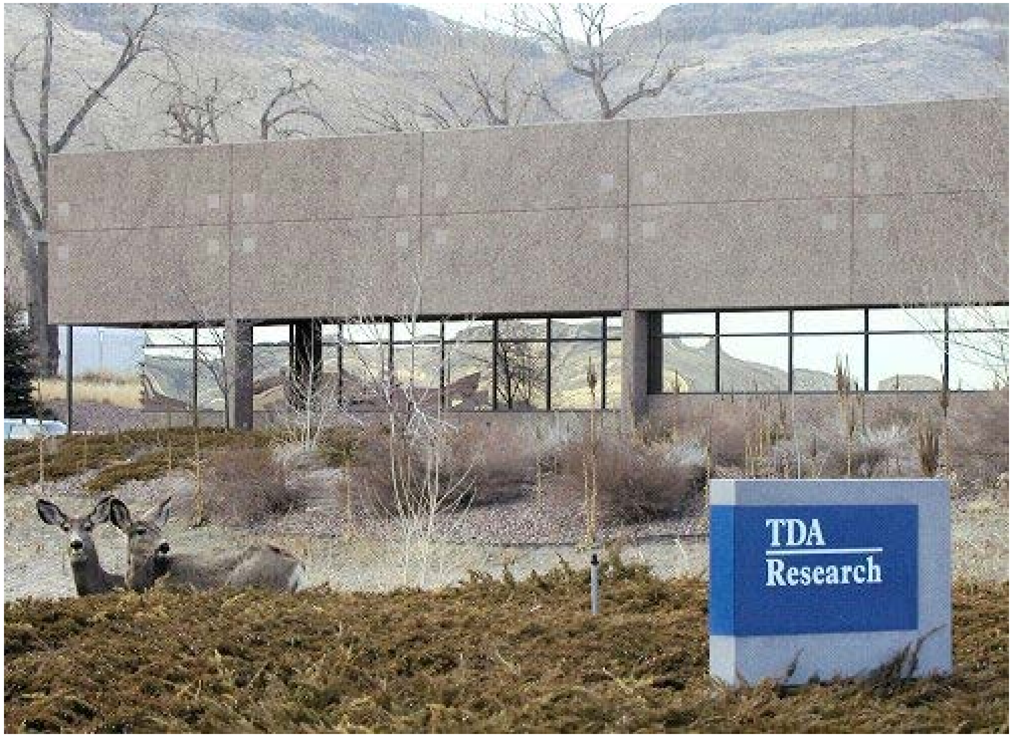
Integrated WGS Reactor/CO_2 Capture System for Pre-combustion Carbon Capture (Contract No. DE-FE-0023684)



Gökhan Alptekin
Ambal Jayaraman
Mike Bonnema

DOE/NETL
Project Kick-off Meeting

January 9, 2014

TDA Research, Inc.

- Privately Owned / Began operations in 1987
- 82 full-time technical staff
  - Primarily chemists and engineers, more than half with advanced degrees (28 PhDs)

12345-12355 W 52nd Avenue

22,000 ft^2 offices and labs

Synthetic Chemistry, Catalyst/Sorbent Synthesis and Testing, Machine and Electronics Shops, SEM, TOF Mass Spec

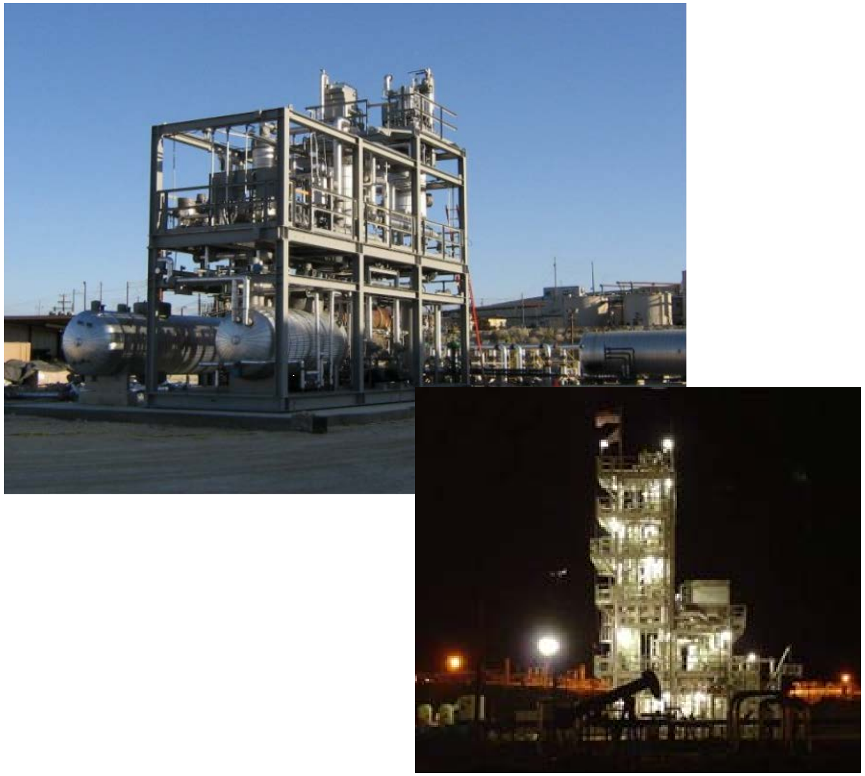
4663 Table Mountain Drive

27,000 ft^2 offices and labs

27 fume hoods, Synthetic Chemistry, Catalytic Process Development

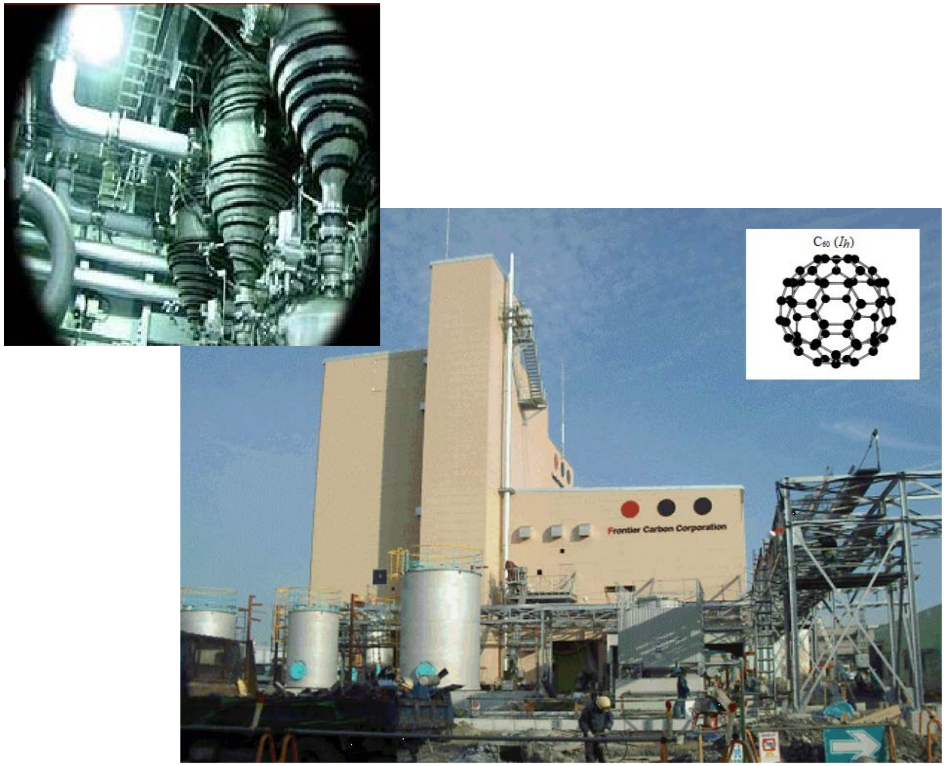
TDA Products - Licences

- **Technologies with high capital investment requirement commercialized via licensing/strategic partnerships**



Direct Oxidation for Bulk Sulfur Removal

Licenses with SulfaTreat DO and GTC (1.3 and 6 ton/day plants at Bakersfield, CA)



Fullerene Synthesis
License with Frontier Carbon
40 ton/year plant in Kitakyushu, Japan
TDA built the reactors

TDA Products – Direct Sales

SuperSoap™

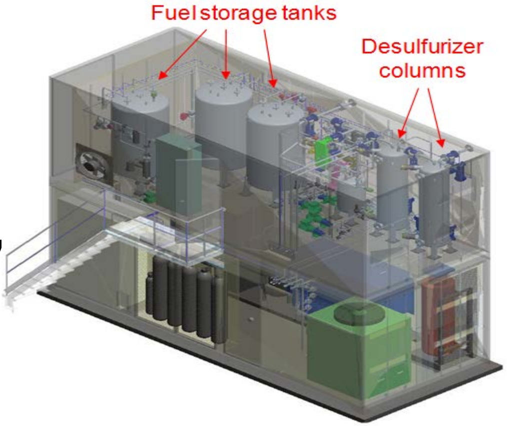
Ambient Temperature CO Oxidation Catalyst

Oligotron™ - Conducting polymers available through Sigma-Aldrich

TDA Spin-off - SulfaTrap™ Sorbents

SulfaTrap™ sorbents for stationary/mobile fuel cell applications

- **SulfaTrap™ sorbents desulfurizes various gas streams**
  - Natural gas, LPG, biogas, reformate gas desulfurization, diesel fuel, logistics fuel
- **~50% of fuel cells installed globally (MCFC, SOFC and PEM fuel cells) uses SulfaTrap™ products**



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Project Objective

- **The objective is to demonstrate techno-economic viability of an integrated WGS catalyst/CO_2 removal system with thermal management used in an IGCC power plant**
  - **A high temperature PSA adsorbent for CO_2 removal above the dew point of the synthesis gas**
  - **A commercial low temperature water-gas-shift catalyst**
  - **Heat removal/recovery using a membrane evaporator (or a direct water injector)**
- **Project Tasks**
  - **Design and fabrication of an integrated WGS/CO_2 removal system (15 kg/hr CO_2 removal capability)**
  - **Bench-top evaluation of material performance for 30,000 cycles**
  - **Evaluate the best design in a slipstream test at NCCC using coal derived syngas**
  - **Evaluate the best design in a slipstream test at the Wabash River IGCC plant using coal derived syngas**
  - **A high fidelity engineering design and cost analysis**

Project Partners

TDA Research

SOUTHERN COMPANY

CB&I

icci

gti

UNIVERSITY of CALIFORNIA • IRVINE

Indigo Power FZC

Innovative Solutions for the Power Industry

<u>Project Duration</u>

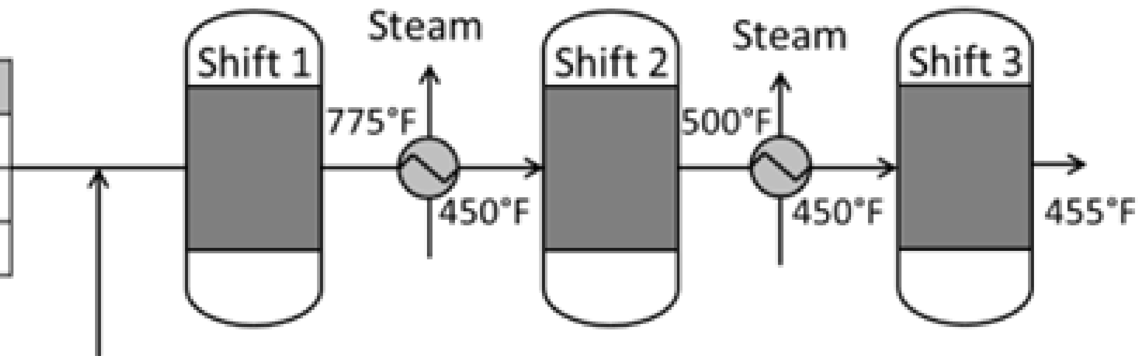
- **Start Date = October 1, 2014**
- **End Date = September 30, 2017**

<u>Budget</u>

- **Project Cost = $5,632,619**
- **DOE Share = $4,506,719**
- **TDA and its partners = $1,125,900**

TDA's Approach

- **A high temperature CO_2 adsorbent is combined with a low temperature shift catalyst for complete shifting of CO *<u>at low steam:carbon ratios</u>***
- **Traditional approach used multi-stage WGS reactors with inter-stage cooling**
  - **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**



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

Expected Benefits

- **Reducing the need to raise excess quantities of steam improves the power cycle efficiency**
- **Water in the synthesis gas is useful <u>but to a point</u>**
  - **It reduces the gas turbine temperature and prevents NO_x formation**
- **The removal of CO_2 reaction product will shift the WGS reaction equilibrium even at low steam:carbon ratios**

$$CO + H_2O = H_2 + CO_2$$

  - **Lower energy consumption to raise steam**
- **Process intensification reduces the number of hardware components and cost**

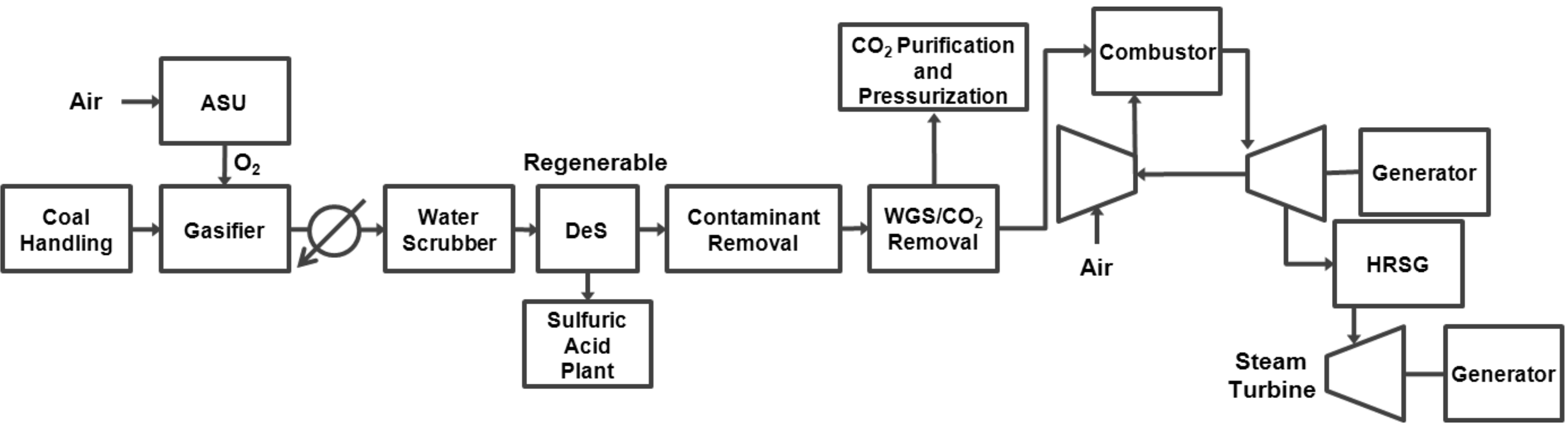
Sorbent's point of view:

