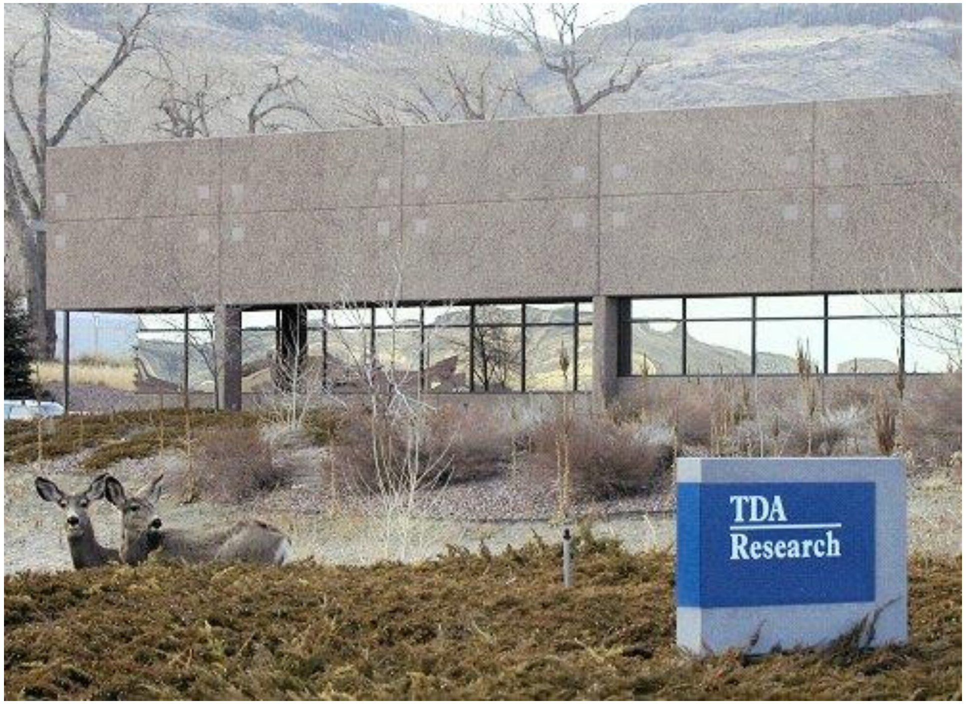
A New Thermal Swing Adsorption Process for Post-Combustion Carbon Capture from Natural Gas Combined Cycle Plants
(DE-FE-0032151)



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2022 NETL Carbon Management Project Review Meeting

Pittsburgh, PA

August 19, 2022

Project Team and Objectives

Dr. Ashok Rao

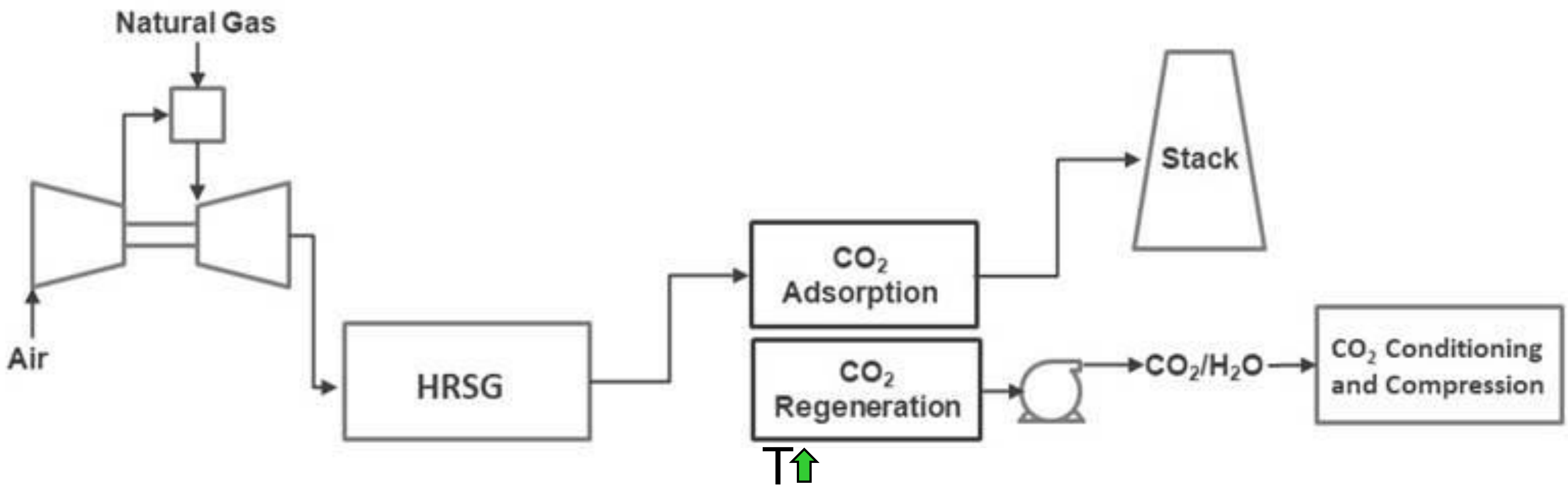
Project Duration
- Start Date = July 15, 2022
- End Date = July 14, 2025

Budget
- Project Cost = $3,125,524
- DOE Share = $2,500,000
- TDA & its partners = $625,000

- **Demonstrate the viability of a transformational microwave-assisted thermal swing adsorption (MTSA) based carbon capture process to efficiently capture CO_2**
  - **CO_2 capture efficiency target ≥ 95%**
  - **CO_2 product purity target ≥ 95% CO_2**
  - **CO_2 source is flue gas from a natural gas combined cycle power plant (simulated)**
- **Reduce the cost of capture by more than 25% against a reference NGCC plant with liquid amines (e.g., Cansolv®)**

