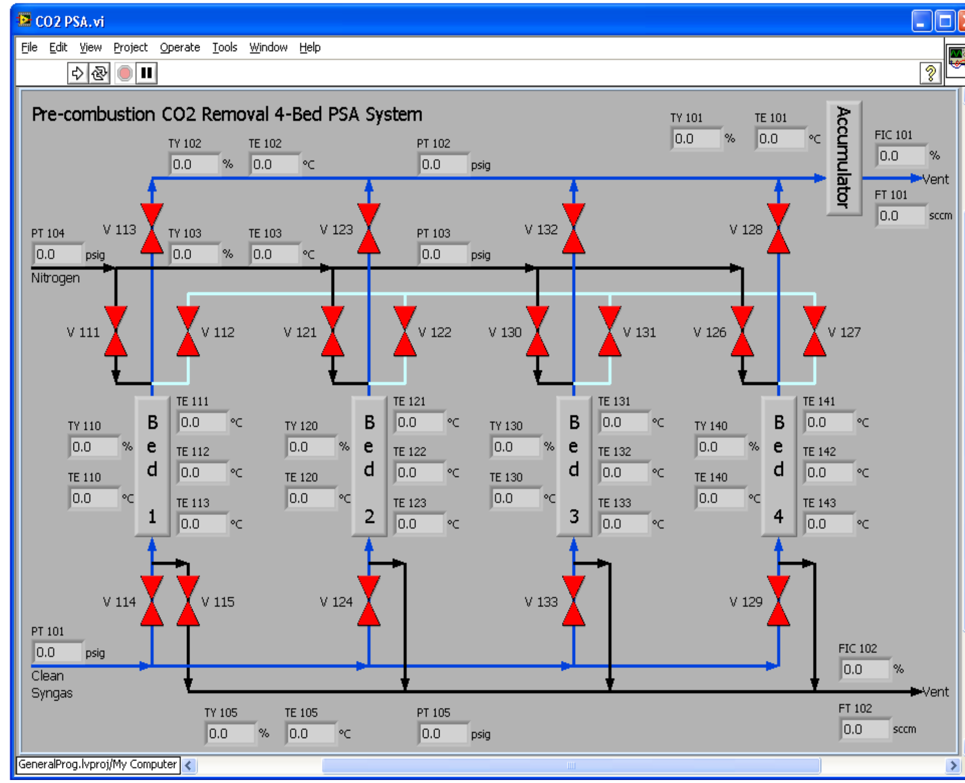
Gas Conditioning Skid

Control System

Skid #1



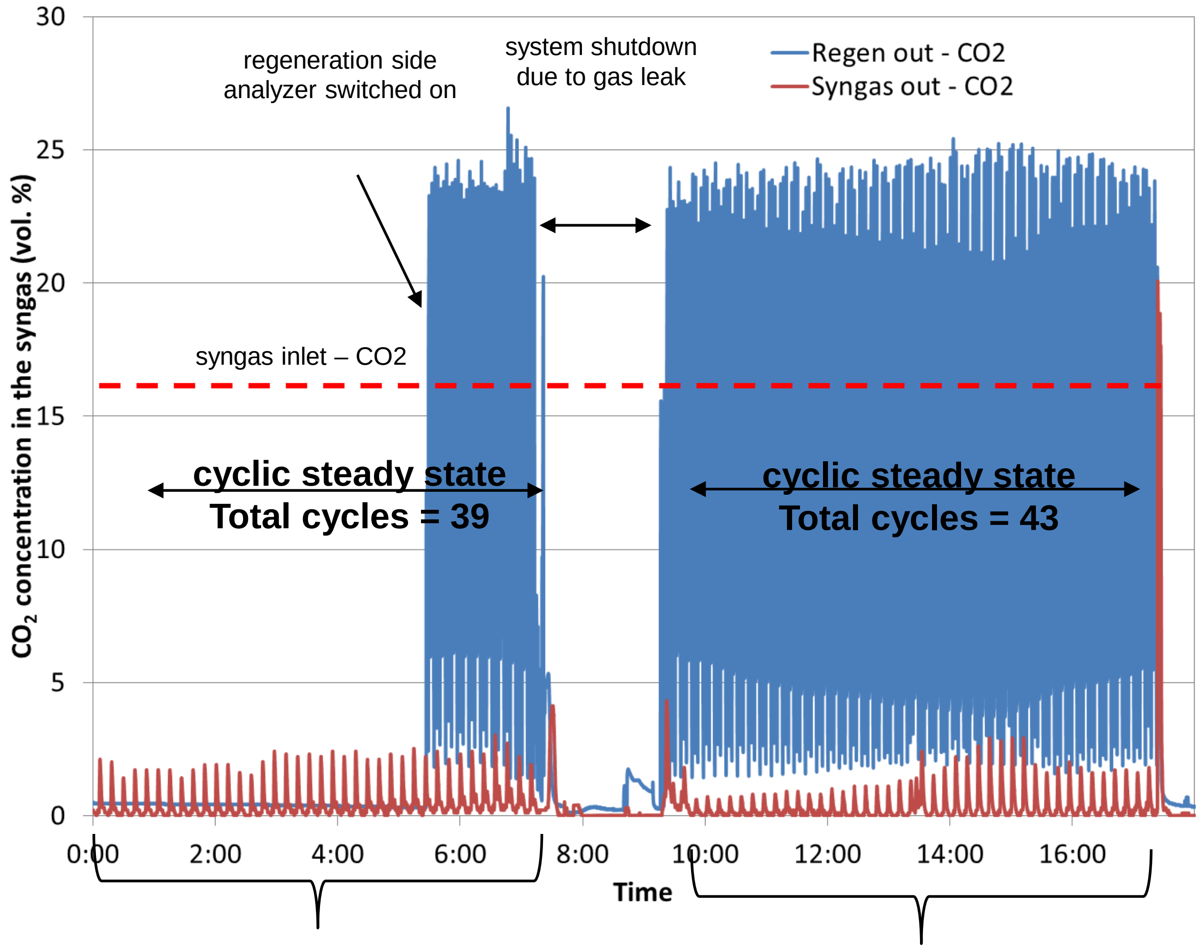
Skid #2



- **System is fully automated and remotely controlled**

Field Test Units Installed at Site

Field Test Data – November 23 2011



~0.6 CFM Product Flow