- **Less dilution w/water higher CO_2 partial pressure**

TDA's Approach to Sorbent

- **The sorbent consists of a mesoporous carbon modified 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, the energy input for regeneration is low
- **Heat of CO_2 adsorption is measured as 4.9 kcal/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)
- **Net energy loss in sorbent regeneration is similar to Selexol**
  - A much better IGCC efficiency due to high temperature CO_2 capture
  - Warm gas clean-up improves cycle efficiency 2 to 4%

Integrated WGS/CO_2 Capture System



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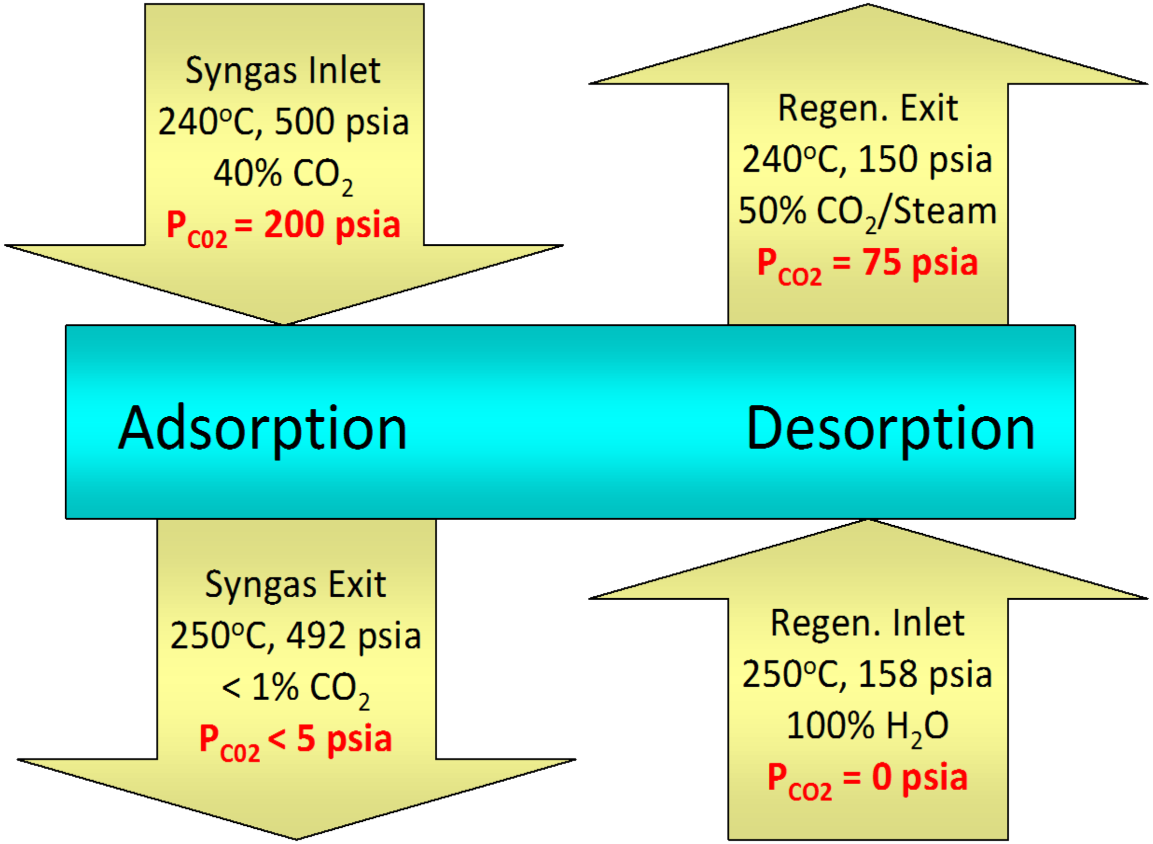
Operating Conditions

- Isothermal operation is critical to eliminate heat/cool transitions which reduces cycle time and increases sorbent utilization
- Steam consumption can be significantly reduced if steam purge is carried out at low pressure
- Commercial WGS catalyst (Shiftmax 230) is co-located with the sorbent



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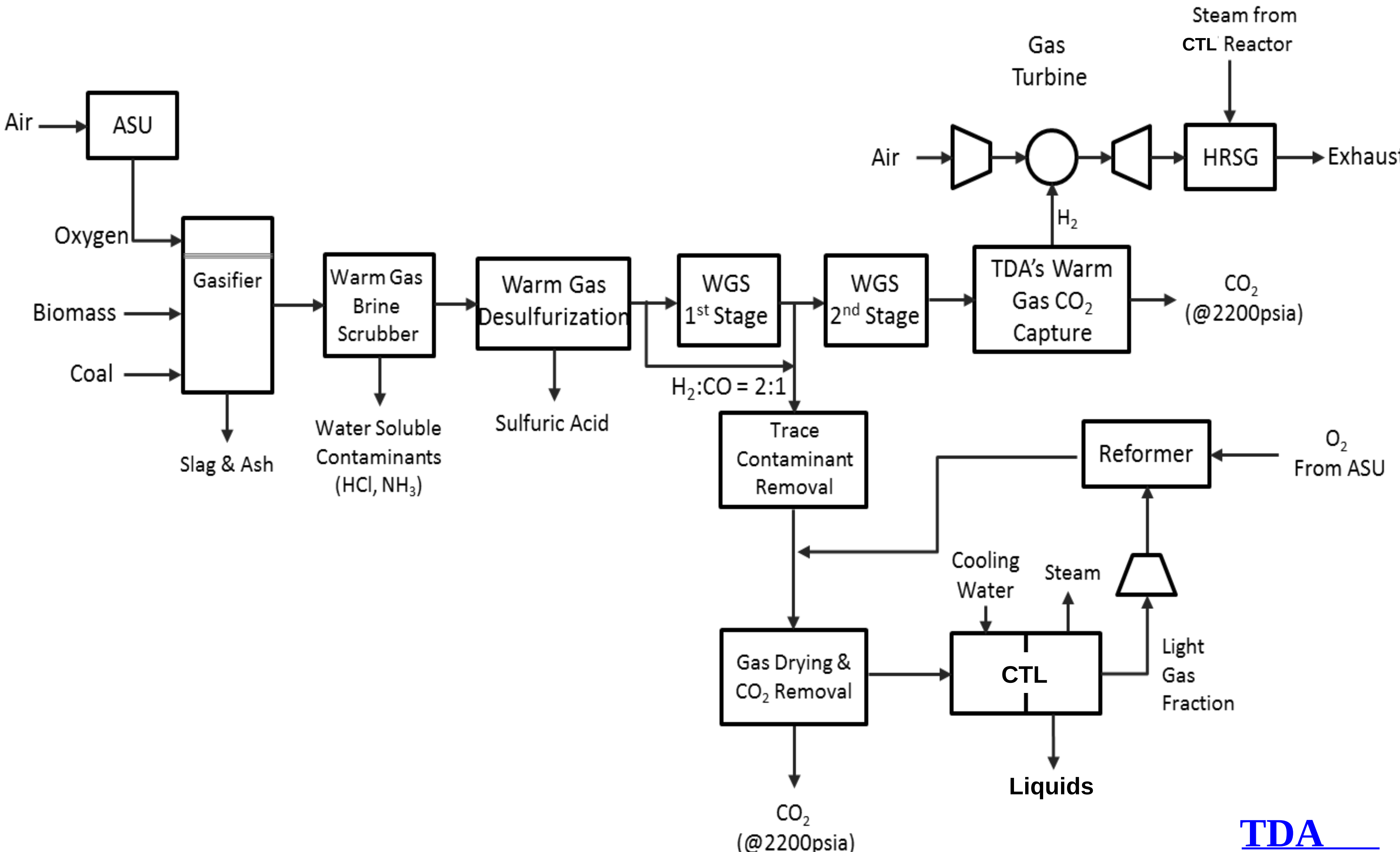
Application to CTL



TDA Research

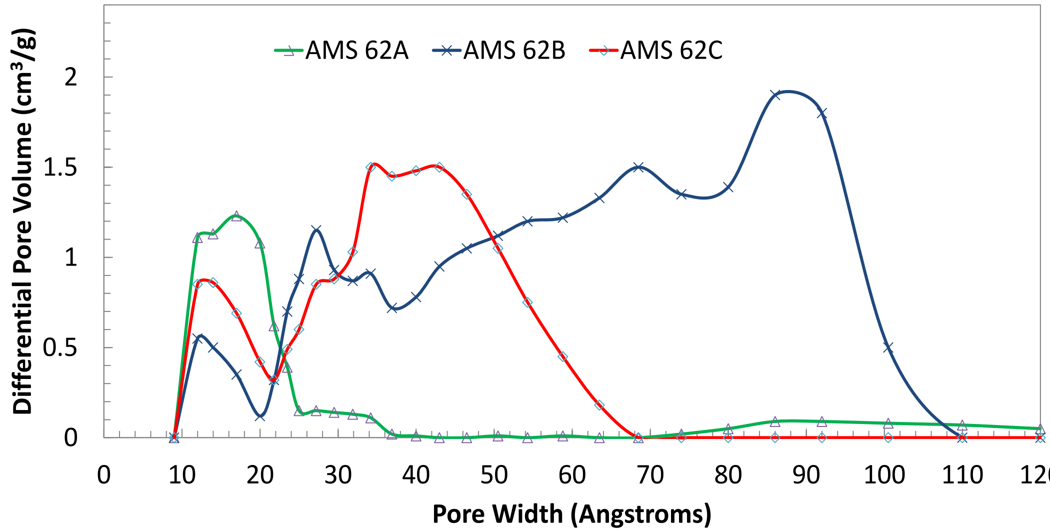
Technology Status/R&D Needs

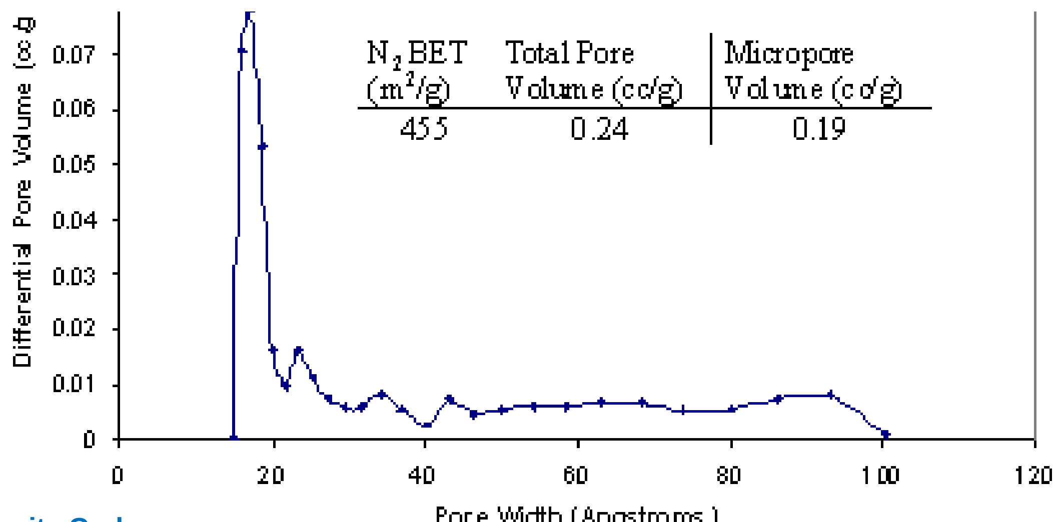
- **Sorbent is developed under a separate DOE project (DE-FE0000469)**
- **WGS catalyst is commercially available**
- **Early-stage concept demonstration has already been completed (under DE-FE0007966)**
  - **Integrated sorbent/catalyst operation**
- **Early-stage prototype demonstration of an integrated system with heat management is also under progress (under DE-FE-00012048)**
  - **~0.2 kg/hr CO_2 removal**
  - **Slipstream test at the NCCC**
- **Key R&D need is the design/development of a high fidelity prototype to fully demonstrate the concept using actual coal-derived synthesis gas**

Previous Work
Sorbent Development
DE-FE0000469

TDA's Sorbent

- A mesoporous carbon is used to disperse the active sorbent phase
- Pore size can be finely tuned in the 10 to 100 A range
- Mesopores eliminates diffusion limitations and rapid mass transfer, while enables high surface area
- The preparation process also enables us to introduce various surface groups active for removing different compounds



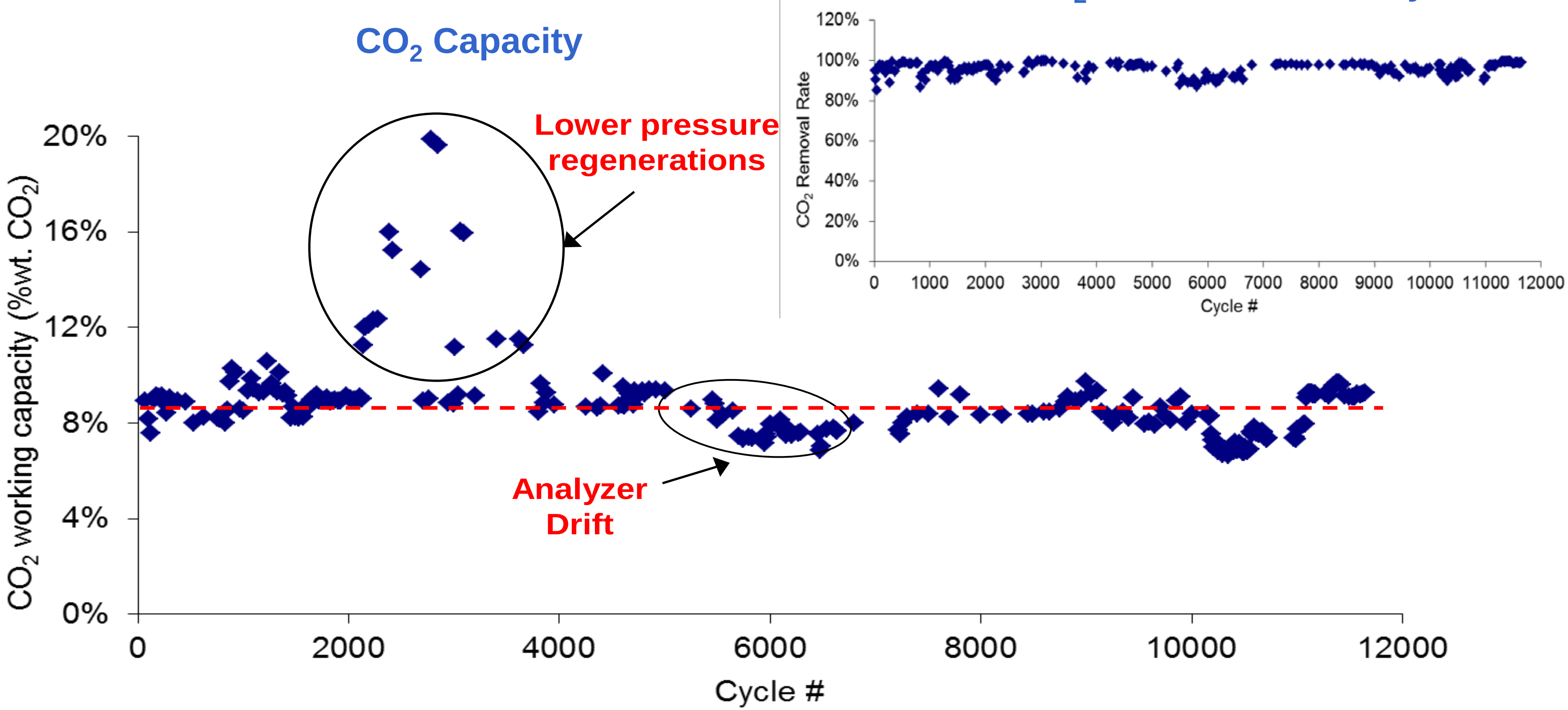


US Pat. Appl. 61787761, Dietz, Alptekin, Jayaraman "High Capacity Carbon Dioxide Sorbent"
US Pat. Appl. 61790193, Alptekin, Jayaraman, Copeland "Pre-combustion Carbon Dioxide Capture System Using a Regenerable Sorbent"