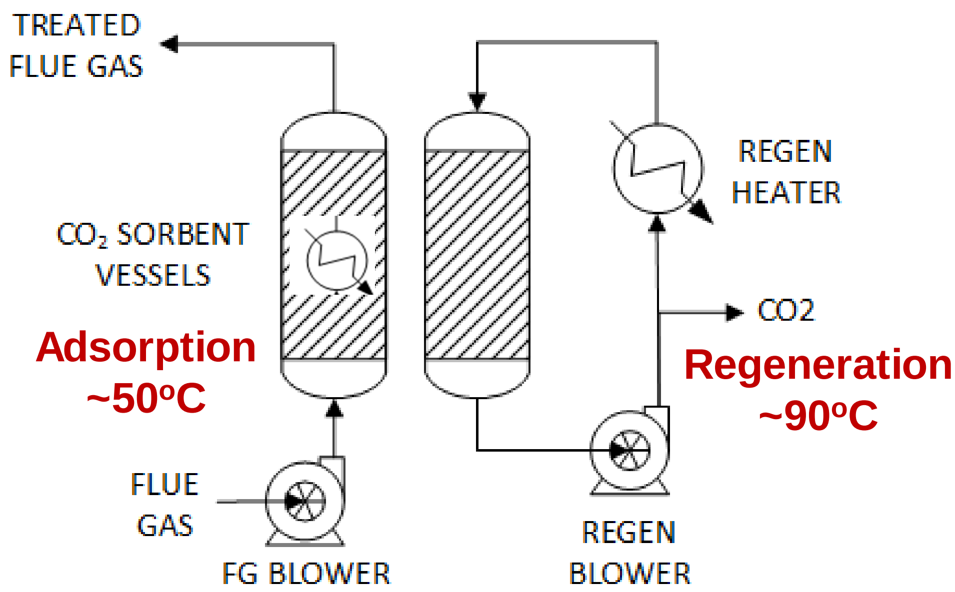
BP	Period	Main Activity
1	Year 1	Material synthesis Adsorption & CFD modeling Bench-scale system design Preliminary TEA
2	Year 2	Bench-scale system fabrication Commissioning/troubleshooting
3	Year 3	Bench-scale evaluations Techno-economic Assessment Life Cycle Analysis EH&S nalysis

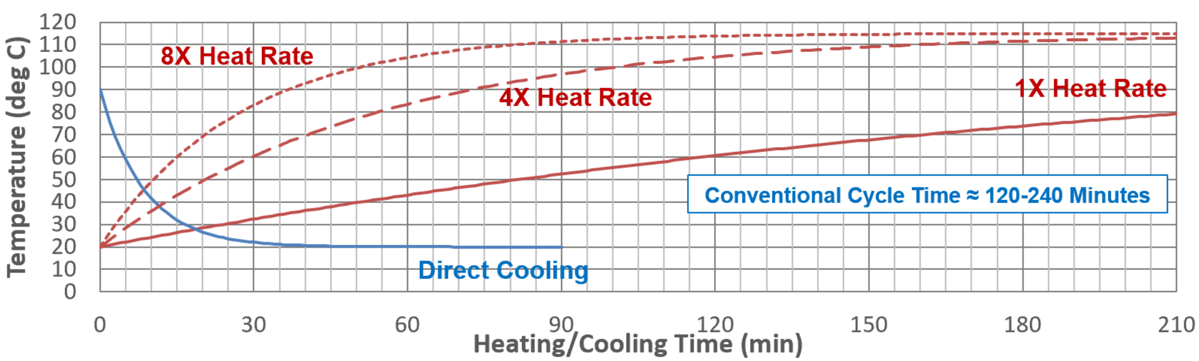
MTSA-Based Carbon Capture Process



- **A mild temperature swing adsorption process (30-40^{o}C temperature difference) is employed to remove and concentrate the CO_2**
- **The regeneration heat is provided by a microwave system to achieve rapid heating of the bed**
- **Fast cycling improves the sorbent utilization (i.e., CO_2 productivity)**

Heating Options - Conventional vs Microwave

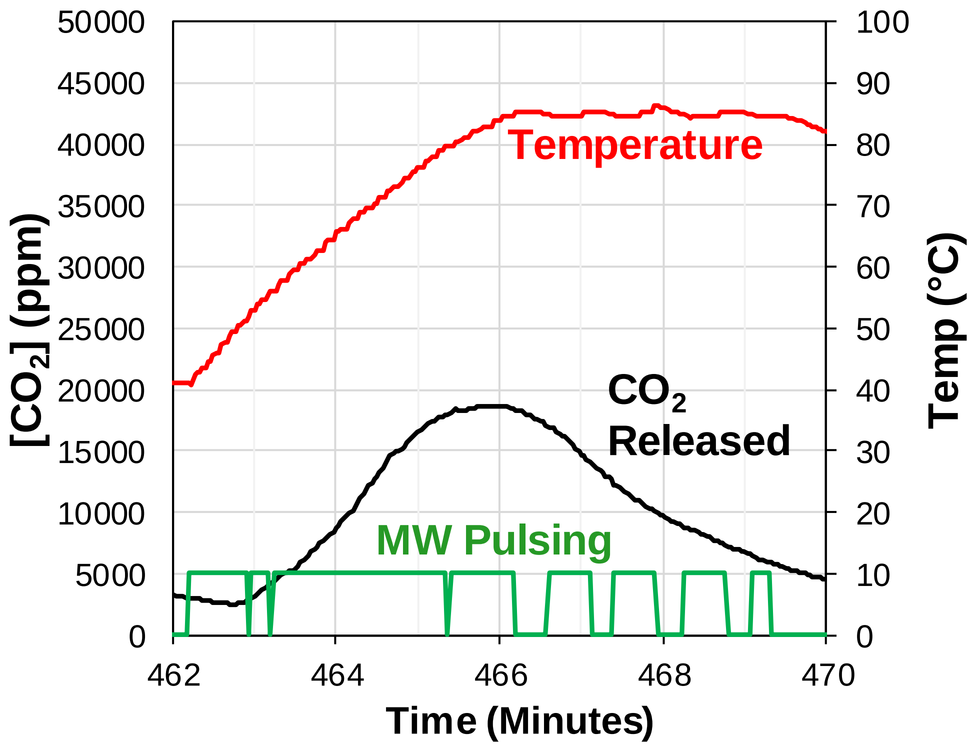




- In conventional approach, CO_2 desorbing from the bed is circulated through an external heater to supply the heat for regeneration
- A fraction of this is removed from the circulating loop for purification and compression
- Heating rate is controlled by external heater temperature and circulation rate
- Heater temperature limited by sorbent material temperature tolerance
- Higher circulation rates increase heating rate, but at the expense of electric power (blower) and thermal load (heater)

Why Use Microwave Heating?

- Microwave heating is common in several industrial settings
- Uniform heating can be achieved by optimizing the RF frequency, wave penetration depth (sorbent) and reactor geometry
- As confirmed by experimental measurements, heating times can be reduced to a few minutes with full-cycle times <10-20 min



- Sorbent packing in the bed is increased by eliminating heat transfer elements from the bed volume—reducing vessel size and cost
- Through cavity/reactor integration, directed/precision heating can be achieved
- Heat can be only applied to the sorbent (not heating the vessel and structure) improving overall efficiency

Polymeric Sorbent

Various forms of polymer sorbent: (left) pellets (middle) laminate and (right) 3D printed monolith

- **A new polymer sorbent will be used in the process**
- **Reasonable thermal stability**
- **Potential for use in pellets, laminates and 3D printed structures**
- **TRL = 3-4**