CO2 capture ~ 98.3%
Bed Temperature = 229C
Pads = 188 psig; Pdes = 59 psig

CO2 capture ~ 98.7%
Bed Temperature = 226C
Pads = 188 psig; Pdes = 54 psig

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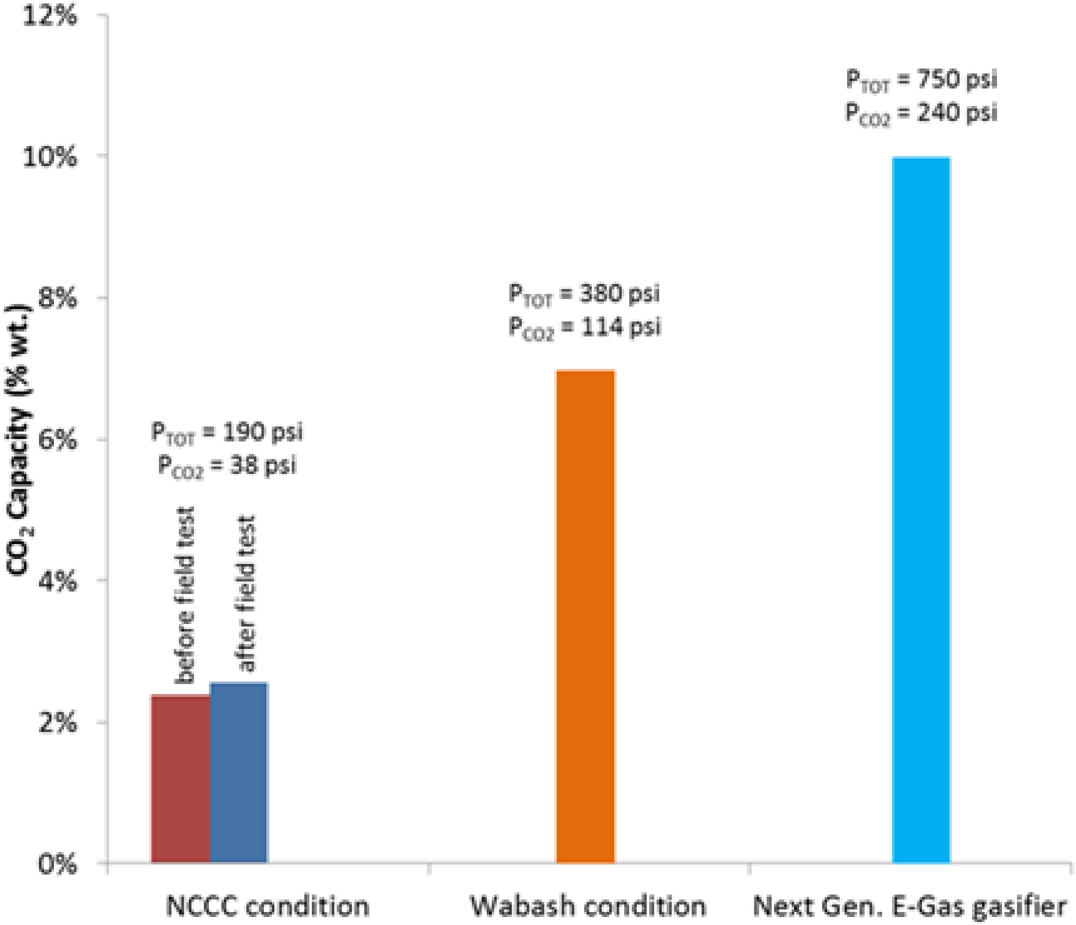
Performance in Slipstream Tests