TDA Research

Multiple Cycle Tests – Bench-scale

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 12,650 cycles**

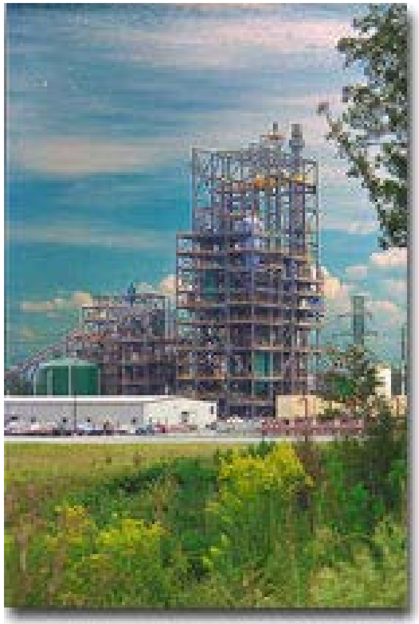
TDA Research

Slipstream Demonstrations

- Several for proof-of-concept tests were completed at two different facilities

<u>Wabash River IGCC Plant, Terre Haute, IN</u>

- Demonstration carried out in September 2012
- Largest single-train Gasifier (262 MW)
- Oxy-blown E-Gas^{TM} Gasifier
- Operates on petcoke



<u>National Carbon Capture Center, Wilsonville, AL</u>

- 1st Demonstration carried out in November, 2011
- 2nd Demonstration carried out in April, 2012
- Pilot-scale air blown TRIG gasifier
- Operates on low rank coals

Test Units – In NEMA-Rated Enclosures

CO_2 Removal Skid

Gas Conditioning Skid

Field Test Units Installed at NCCC

TDA Research

Field Test Units at Wabash River IGCC

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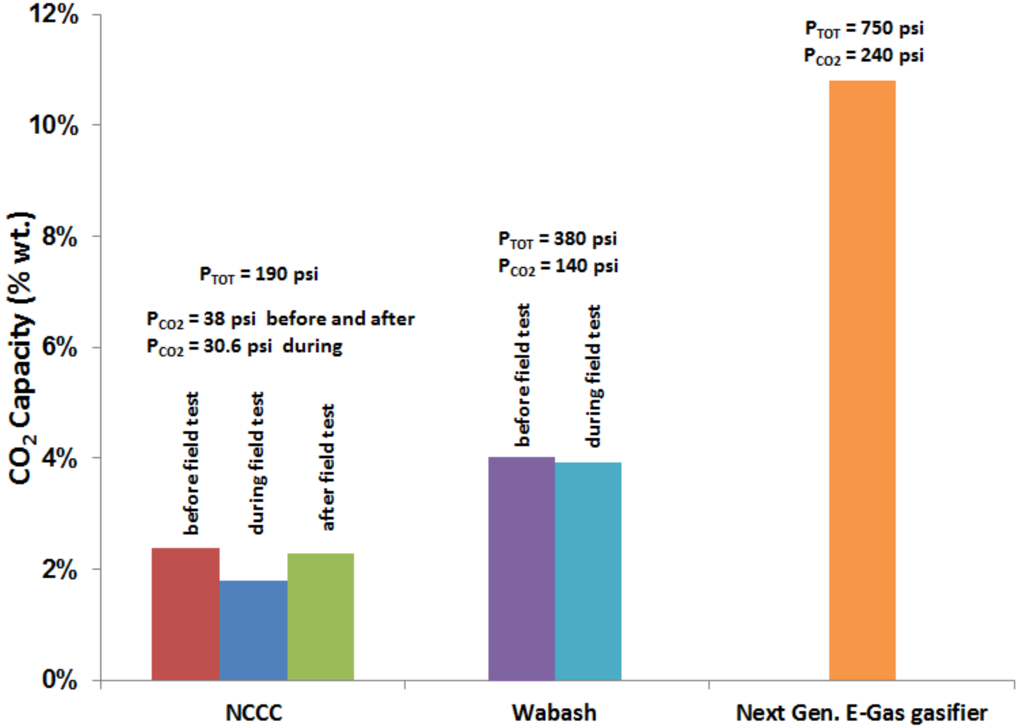
TDA Proprietary

Prototype Performance



- **Sorbent achieved similar CO_2 capacity before and after the field test**
  - **2.6% wt. CO_2 at P_{CO2} = 38 psi**
- **Prototype unit under Wabash condition (P_{CO2} = 140 psi) achieved 4.1% wt. CO_2 capacity**
- **Next generation E-Gas gasifier is expected to operate at 750 psi (P_{CO2} = 240 psi) and capacity will exceed 10% wt. CO_2**

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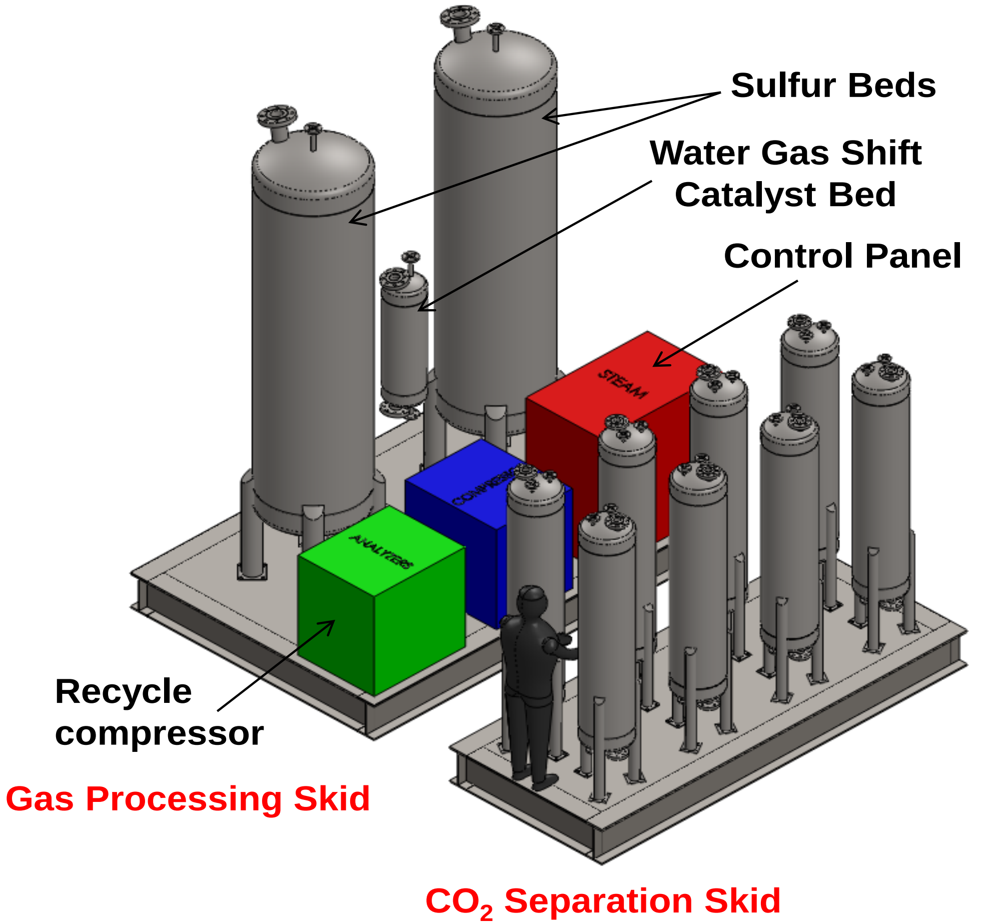
System Analysis Results

	Cold Gas Cleanup Selexol™	Warm Gas Cleanup TDA's CO_2 Sorbent
CO_2 Capture, %	90.0	90.0
Gross Power Generated, kWe	691,247	733,028
Gas Turbine Power	464,000	464,000
Steam Turbine Power	227,247	269,028
Auxiliary Load, kWe	175,994	131,163
Net Power, kWe	515,253	601,865
Net Plant Efficiency, % HHV	**31.6%**	**34.0%**
Coal Feed Rate, kg/h	216,187	234,867
Raw Water Usage, GPM/MWe	11.8	11.2
Total Plant Cost, $/kWe	2,754	2,418
COE without CO_2 TS&M, $/MWh	99.8	87.8
COE with CO2 TS&M, $/MWh	**105.2**	**92.9**

- **IGCC plant with TDA's CO_2 capture system achieves higher efficiency (34.0%) than IGCC with Selexol™ (31.6%)**
- **Cost of per tonne CO_2 avoided is $31.12 for TDA's warm gas CO_2 capture technology compared $49.50 for cold gas cleanup with Selexol™ technology**