Synthesis in 22L reactor

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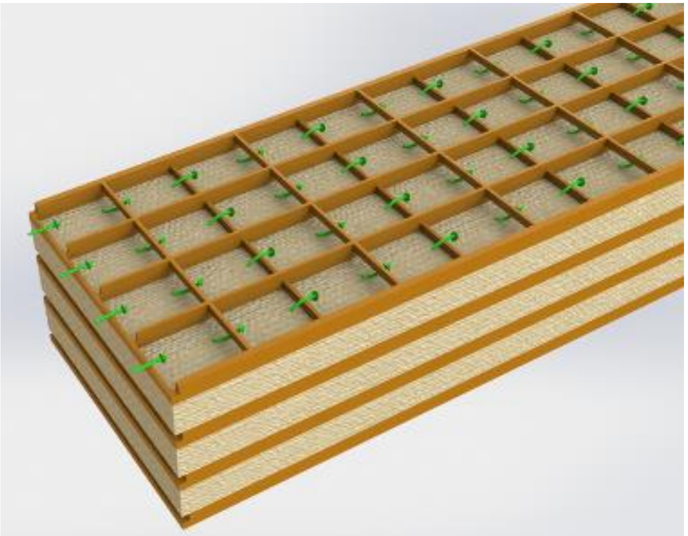
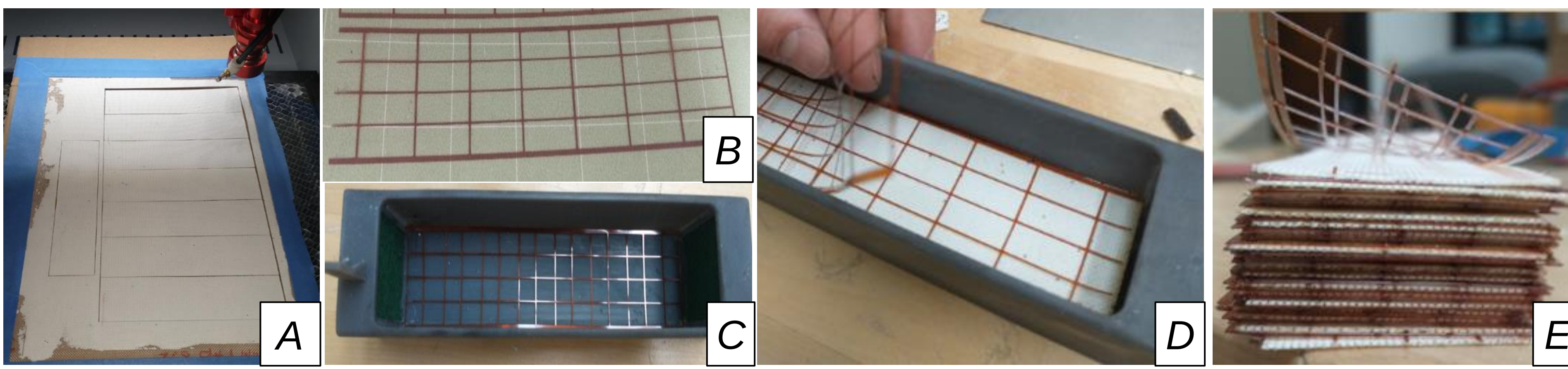
Structured Sorbent Preparation



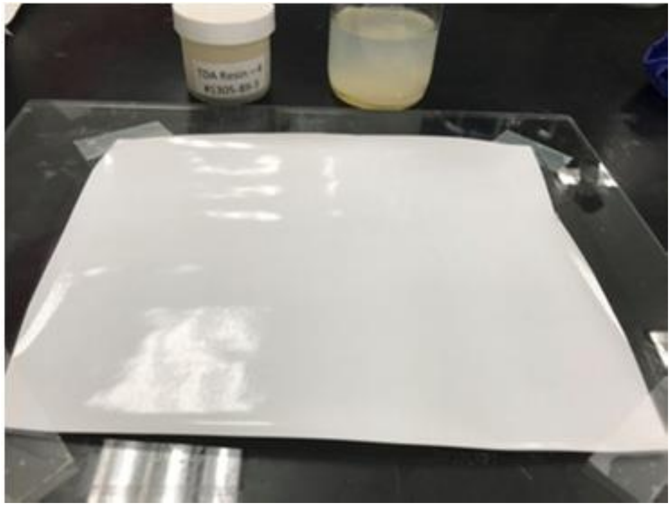
- Structured sorbent will be prepared to reduce pressure drop through the gas-solid contactor
- Microwave guides will be integrated into the structure for rapid heating



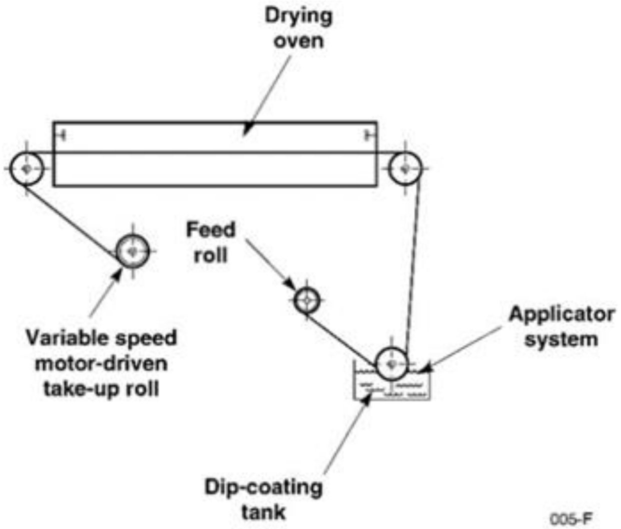
Sorbent films are laser cut (A and B) stacked alternating with spacer grids in a holder (C and D) to make a module or stack (E)

Scale-up of the Laminates

Scale-Up Equipment (MTR)