- Sorbent maintained a stable capacity for 500 hrs of testing and over 2,000 cycles
- Sorbent maintained CO_2 capacity before and after field test
  - 2.6% wt. CO_2 capacity at P_{CO2}= 38 psi
- Sorbent capacity under Wabash condition (P_{CO2} = 114 psi) increases to 7.03% wt.
- Next generation E-Gas gasifier is expected to operate at 750 psi (P_{CO2}= 240 psi) and the prototype unit achieved 9.94% wt. CO_2 capacity at 750 psi



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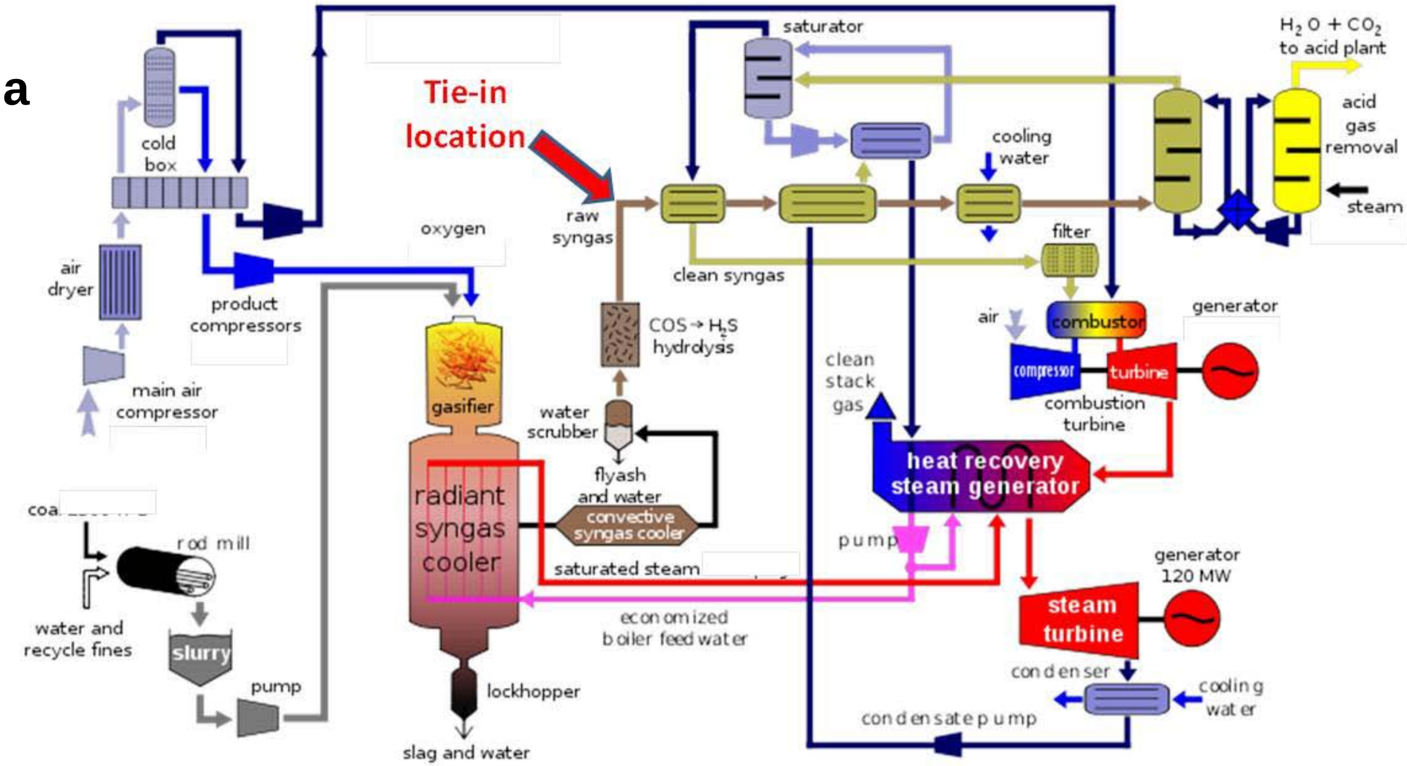
Wabash River IGCC Demonstration

- Process Hazard Analysis is complete
- Tie-in location is identified
  - Downstream of a COS hydrolysis unit
  - T= 194^{o}C
  - P= 357 psia



- All site modifications are completed based on TDA's utility requirements
- Scheduled to start in early August 2012

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Acknowledgements

DOE/NETL

Arun Bose - DOE Project Manager

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