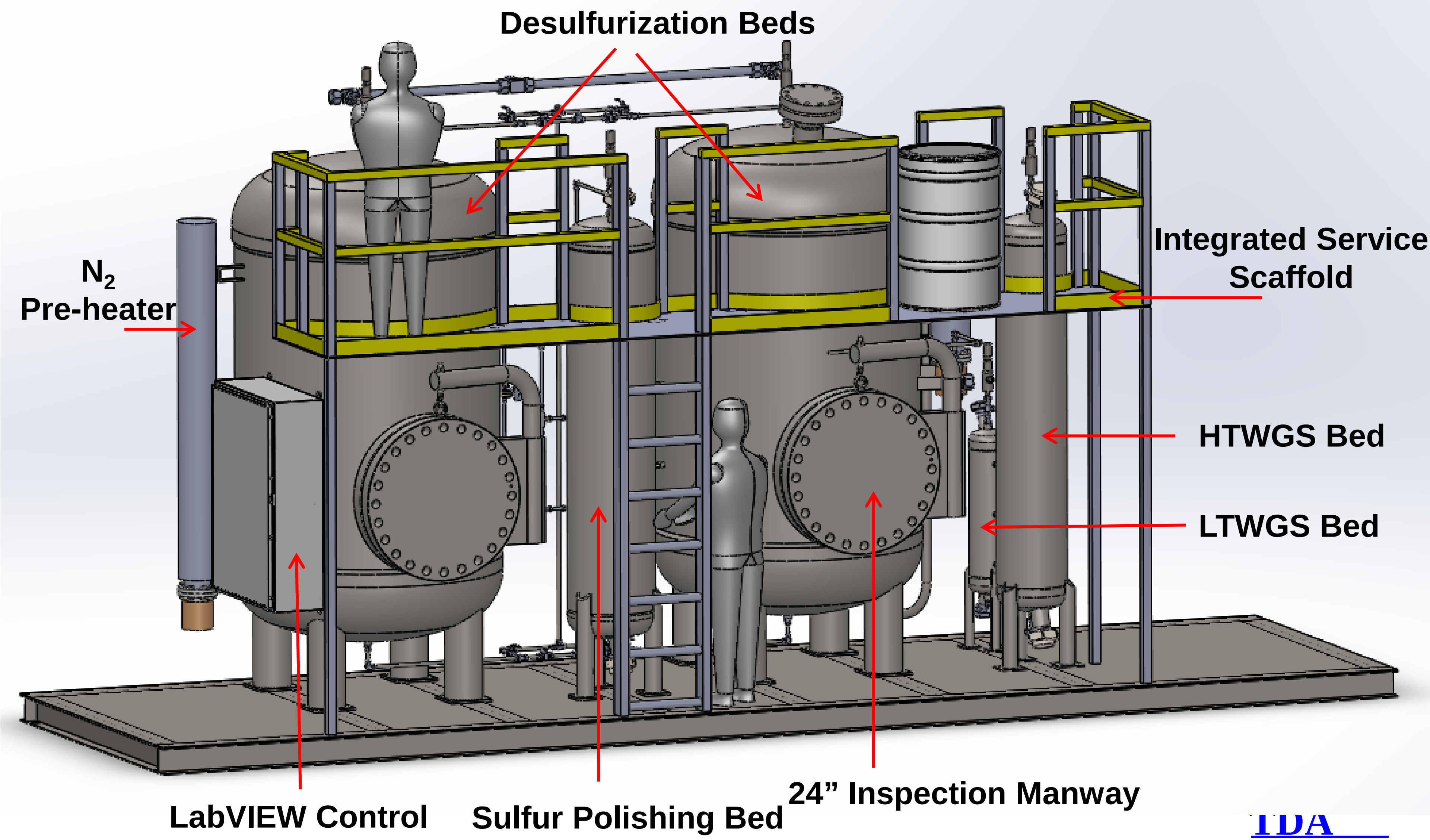
0.1 MW Slipstream Demonstration



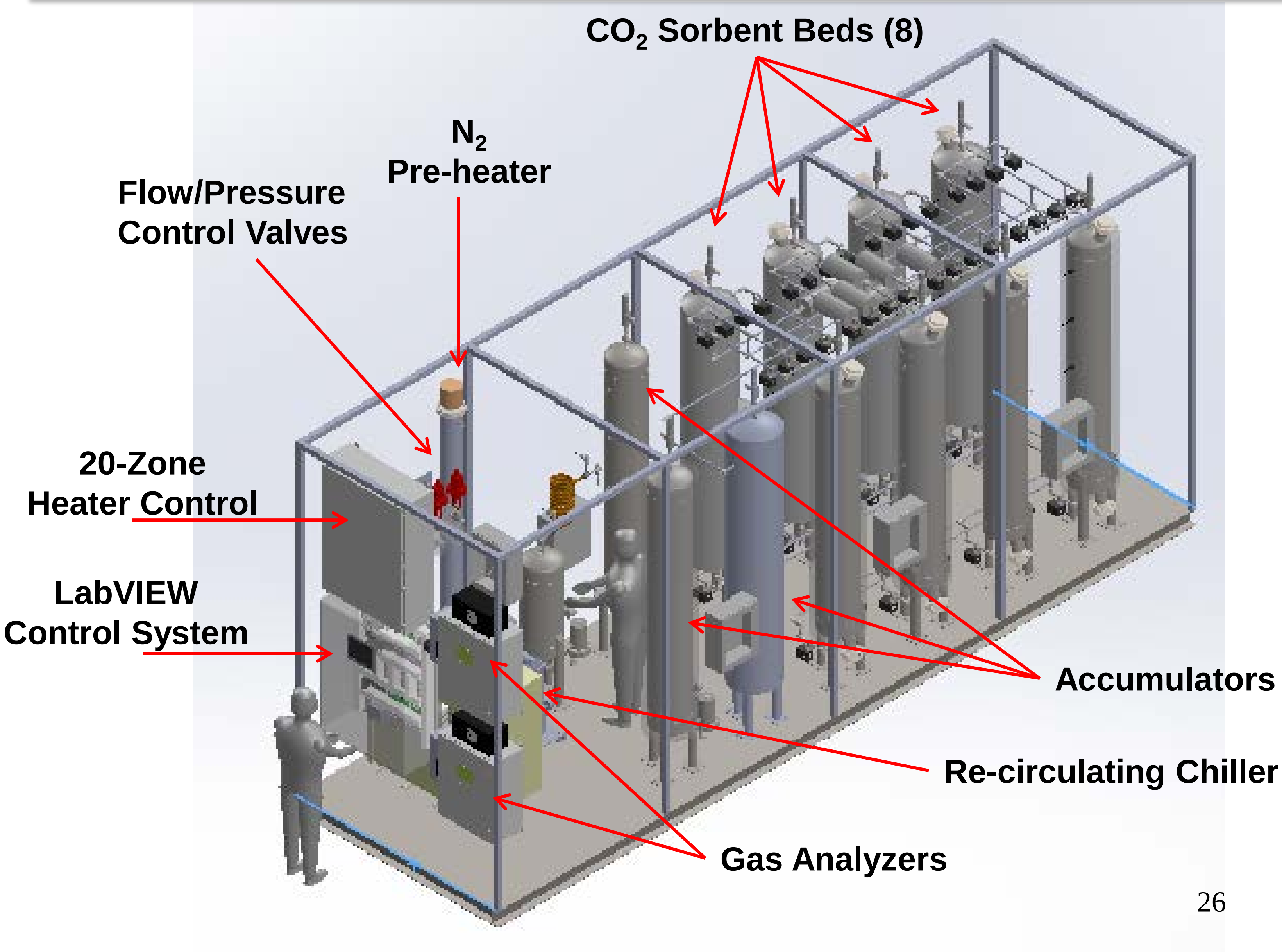
- **0.1 MW demonstration at Sinopec's Fujian ethylene complex**
  - **Asphaltene fractions/petcoke feed**

TDA Research

Gas Conditioning Skid

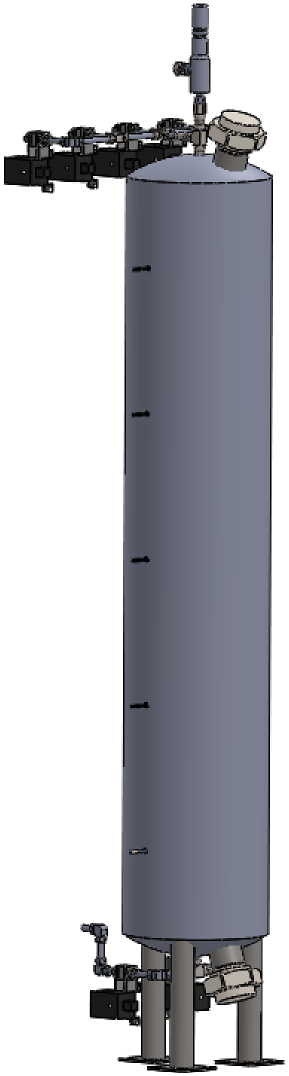


CO_2 Separation Skid

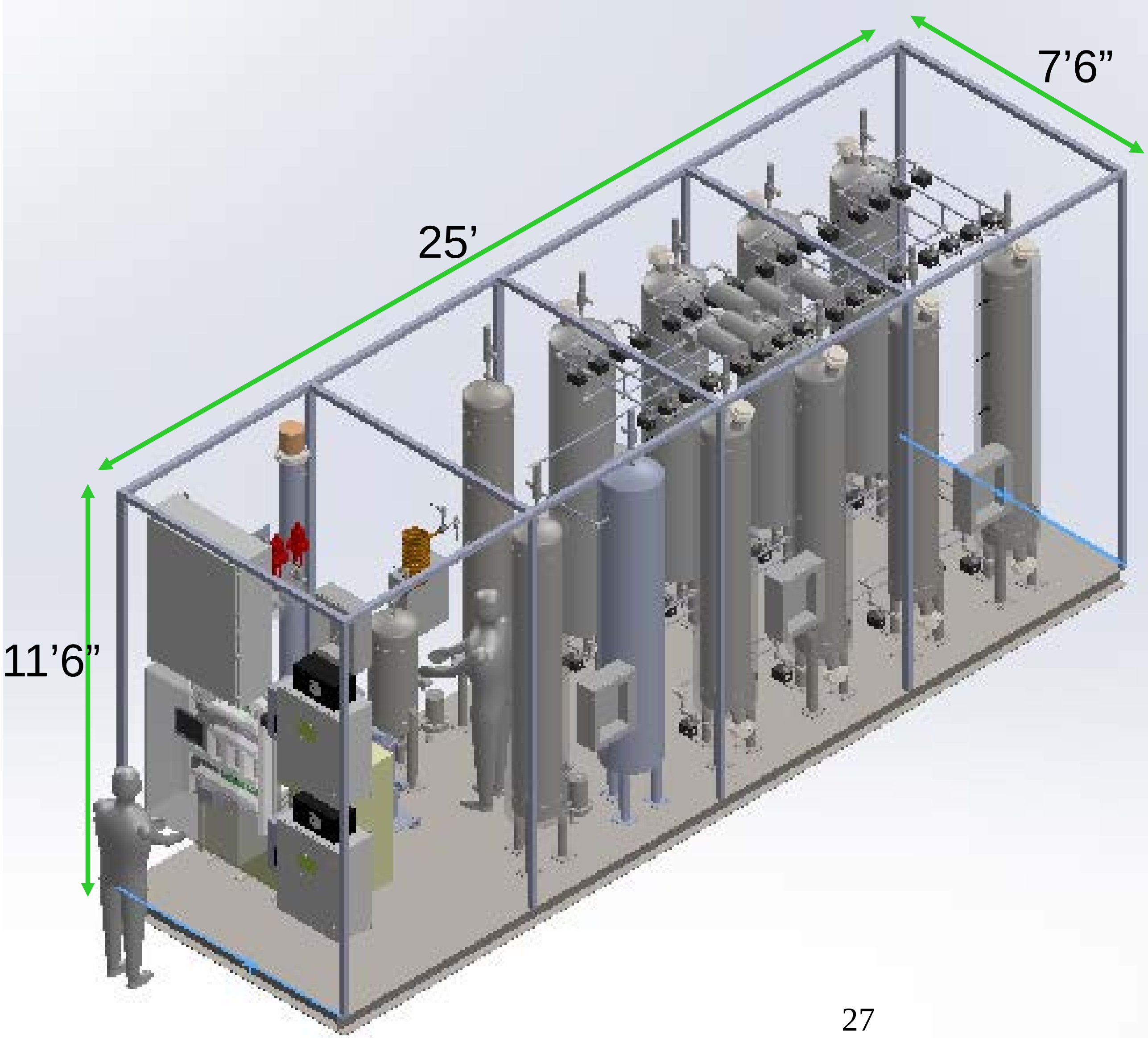


TDA Research

CO_2 Separation Skid

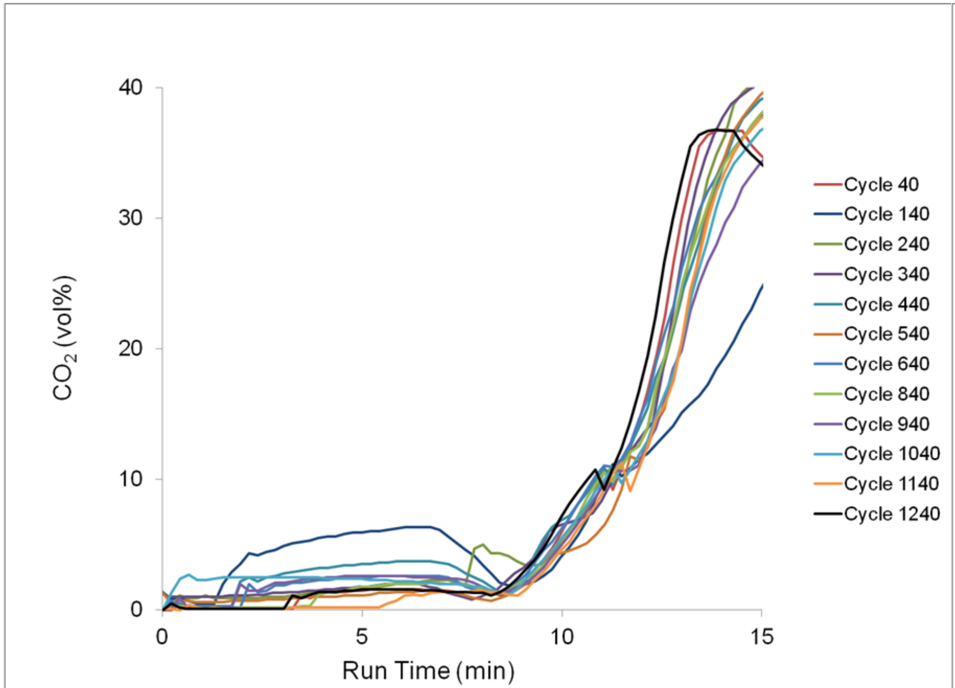


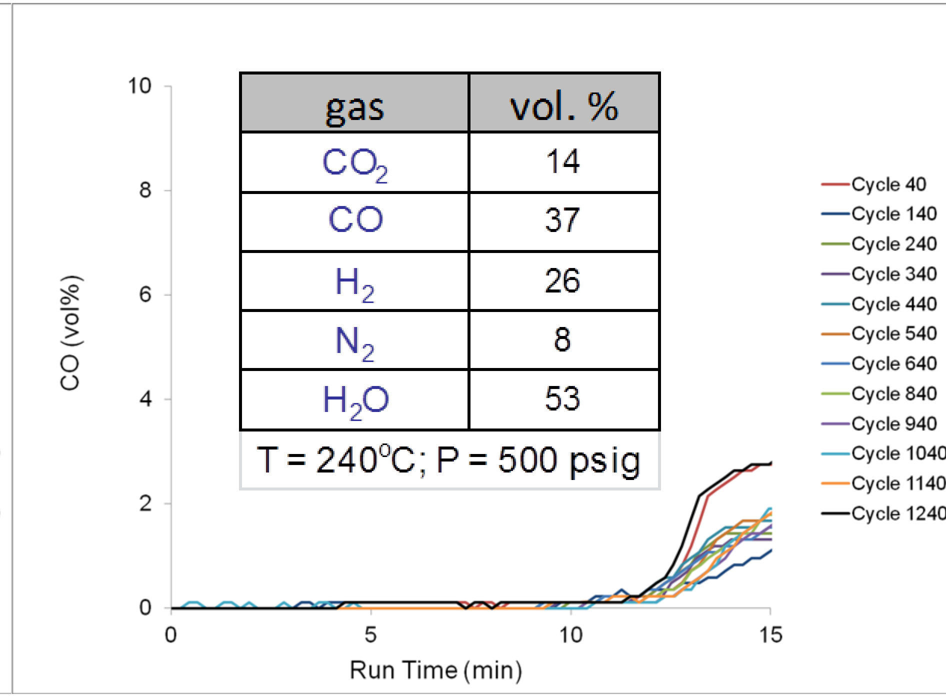
14" OD x 8ft
200 L
304 SS
Rated 450°C/
750 psig