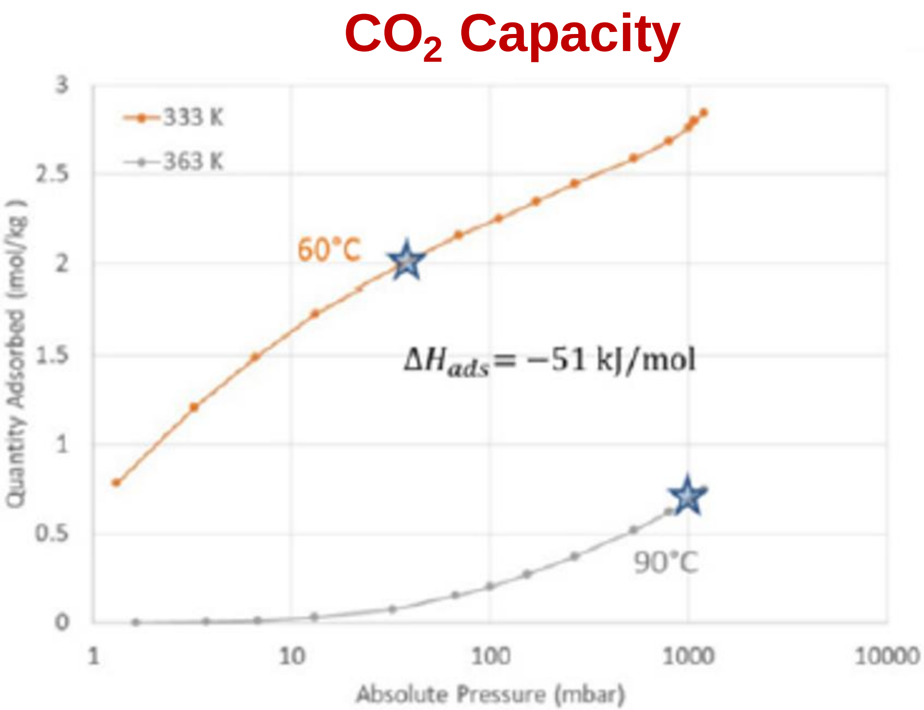


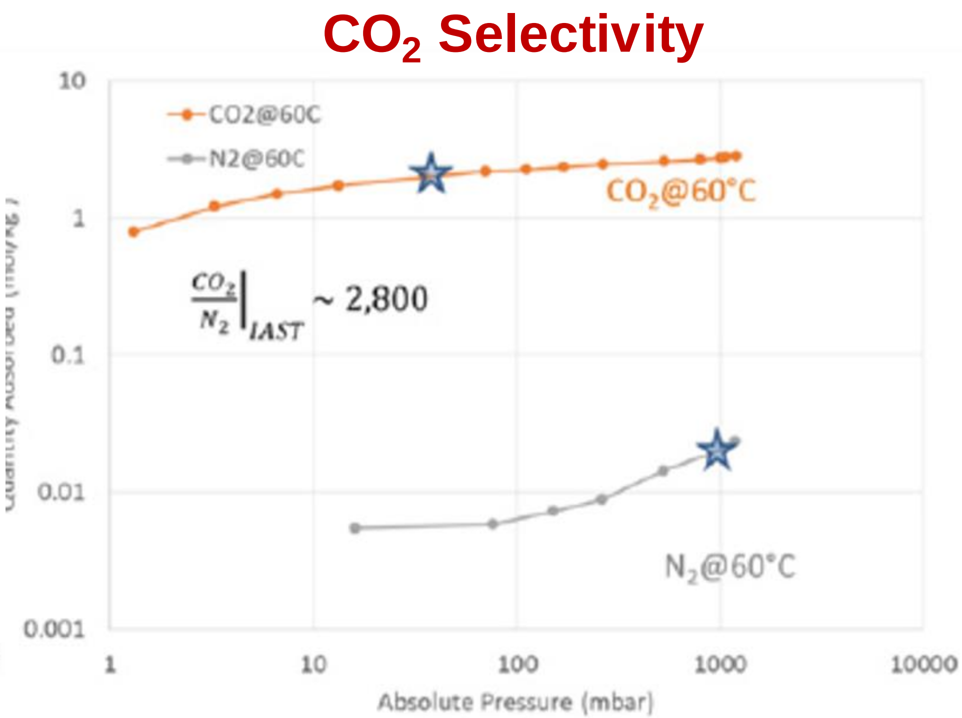
Bench-Scale Sheets



- Membrane Technology Research will assist with the scale-up work
- Preparation of large sheets using their existing equipment
- Similar collaboration in an SBIR Phase IIB project

Adsorption Isotherm for the Polymer Sorbent

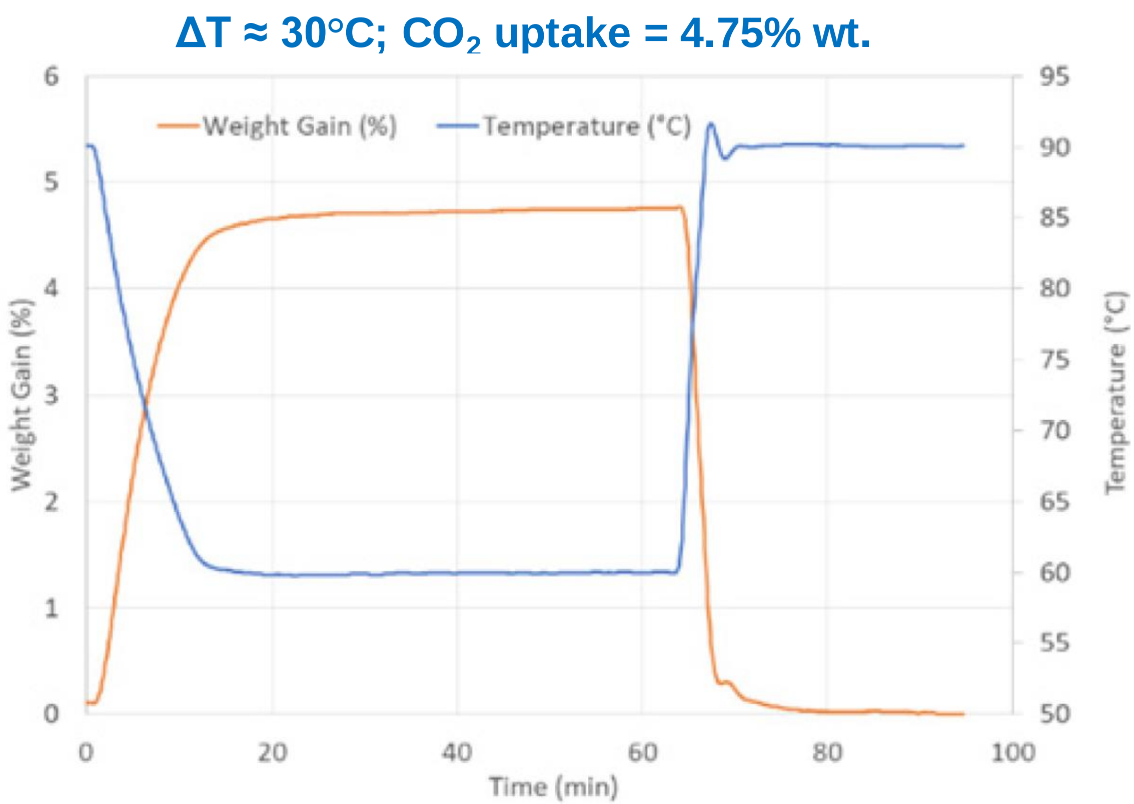




CO_2 adsorption isotherms at 60°C (orange) and 90°C in the form of beads

- Working capacity of ~1.2 mmol/g is expected
- High CO_2/N_2 and CO_2/O_2 selectivity
- Heat of adsorption of CO_2 is estimated as 51 kJ/mol

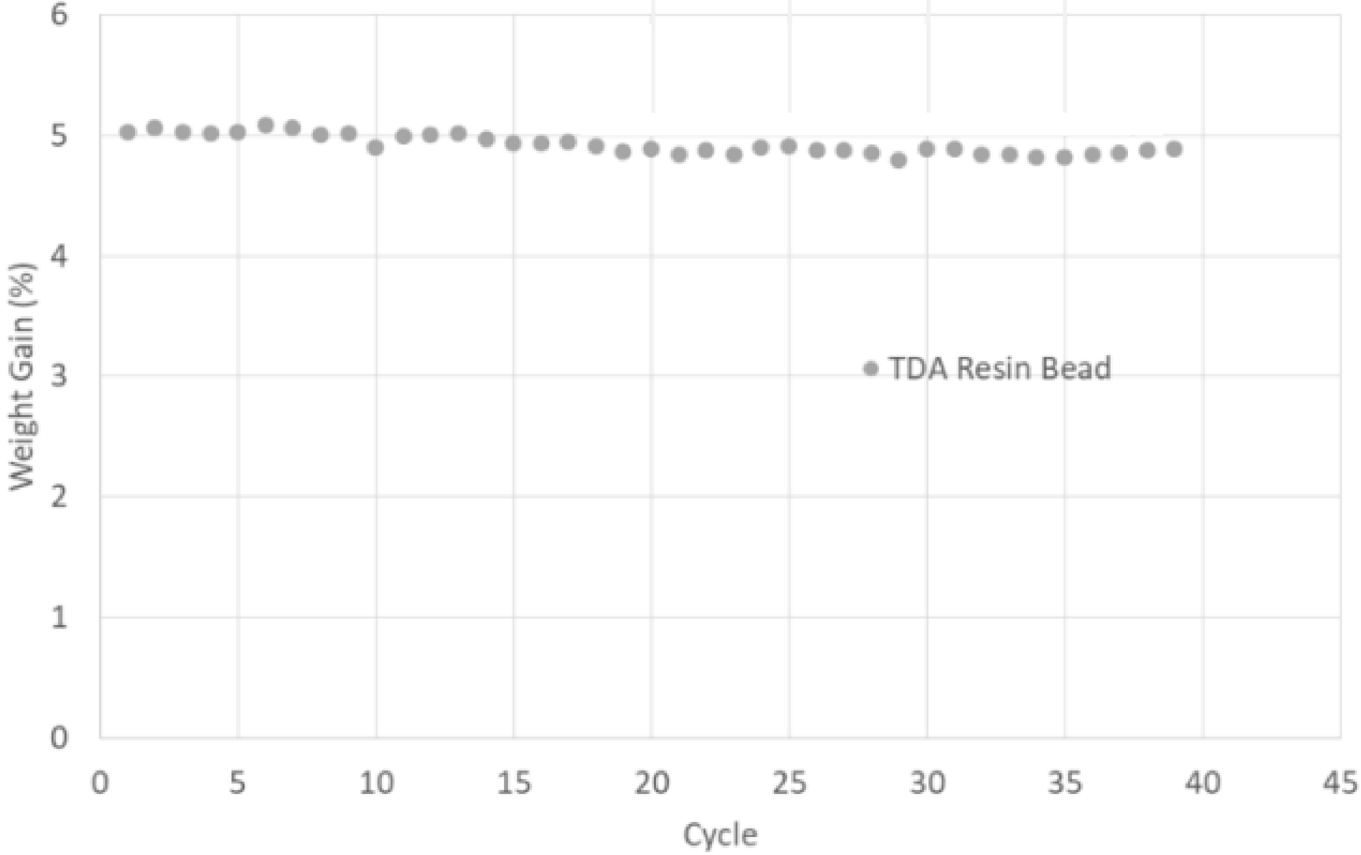
Thermogravimetric Analysis



- **TGA tests showed relatively rapid release and uptake of CO_2**
- **Regeneration will be the rate limiting step**
  - **All adsorbed CO_2 is released in less than 7 min upon heating the media from 60 to 90°C**

Sorbent Stability

Cycling between 60–90°C in 4% CO_2 balance N_2



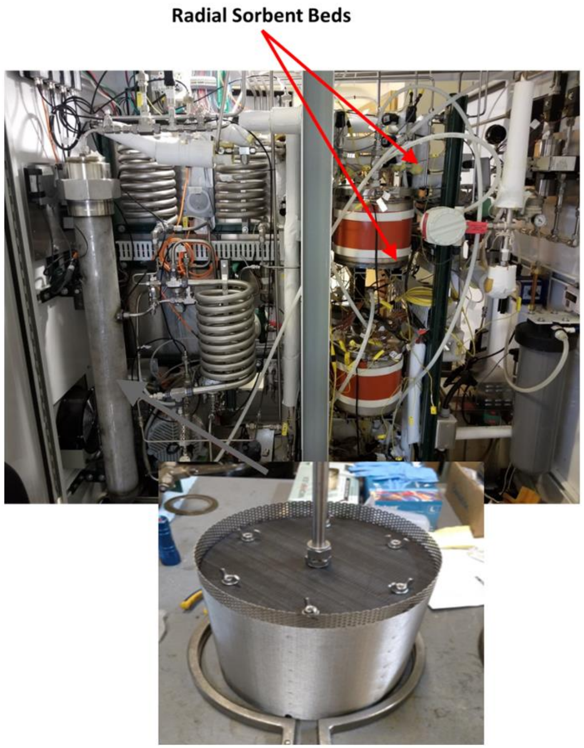
- **TDA's material shows good thermal stability in multi-cycle TGA screening (conventional heating)**

Field Testing Sorbent (Conventional Heating)

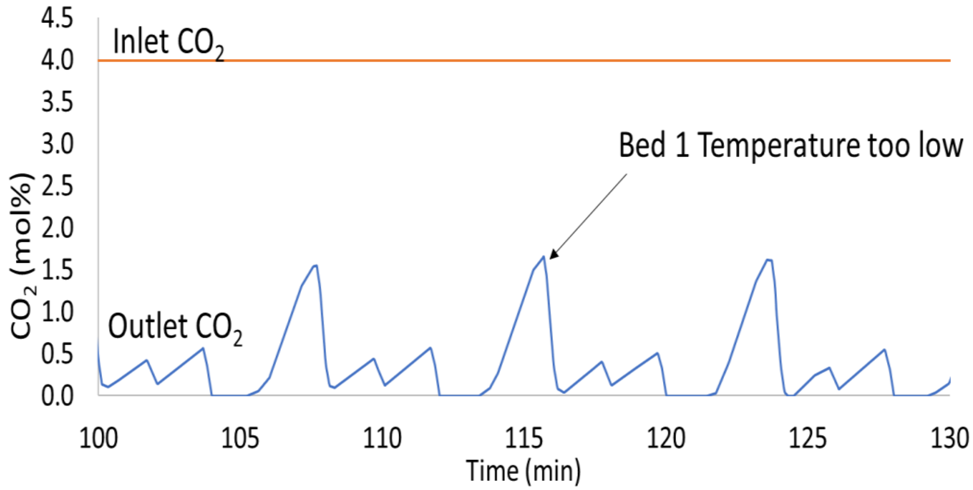
Wyoming Integrated Test Center (WITC) Basin Electric's Dry Fork Station Gillette, WY