Previous Work
Integrated WGS/CO_2 Capture
Concept Demonstration
DE-FE0007966

Bench-scale Evaluations

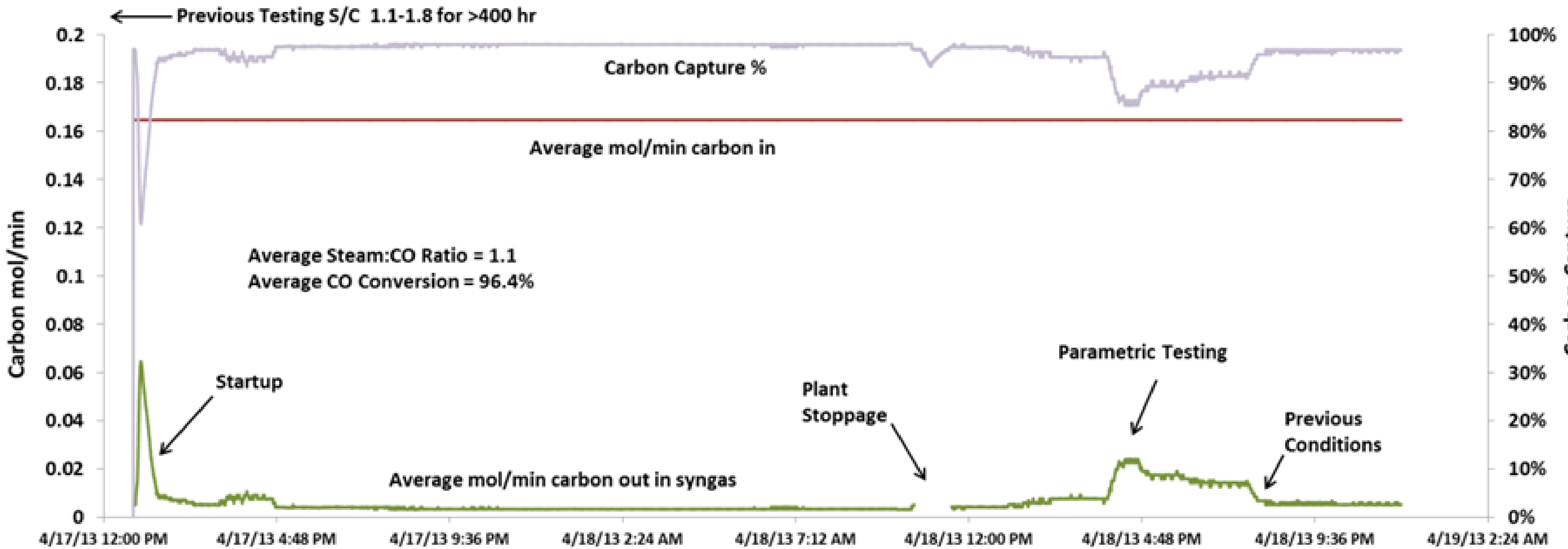




gas	vol. %
CO_2	14
CO	37
H_2	26
N_2	8
H_2O	53
T = 240°C; P = 500 psig	

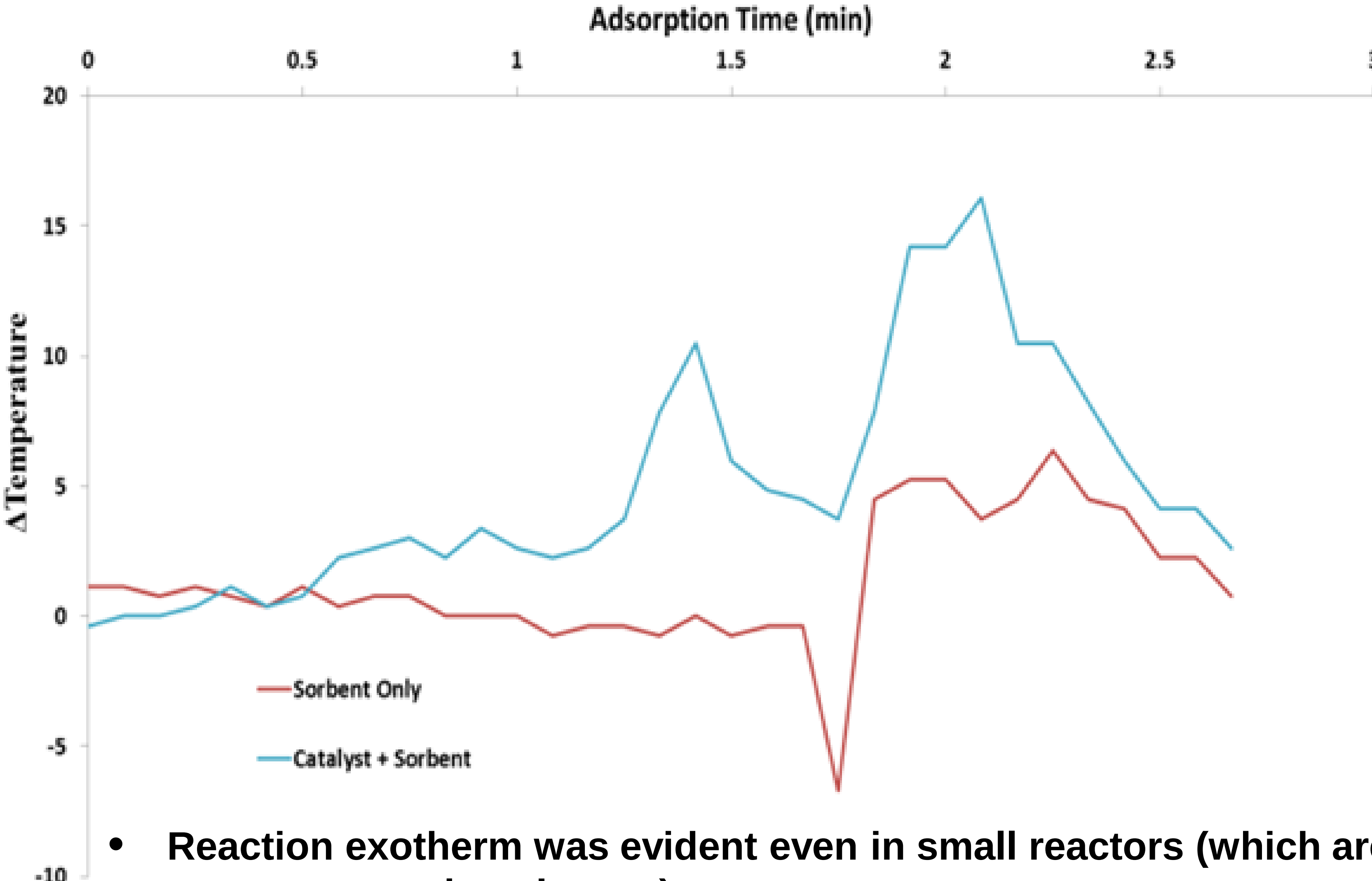
- **We carried out multiple cycle tests with combined WGS catalyst and CO_2 sorbent using partially shifted synthesis gas**
  - **CO concentration climbed up to equilibrium level only after sorbent reached its CO_2 capacity**
- **The sorbent and the catalyst maintained their performance over 1240 cycles breakthrough data**

NCCC – 2nd Field Test



- **Prototype system achieved 90+% carbon capture under Steam:CO ratio of 1:1.1 with average CO conversion of 96.4%**

Reaction Exotherm During Field Test



- **Reaction exotherm was evident even in small reactors (which are prone to more heat losses)**

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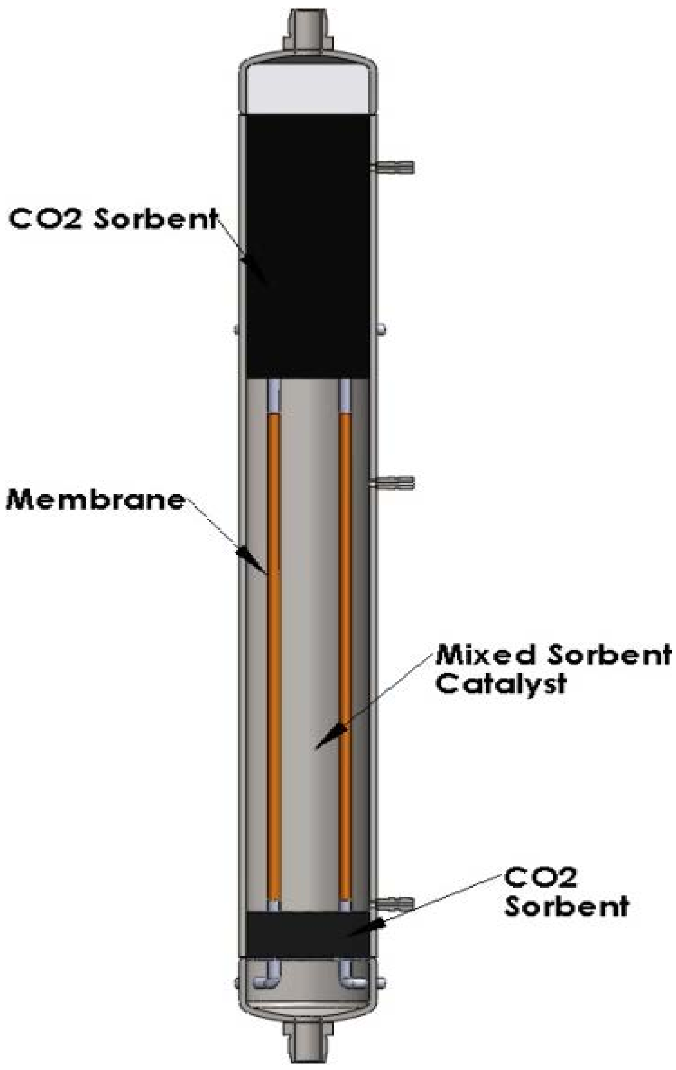
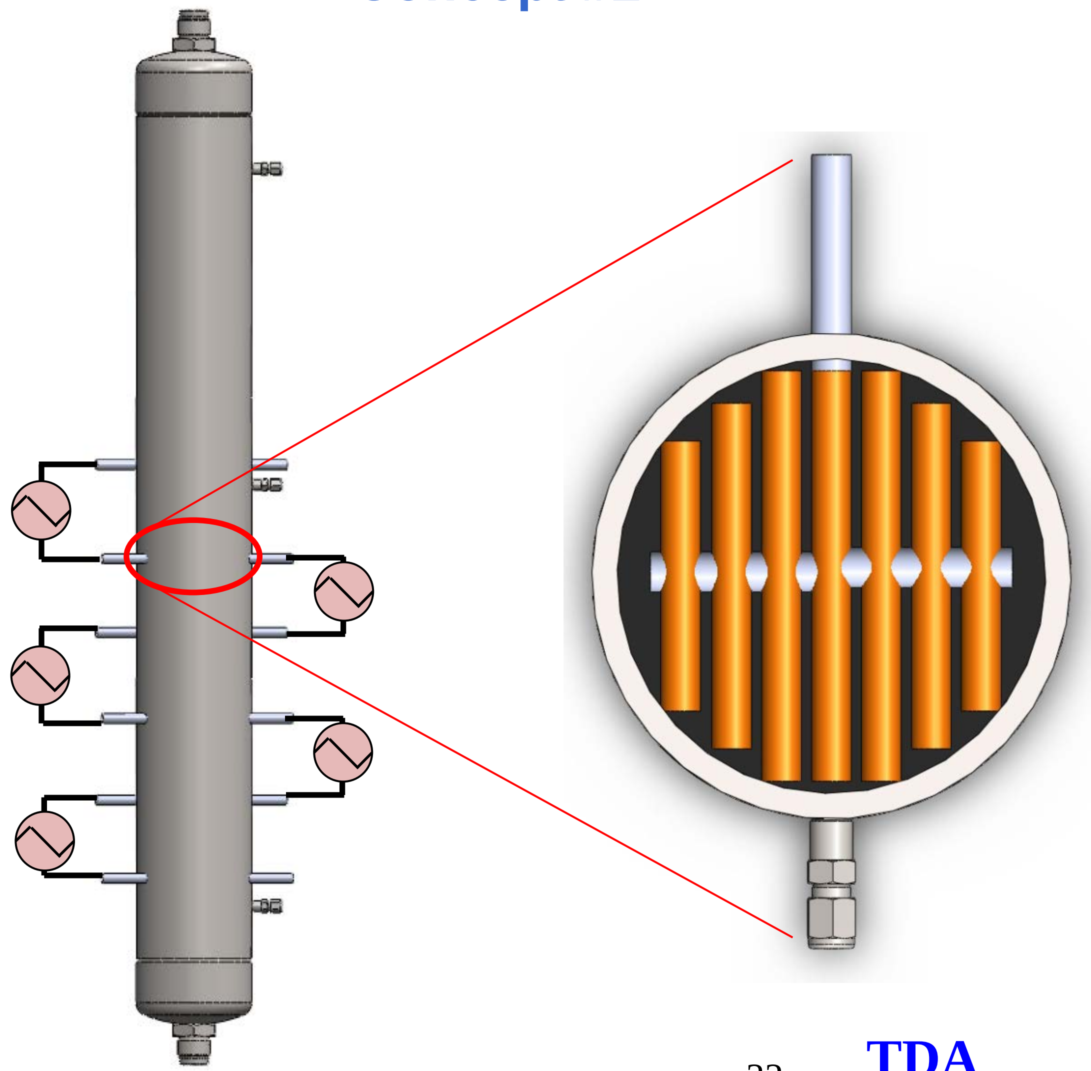
Reactor Design Concepts

Concept #1

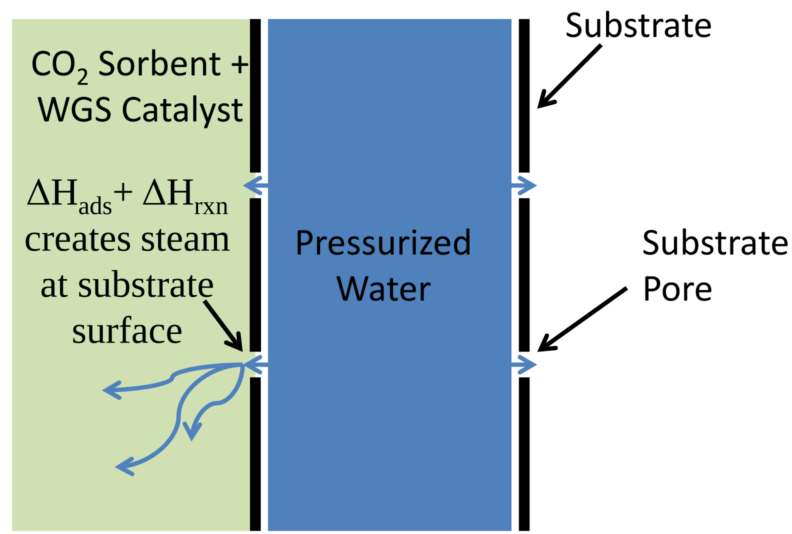


Concept #2



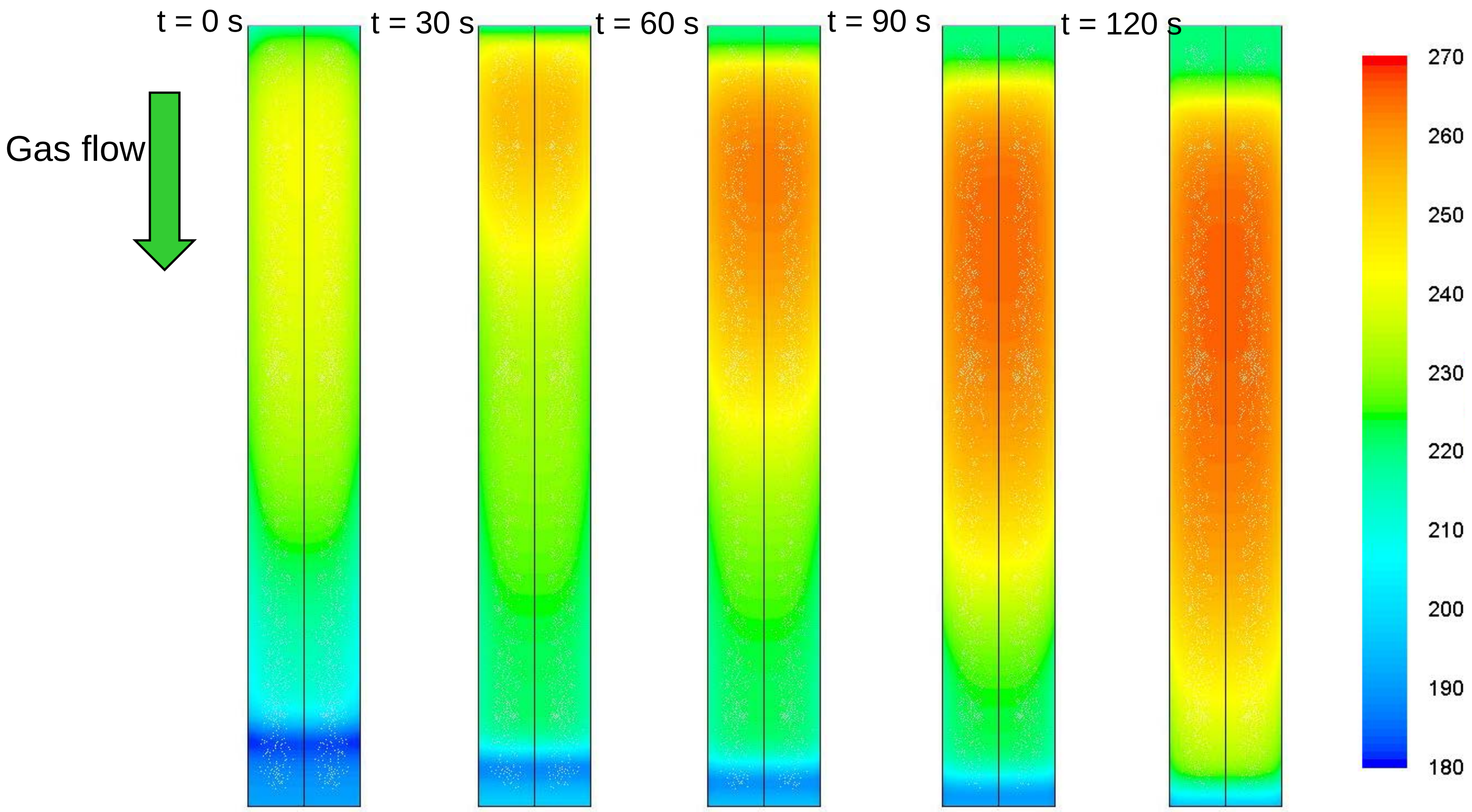
Reactor Design

Conventional Internally-cooled Fixed-Bed Reactors



Current Concept
In addition to take advantage of the conductive cooling takes advantage of evaporative/convective cooling