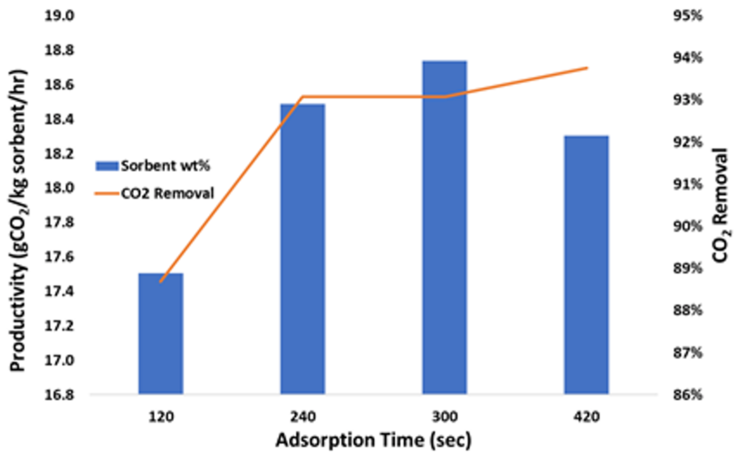
TDA's 4-bed scale-up system (right) in the TDA-built shelter at the Wyoming Integrated Test Center

Field Testing Sorbent (Conventional Heating)



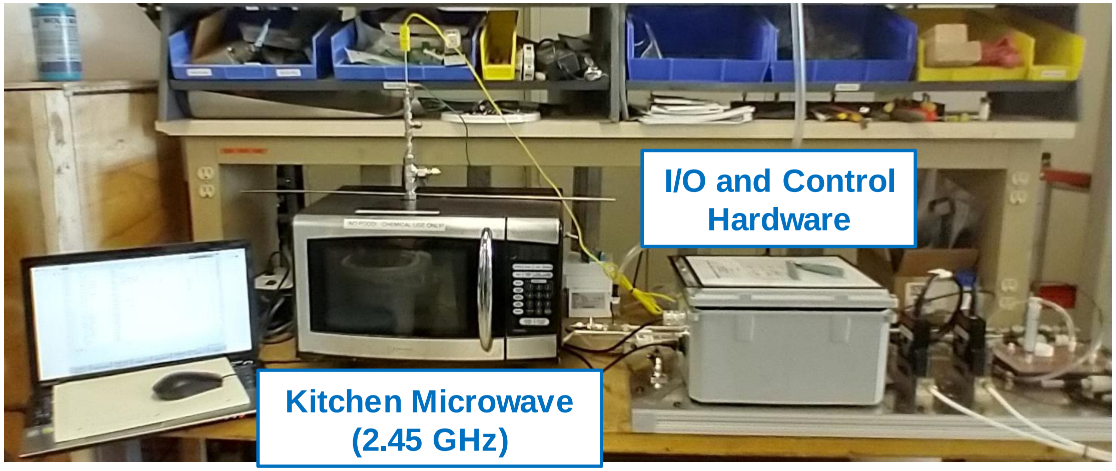
Inner porous sorbent support and top/bottom supports with baffled inserts ready for assembly