Heat Wave During CO_2 Capture Only



- **Adsorption heat wave results which gets canceled during desorption**

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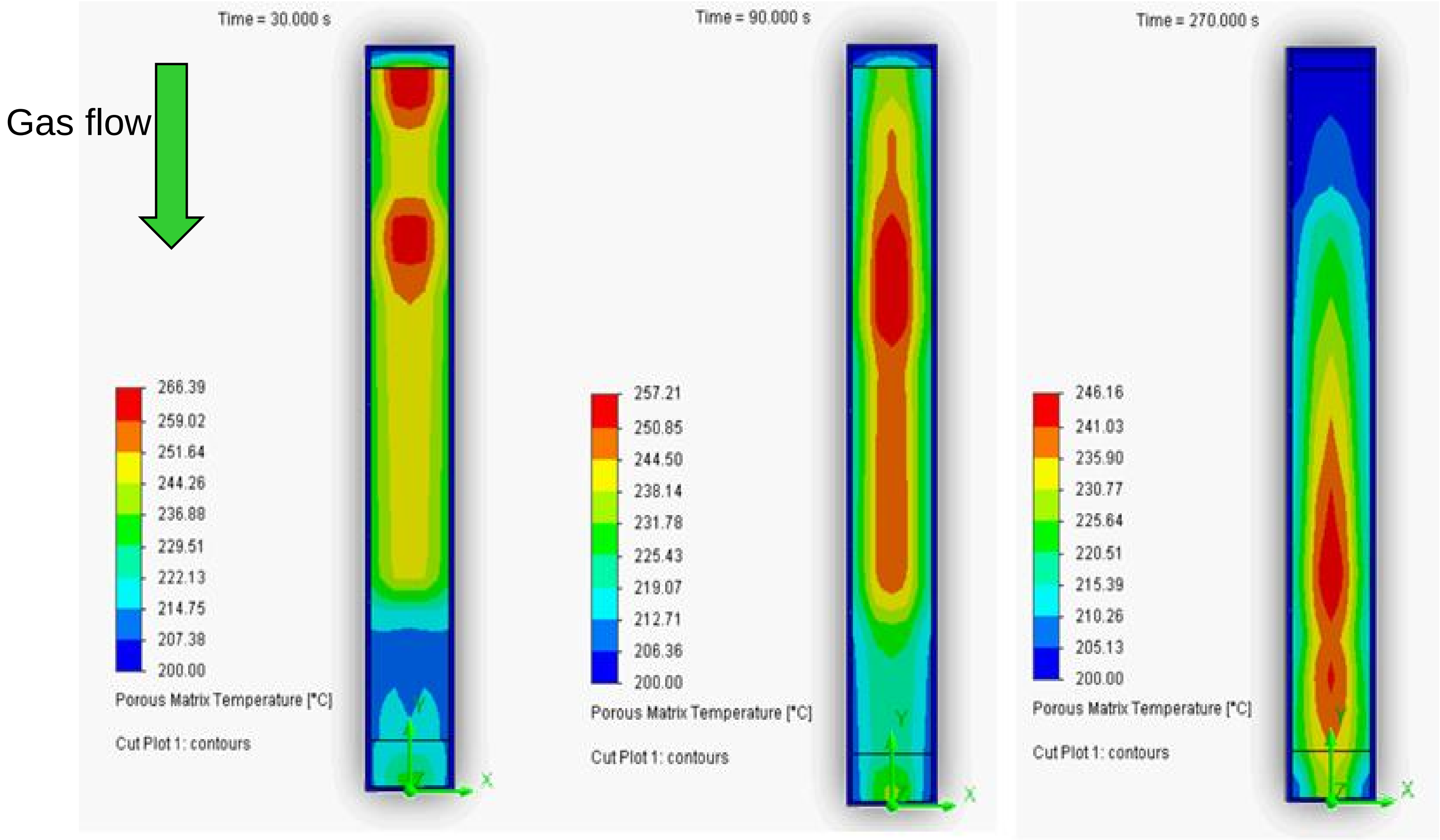
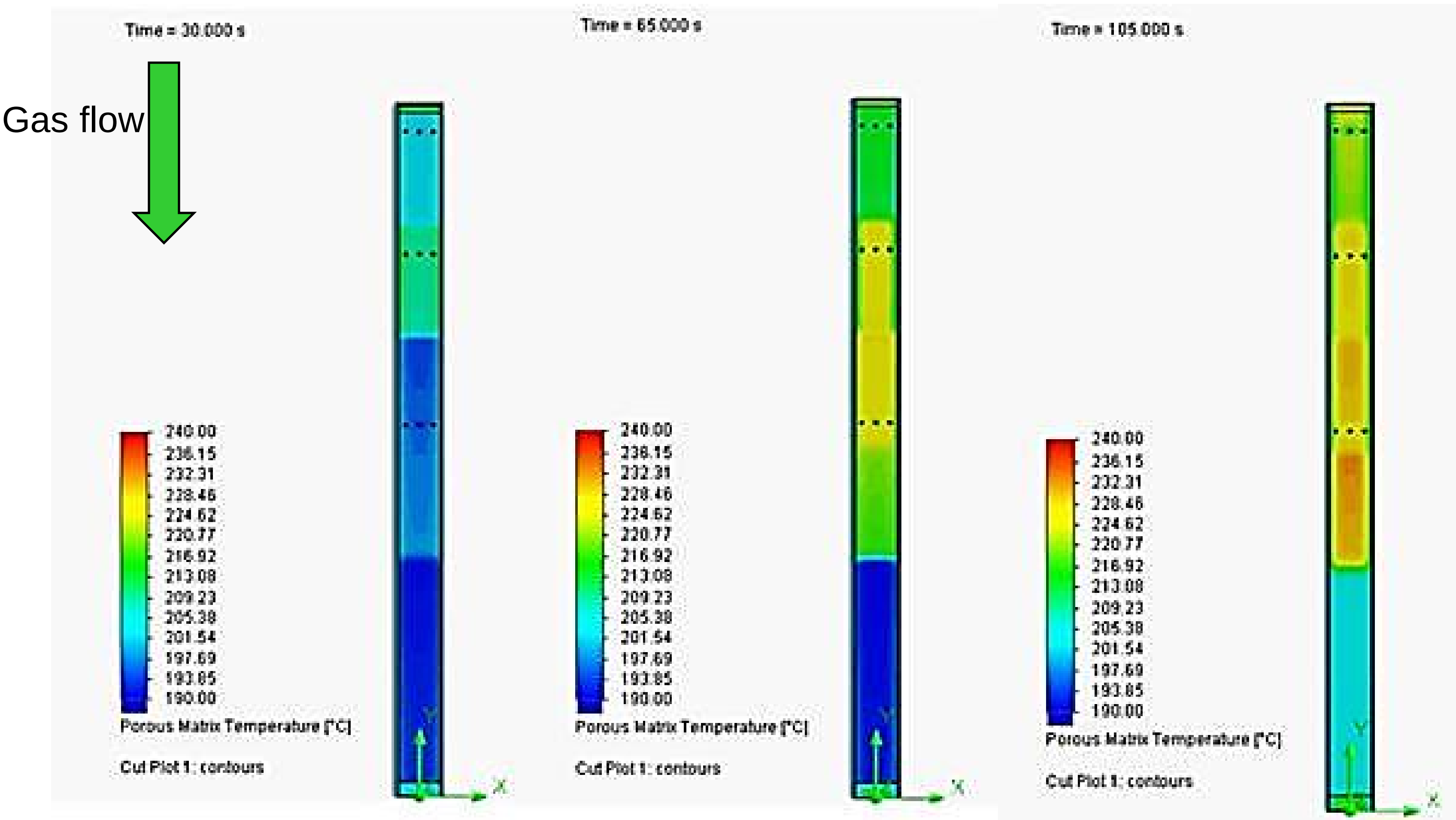
Heat Wave WGS & CO_2 Capture



- **Combined WGS & CO_2 capture results in higher ΔT and the beds are not ideal for CO_2 capture (the WGS heat accumulates in the beds)**

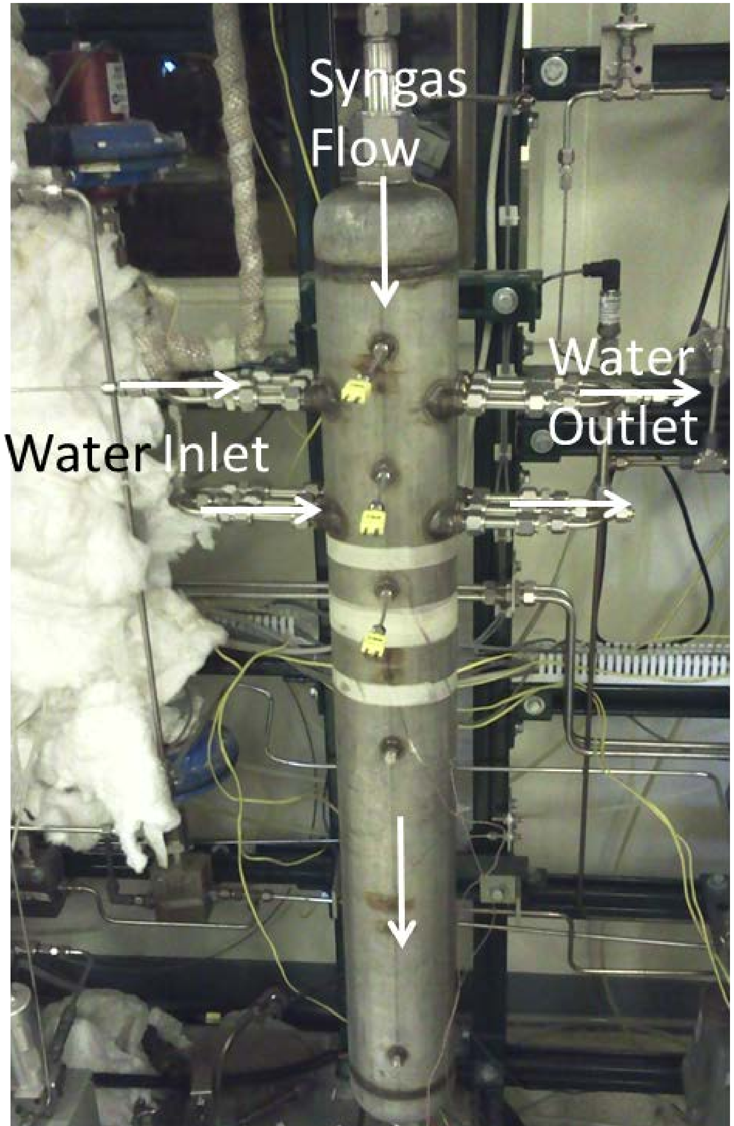
Heat Integrated WGS & CO_2 Capture



- **When using steam introduction at three different locations in the beds the maximum temperature in the beds can be reduced from 245 to 230°C**

TDA Research

Early-stage Evaluations



- 8L reactor was modified with the permeable tube design
  - Testing under once through flow
- Water flows through all or some of the 6 tubes positioned perpendicular to the syngas flow

- Successful proof-of-concept demonstrations
- Several problems
  - Control of water injection rate (which reduces the temperature early in the adsorption process)
  - Steam loss to the regeneration side

Scope of Work

Budget Period 1 (BP1: 10/1/2014 – 9/30/2015)

- Design a field test unit including detailed design of the sorbent reactors, using multi-component adsorption and CFD simulation models
- Have the input and full approval of NCCC and CB&I
- Complete sorbent manufacturing based on the current Manufacturing Plan
- Initiate a long-term sorbent life evaluation (8,000 cycles)

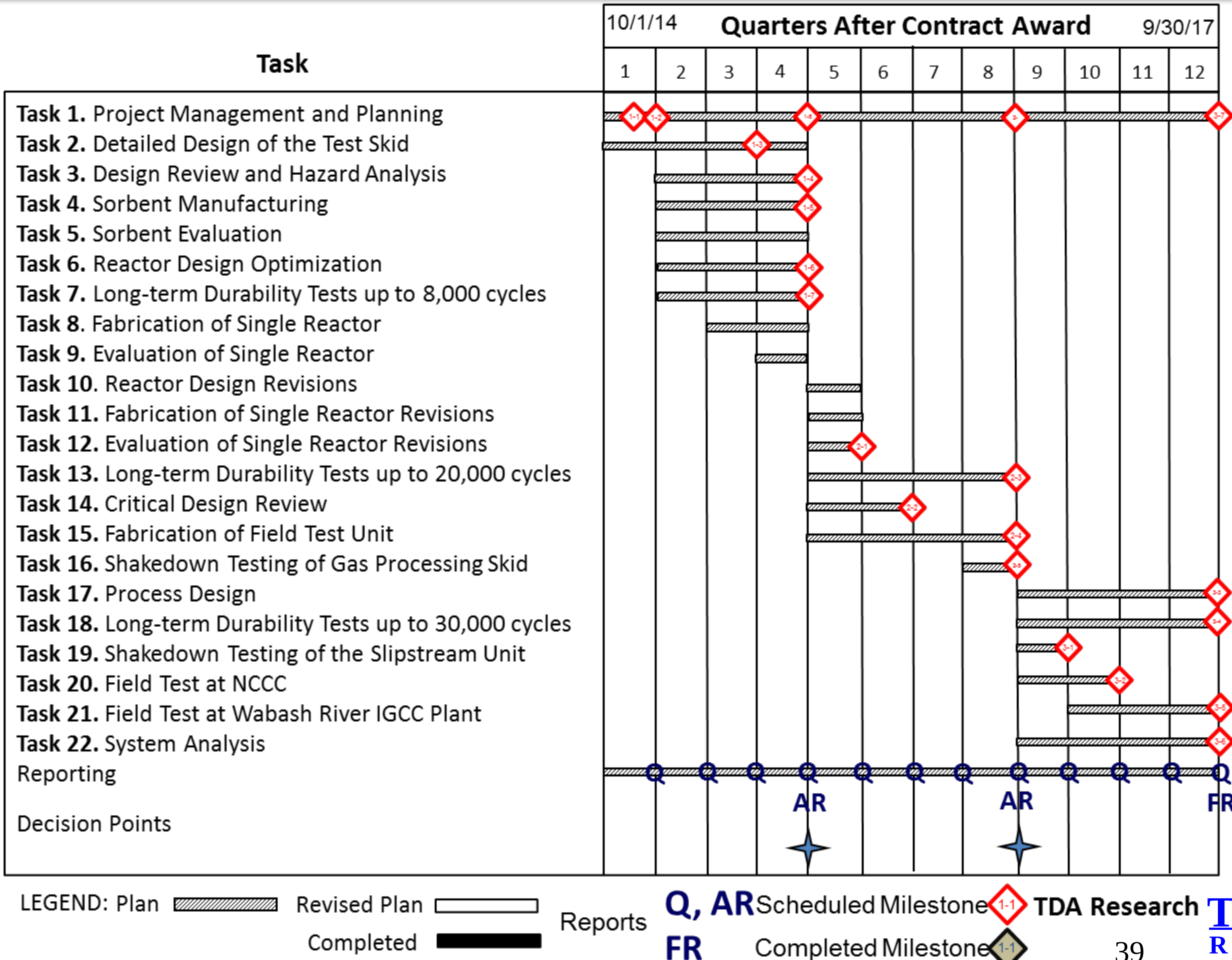
Budget Period 2 (BP2: 10/1/2015 – 9/30/2016)

- Complete evaluation of single integrated reactor with simulated syngas
- Revise our reactor design based on results from single reactor tests
- Complete fabrication of the slipstream test unit
- Continue long-term testing of the sorbent (20,000 cycles)

Budget Period 3 (BP3: 10/1/2016 – 9/30/2017)

- Complete long-term testing of the sorbent (30,000 cycles)
- Complete field tests at the NCCC and Wabash River IGCC Plants
- Complete a high-fidelity system design/analysis and cost estimate
- Complete an Environmental, Health and Safety (EHS) assessment

Project Work Plan and Schedule



TDA Research

TDA Research

Task 1. Project Management & Planning

- Undertake necessary activities to ensure coordination and planning of the project with DOE/NETL and other project participants
- Monitor and control the project scope, cost, schedule, and risks,
- Submit and get approval for the required NEPA documentation
- Maintain and revise the Project Management Plan (PMP) and manage and report on activities in accordance with the plan
- Update the Project Management Plan as the project progresses, and report progress against milestones, schedule and budget, including any variances
- Prepare and deliver required reports and briefings

Task 2. Detailed Design of the Test Skid

- **Slipstream test unit will be designed to treat 300 SLPM of synthesis gas flow**
  - 15 kg/hr CO_2 capture capability (based on the gas flow at the Wabash River IGCC Plant)
- **Two sub-units will be provided on separate skids:**

  1) Integrated WGS/CO2 Separation Skid

  2) Gas Processing Skid
- **CO_2 Separation Skid will consist of the eight sorbent reactors, two accumulators, all valves and manifolds and a compressor that will allow recycle of some of the process gases**
- **This will allow us to fully demonstrate the PSA cycle with all steps in the sequence (e.g., pressure equalizations, product pressurization)**

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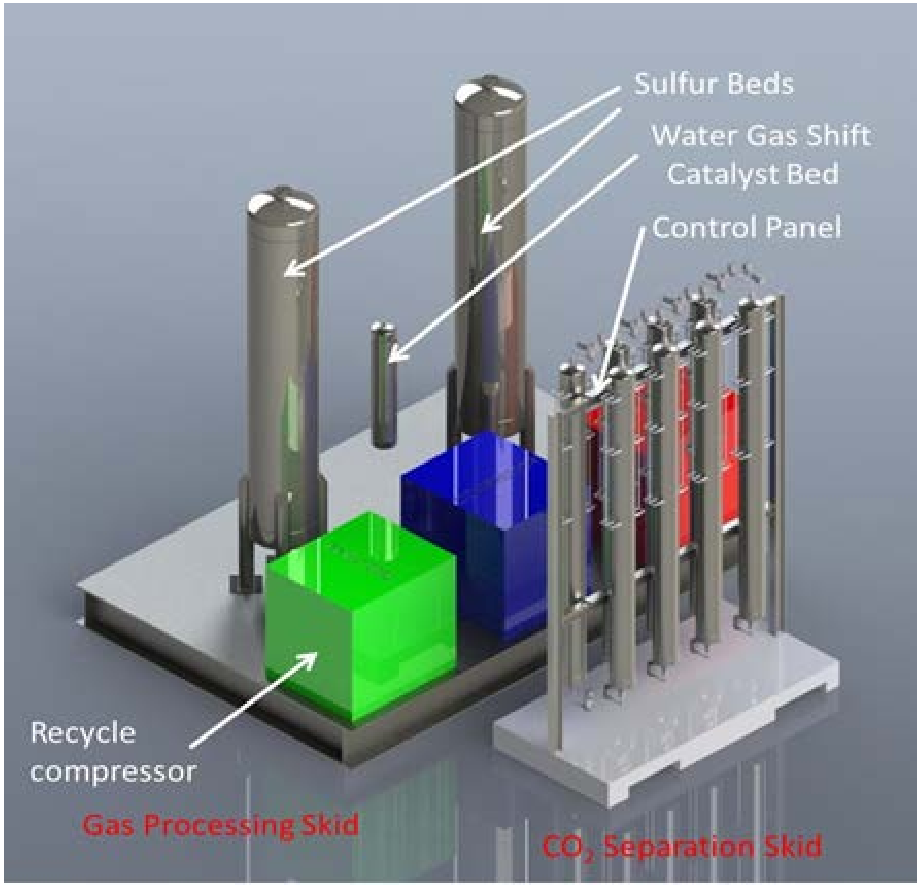
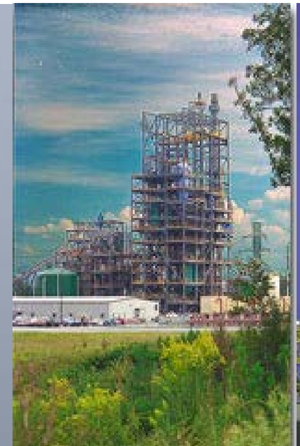
Slipstream Unit Demonstration





- **Demonstration at PSDF in the NCCC (Wilsonville, AL)**
- **15 kg/hr CO_2 capture demonstration at Wabash River IGCC Facility**

Task 3. Design Review and Hazard Analysis

- **Details of the unit will be discussed and reviewed with the site operators to ensure that it will meet all of their facility requirements**
- **A preliminary design of the slipstream test unit will be submitted to the site operators**
- **We will complete a Hazard Design Review with the NCCC and CB&I, to identify all safety precautions that must be included into the design**
- **We will obtain the necessary approval from site operators to proceed with the fabrication of our slipstream test unit**

Task 4. Sorbent Manufacturing

- **All the material needed for the field unit will be produced at 100 L batch size using semi-continuous/continuous manufacturing equipment in our pilot-scale production facility in Golden, CO**
  - 500 L of sorbent material to support both field demonstrations
- **Each batch will be characterized via physical and chemical analysis (e.g., surface area, pore size distribution, chemical composition, crush strength) to ensure that the properties meets our Product Specification Criteria**

Feeder

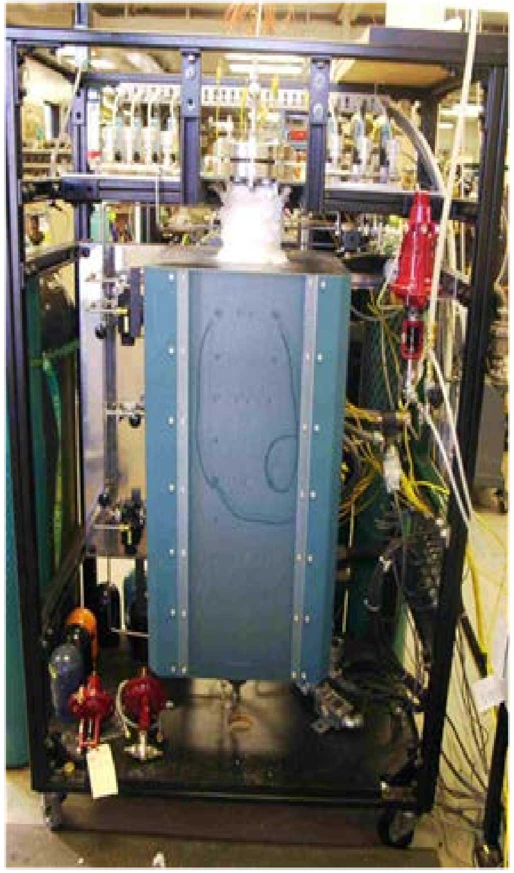
Continuous rotary kiln

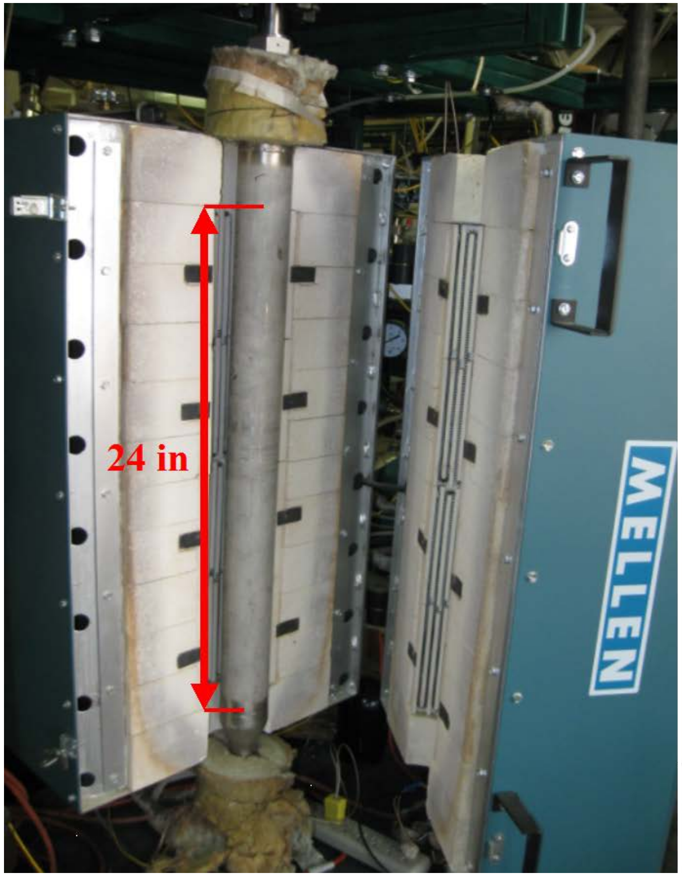
Exhaust gas treatment

TDA Research

Task 5. Sorbent/Catalyst Evaluation

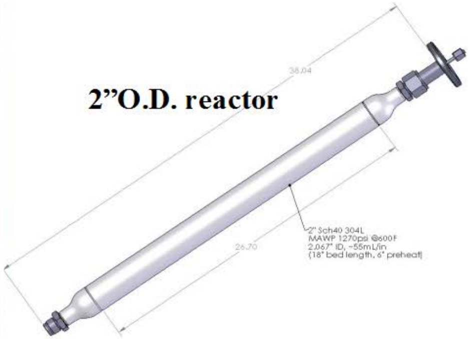
- **The samples from each production batch will be evaluated using a bench-top reactor (1.3 L volume) with the commercial WGS catalyst**
- **Demonstrate performance under a baseline test condition for 500 cycles**





New Reactor for long-term cycling experiments
2 in Schedule 40 Stainless Steel Reactor
2.07 in Internal Diameter
24 in Heated Bed Length
1324 cm³ Sorbent Bed

Schedule 40 2" Pipe Reactor		
Internal Diameter	2.07	in
Cross Sectional Area	3.37	in²
Heated Length	24.00	in
Bed Volume	80.77	in³
	1323.56	cm³



Task 6. Optimization of Reactor Design

- **Utilize CFD models for optimum integration of the WGS catalyst, CO_2 separation sorbent and heat rejection system**
- **Task 6.1 Optimization of Heat Rejection System**
  - Evaluate various reactor geometries and key process parameters (e.g., regeneration time, product purity) using a 2D model
- **Task 6.2 CFD Simulation**
  - For the best design, generate detailed transient 3D concentration and temperature profiles
  - Using a FLUENT code, we will explore all local heat and mass transfer processes and develop axial and radial temperature and concentration profiles across the bed
- **Task 6.3 Optimization of Cycle Sequence**
  - Optimize the cycle sequence to ensure highest CO_2 product purity and highest H_2 recovery based on the CFD results

TDA Research

Task 7. Long-term Durability Tests up to 8,000 Cycles

- **Bench-scale tests will be conducted to assess sorbent life**
- **Sorbent has an estimated replacement cycle of every 2 years, which corresponds to 52,500 cycles (based on 20 minute full cycle)**
- **Due to budget and schedule constraints, the planned field test will not be sufficiently long to fully evaluate the sorbent life**
- **Long term durability of the sorbent will be carried out under representative temperature and pressure conditions.**
  - 5 SLPM simulated synthesis gas flow
- **8,000 adsorption/regeneration cycles on the sorbent in BP1**

Task 8/9. Fabrication/Evaluation of a Single Test Reactor

- **We will fabricate a single reactor and evaluate the performance using simulated gas**

BP1 – Milestone Log

BP	ID	Task No.	Title	Description	Planned Completi-on Date	Verification Method
			Anticipated Project Start Date		10/12014	
1	1-1	1	Update Project Management Plan (PMP)	Update PMP with inputs from DOE Project Manager	11/1/2014	PMP file
1	1-2	2	Kickoff meeting	Kickoff Meeting at NETL	12/1/2014	Presentation file
1	1-3	3	Preliminary Design Package	Provide preliminary design package to field test site operators for feedback	6/30/2015	P&ID & interface requirements
1	1-4	4	Initial Design Review and Hazard Analysis	Complete initial design review and HAZOP	9/30/2015	Site approval letters for TDA skid design
1	1-5	5	Sorbent Manufacturing	Complete the production of sorbent needed for field tests	9/30/2015	Quality Assurance Data for sorbent
1	1-6	6	Reactor design Optimizations	Complete reactor design optimizations	9/30/2015	3-D drawings of optimized design
1	1-7	7	Long-term Durability Target I	Complete up to 8,000 cycles at bench-scale	9/30/2015	Results update
1	1-8	1	Annual Review Meeting	Present the BP1 results to DOE/NETL	9/30/2015	presentation file
			Go/No-go Decision Point End of Year 1		9/30/2015	

TDA Research

BP1 – Decision Points

- **DOE funding is not authorized beyond Budget Period 1 without the written approval of the Contracting Officer**
- **DOE's decision whether to authorize funding for Budget Period 2 will be specifically based on:**
  1) Successful completion of all work proposed in the Budget Period
  2) Satisfactory achievement of applicable success criteria as identified in the Project Management Plan
  3) Submission and approval of the Continuation Application

Decision Point	Date	Success Criteria
Go/No-go Decision Point: End of Year 1	9/30/2015	Complete Final Design Package for Pilot Unit with Site Approvals.
Go/No-go Decision Point: End of Year 1	9/30/2015	Complete 8,000 cycles in the life test with less than 5% degradation per 10,000 cycles in sorbent performance.