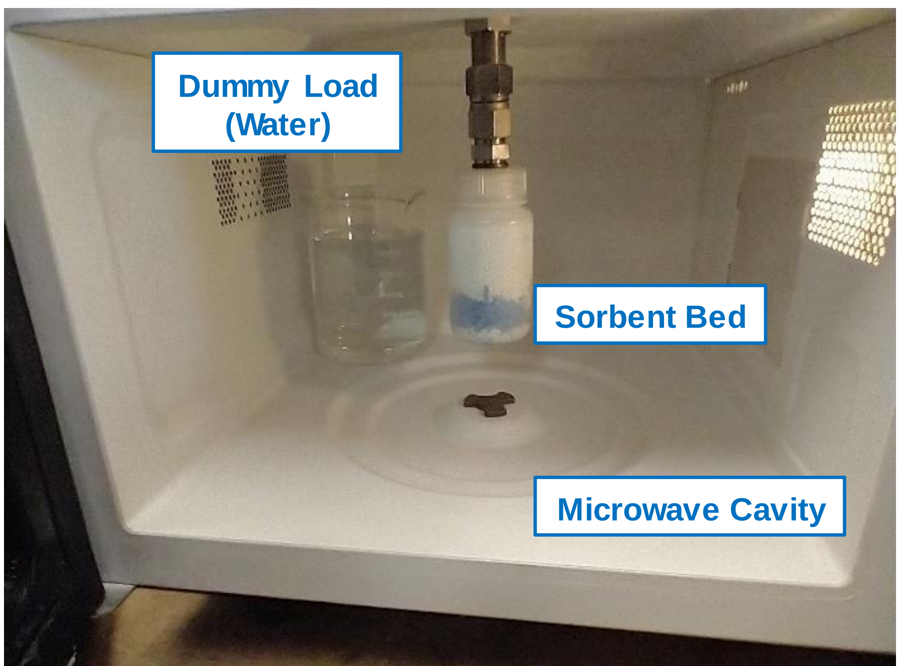


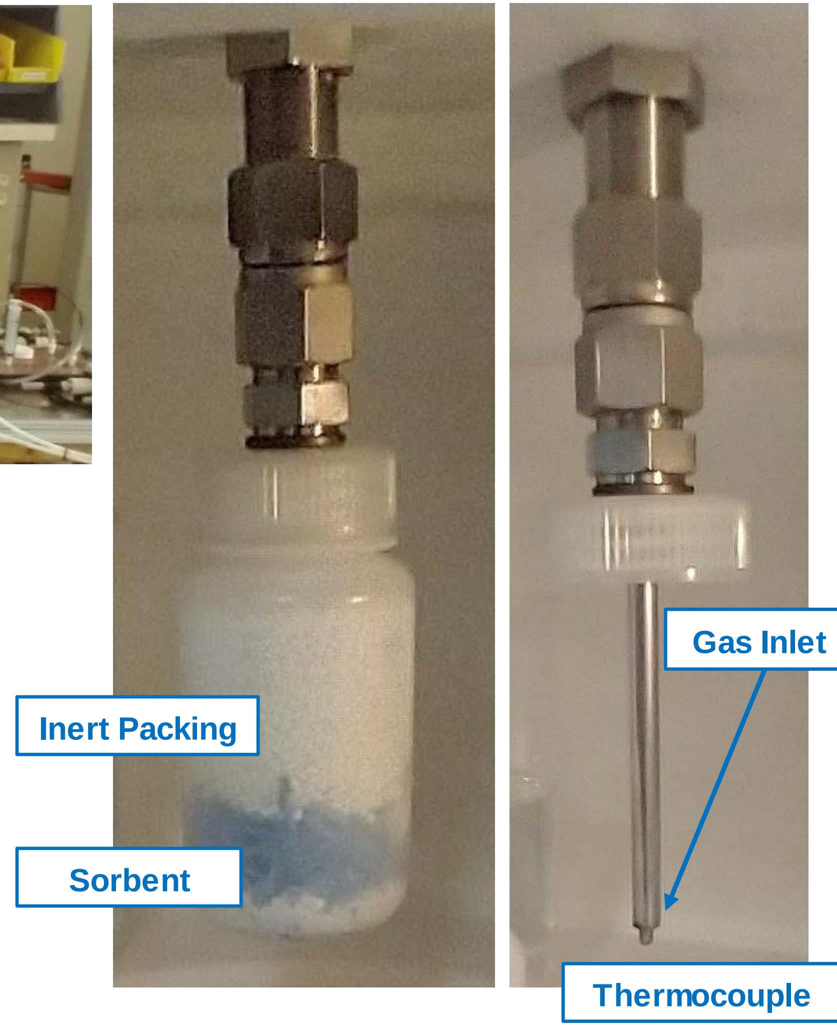


- We expect the productivity to increase over 60g CO_2 / kg sorbent –hr with MTSA

Experimental Setup

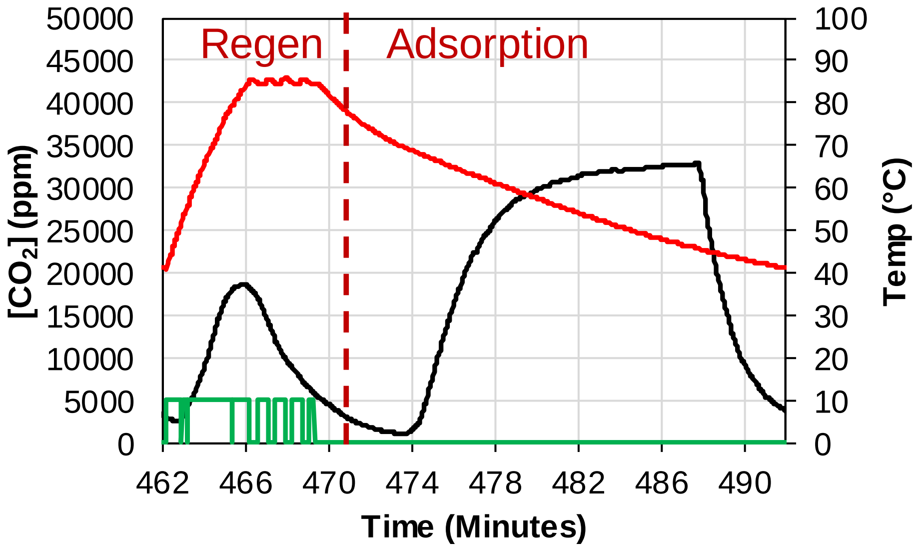




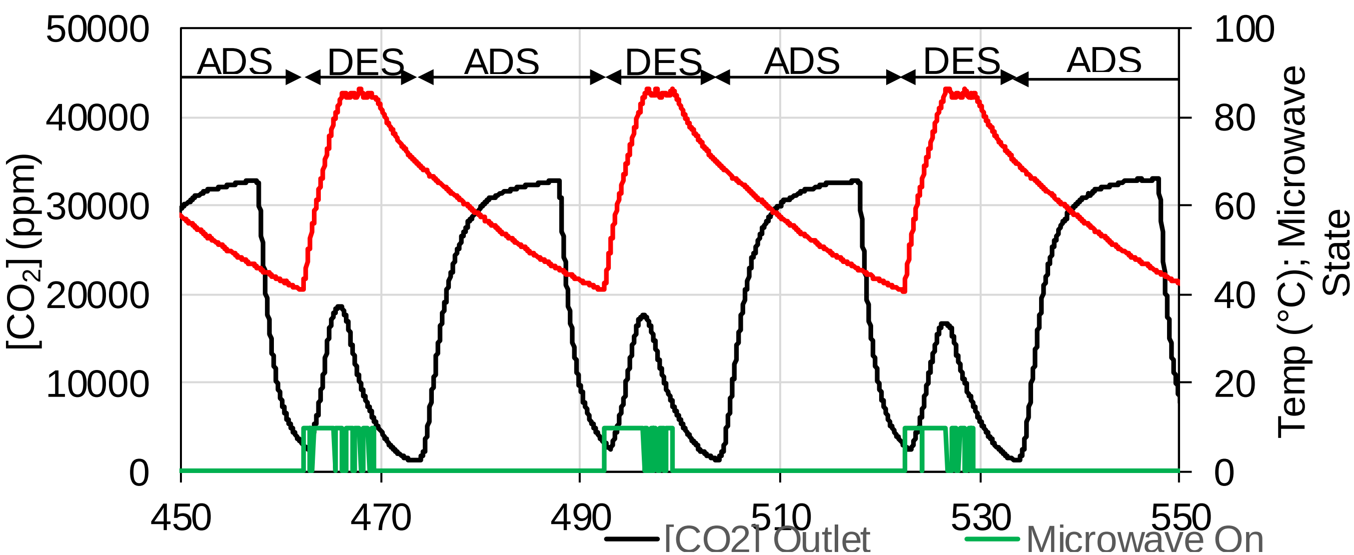


Microwave-Assisted Regeneration

Single Cycle; ADS <20 Minutes; DES <8 Minutes



- **Heating and the subsequent CO_2 recovery are nearly instantaneous upon microwave energization—allowing for reduced regeneration cycle times**



Preliminary TEA

Power Plant Type	Natural Gas Combined Cycle Power Plant		
Case No.	**B31A**	**B31B**	**TDA - 1**
CO_2 Capture Technology	**No Capture**	**Amine based CO_2 Capture Case 10**	**TDA's MTSA based CO_2 Capture**
CO_2 Capture, %	0	90	90
GT Power Generated, MW_e	477	477	477
ST Power Generated, MW_e	263	213	263
Gross Power Generated, MW_e	740	690	740
ST Power Lost, MW_e	-	50	0
CO_2 Capture Auxiliaries, MW_e	-	11	29
CO_2 Compression Power, MW_e	-	17	29
Other Auxiliaries, MW_e	14	16	16
Total Auxiliary Load, MW_e	14	44	74
Net Power, MW_e	**727**	**646**	**666**
Net Plant Efficiency, % HHV	53.6	47.7	49.1
Natural Gas Feed Rate, kmol/h	5383	5383	5383
Total Plant Cost, $/kW	780	1984	1302
COE without CO_2 T&S, $/MWh	43.3	70.9	59.1
COE with CO_2 T&S, $/MWh	-	74.4	62.5
Cost of CO_2 Captured, $/tonne	-	80	47
Cost of CO_2 Avoided, $/tonne	**-**	**102**	**63**