TDA Research

BP2 - Tasks

Task 10. Reactor Design Revisions

- We will revise the CFD model and Reactor Design based on results from single reactor evaluations

Task 11. Fabrication of Revised Single Reactor

- We will fabricate revised reactor

Task 12. Evaluation of Revised Single Reactor

- We will evaluate the revised reactors.

Task 13. Long-term Durability Tests up to 20,000 cycles

- 20,000 cycles will be completed in the bench-scale unit

Task 14. Critical Design Review

- We will complete a final design review with all site operators

BP2 – Tasks (Cont'd)

Task 15. Fabrication of Field Test Unit

- **Based on the final design approved by NCCC and, CB&I, we will fabricate the Slipstream Test Unit.**
  - Task 15.1 Fabrication of the Integrated WGS/CO_2 Separation Skid: We will construct the Integrated WGS/CO_2 Separation Skid to be used in hazardous environment (i.e., Class I Division II rated)
  - Task 15.2 Fabrication of the Gas Processing Skid: We will construct the Gas Processing Skid, it will be designed and fabricated to allow operation in Class I Division II environment
  - Task 15.3 Fabrication of Process Control Module: The control system will allow stand-alone operation, with monitoring and controls to operate the system without TDA personnel being on-site

Task 16. Shakedown Testing of Gas Processing Skid

- **We will carry out shakedown and troubleshooting of the gas processing skid at GTI facilities**

BP2 – Milestone Log

BP	ID	Task No.	Title	Description	Planned Completi-on Date	Verification Method
2	2-1	12	Single Reactor Evaluations	Complete Evaluation of revised singe reactor	12/31/2015	Results update
2	2-2	14	Critical Design Review	Complete the final critical design review	3/31/2016	Site Approved SOP for the test skid
2	2-3	13	Long-term Durability Target II	Complete up to 20,000 cycles at bench-scale	9/30/2016	Results update
2	2-4	15	Fabrication of Field Unit	Complete the fabrication	9/30/2016	Pictures of the Skid
2	2-5	16	Shakedown Testing of Gas Processing Skid	Complete the Shakedown tests using simulated gases	9/30/2016	Results update
2	2-6	1	Annual Review Meeting	Present the BP2 results to DOE/NETL	9/30/2016	presentation file
			Go/No-go Decision Point End of Year 2		9/30/2016	

Decision Point	Date	Success Criteria
Go/No-go Decision Point: End of Year 2	9/30/2016	Complete Fabrication of the Pilot Unit.
	9/30/2016	Complete 20,000 cycles in the life test with less than 5% degradation per 10,000 cycles in sorbent performance.

BP2 – Decision Points

- **DOE funding is not authorized beyond Budget Period 1 without the written approval of the Contracting Officer.**
- **DOE's decision whether to authorize funding for Budget Period 2 will be specifically based on 1) successful completion of all work proposed in the current Budget Period, 2) satisfactory achievement of applicable success criteria as identified in the Project Management Plan, and 3) submission and approval of the Continuation Application (the Continuation Application should include a detailed budget and budget justification for budget revisions or budget items not previously justified.).**

Decision Point	Date	Success Criteria
Go/No-go Decision Point: End of Year 2	9/30/2016	Complete Fabrication of the Pilot Unit.
	9/30/2016	Complete 20,000 cycles in the life test with less than 5% degradation per 10,000 cycles in sorbent performance.

BP3 - Tasks

Task 17. Process Design

- **Carry out detailed design of the integrated WGS/CO_2 capture process**
- **Detailed design of the full-scale reactors and generate engineering drawings and 3-dimensional layouts**
- **Provide an accurate cost for the unit, including all foundation work, labor and supervision for the installed system and revise the overall system cost estimate (for a most accurate capital requirement and CO_2 capture cost)**

Task 18. Long-term Durability Tests up to 30,000 cycles

Task 19. Shakedown Testing of the Slipstream Unit

- **Integrate the WGS/CO_2 Separation Skid and the Gas Processing Skid with the control system and tune all PID loops and other control systems**

Task 20. Field Test at NCCC

- **We will install the prototype test unit at the NCCC and conduct testing throughout a 3 week test campaign (750 hrs)**
- **The task also includes the de-commissioning of the unit and its shipment to the Wabash River IGCC plant for further evaluations**

TDA Research

BP3 – Tasks (Cont'd)

Task 21. Field Test at Wabash River IGCC Plant

- **TDA will work with CB&I to install the slipstream test unit**
- **Test unit will be evaluated in a 2-3 month campaign using synthesis gas generated from an oxygen-blown gasifier**
- **Following shakedown runs, we will perform a series of tests to evaluate system's performance at different operating conditions**
- **A minimum of 1,440 hours testing is scheduled**

Task 22. System Analysis

- **Using the most recent reactor design data and feedback from CB&I, we will update the Aspen-Plus^{TM} process model developed in a previous DOE/NETL project**
- **We will estimate of COE using DOE Guidelines for Carbon Capture and Sequestration (January 2011 dollars)**

TDA Research

BP3 – Milestone Log and Decision Points

BP	ID	Task No.	Title	Description	Planned Completi-on Date	Verification Method
3	3-1	19	Shakedown Testing of Integrated Skid	Complete the Shakedown tests using simulated gases	12/31/2016	Results update
3	3-2	20	Field Tests at NCCC	Complete Field Tests at NCCC	3/31/2017	Site Approved SOP for the test skid
3	3-3	17	Process Design	Complete the full-scale system & process design	9/29/2017	Results update
3	3-4	18	Long-term Durability Target III	Complete up to 30,000 cycles at bench-scale	9/29/2017	Results update
3	3-5	21	Field Tests at Wabash River IGCC	Complete Field Tests at Wabash River IGCC	9/29/2017	Results update
3	3-6	22	System Analysis	Complete System and Cost Analysis	9/29/2017	Results update
3	3-7	1	Final Review Meeting	Present the BP3 results to DOE/NETL	9/29/2017	Presentation file
			Project Completion		9/29/2017	

TDA Research

Decision Points – Project Completion

Decision Point	Date	Success Criteria
Project Completion	9/29/2017	Complete 30,000 cycles in the life test with less than 5% degradation per 10,000 cycles in sorbent performance.
		Complete a minimum of 2,000 hours of testing with Pilot Scale Unit under coal derived syngas (total including both air blown and oxygen blown gasifier conditions) while achieving 90% carbon capture with 95% CO_2 purity under oxygen blown gasification conditions.
		Increase in COE is 20% lower than that of the Selexol^{TM} based CO_2 capture Systems and Cost of CO_2 captured based on June 2011$ basis is less than $40/tonne with 95+% CO_2 purity.

TDA
Research

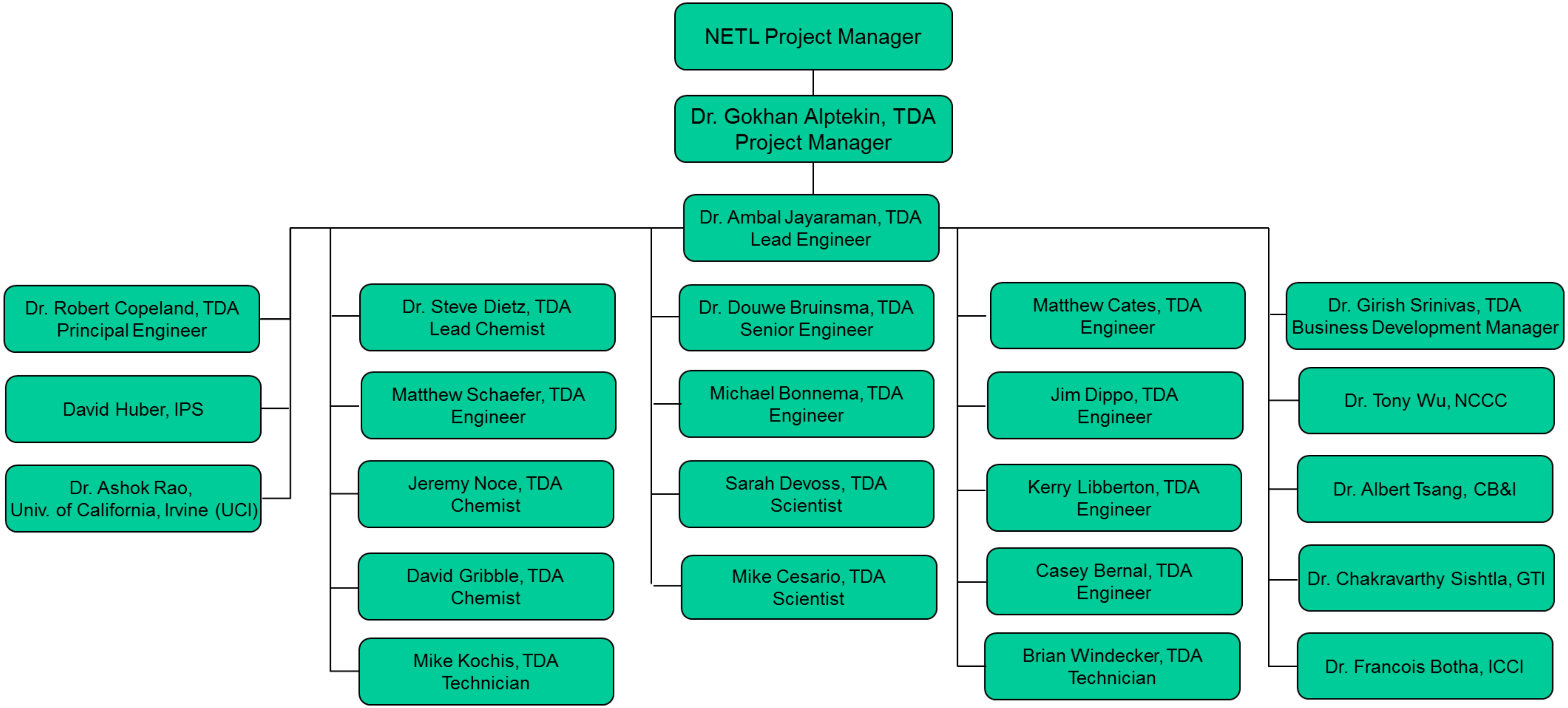
Deliverables & Briefings

- **TDA will provide Periodic Quarterly, Topical, and Final reports in accordance with the "Federal Assistance Reporting Checklist“**
  - Test plan for NCCC Field Test
  - Test Plan for Wabash River Field Test
  - Post-Test analysis of NCCC Field Testing
  - Post-Test analysis of Wabash River Field Testing
  - Techno-economic analysis as defined in Attachment 1 to the SOPO
- **TDA will prepare detailed briefings for presentation to the Project Officer at the Project Officer's facility located in Pittsburgh, PA or Morgantown, WV**
  - Briefings will be arranged with the DOE Project Officer, one at project kick-off and one at the end of each BP
  - A final project briefing at the close of the project will also be given
  - TDA will present a technical paper(s) at a National conference such as MEGA Symposium or The National Meeting of the American Chemistry Society each year upon approval of the DOE Technical Monitor

Project Budget

	BP1		BP2		BP3		Total	
	10/1/14 - 9/30/15		10/1/15 - 9/30/16		10/1/16 - 9/30/17		10/1/14 - 9/30/17	
	Government Share	Cost Share	Government Share	Cost Share	Government Share	Cost Share	Government Share	Cost Share
TDA	$928,068	$150,000	$811,240	$99,000	$12,291,810	$57,000	$3,031,117	$306,000
Air Products	-	$40,000	-	$60,000	-	-	-	$100,000
GTI	$541,580	$165,421	$658,421	$184,689	-	$149,890	$1,200,001	$500,000
CB&I	$75,600	$20,000	$10,000	$20,000	$80,000	$160,000	$165,600	$200,000
UCI	-	-	-	-	$80,000	$19,900	$80,000	$19,900
Indigo Power	-	-	-	-	$30,000	-	$30,000	-
Total	$1,545,248	$375,421	$1,479,661	$363,689	$1,481,810	$386,790	$4,506,719	$1,125,900
Cost Share (%)	80.45%	19.55%	80.27%	19.73%	79.30%	20.70%	80.01%	19.99%

Project Team Organization



TDA Research

Risk Management

Description of Risk	Probability	Impact	Risk Management (Mitigation and Response Strategies)
Technical Risks:			
Heat Management not providing the expected performance of 5°C or lower temperature rise in the beds	Low	Moderate	TDA will be using CFD models and validate models to develop the heat management concepts and design the advanced reactors.
Advanced reactor designs resulting in high capital costs and complex control schemes	Low	High	TDA will be looking designs that would have a low impact on the capital costs and
Resource Risks:			
Demonstration site availability	Low	Low	TDA will get both NCCC and Wabash River IGCC plant involved early and get the necessary approvals we will also look for other options for backup
Advanced reactor design fabrication & testing	Low	Moderate	We will plan ahead and stay ahead of schedule to give us ample time to deal with delays or problems
Management Risks:			
Communication & co-ordination	Low	Low	TDA will have regular meetings and teleconferences to keep the entire team involved and informed on the project progress.
JDA & NDA between partners	Low	Moderate	TDA has prior experience with the partners so we will be able to get the JDA and NDA executed on time