DOE baseline no capture and CO_2 capture plants for NGCC plant comparison

Project Tasks

Task 1. Project Management

BP1 **Task 2. Production of the Sorbent**

Subtask 2.1 Testing and Characterization

Task 3. Preparation of Structured Sorbent (sheets by MTR 12”x12” in size)

Subtask 3.1 Testing and Characterization

Task 4. Design of Integrated Test System

Subtask 4.1 Adsorption Modeling

Subtask 4.2 CFD Analysis

Task 5. Preliminary Techno-economic Analysis

BP2 **Task 6. Fabrication of the Bench-scale System (**2-3 scfm of simulated flue gas)

Subtask 6.1 Sorbent Reactor Module Fabrication

Subtask 6.2 Modifications to Bench-Scale System

Task 7. Life Tests

BP3 **Task 8. Shakedown Testing**

Task 9. Full-scale System Design

Task 10. Bench Scale System Testing and Optimization

Task 11. Proof-of-Concept Demonstration (min 1,000 hours)

Task 12. Final Techno-economic Analysis

Task 13. Life Cycle Analysis

Task 14. Environmental Health & Safety Assessment

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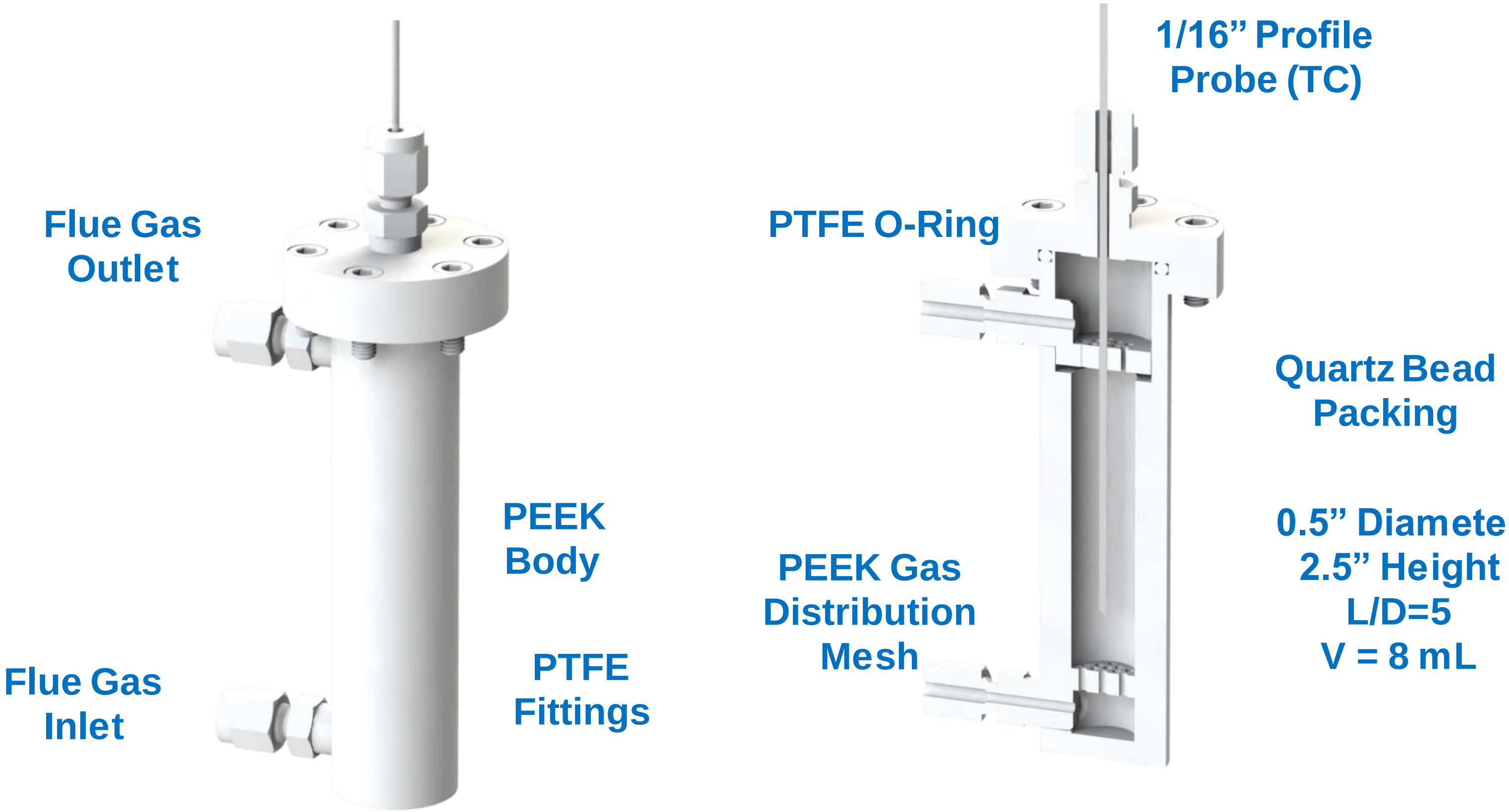
Microwave Reactor Design



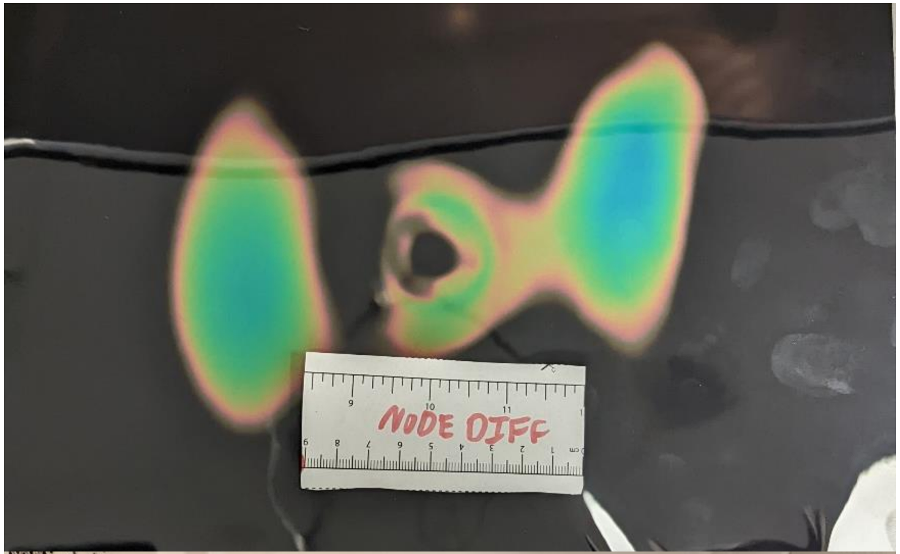
- **Initial experiments will be carried out using sorbent prepared in the form of beads**
- **Reactor is made out of PEEK and PTFE materials**
  - **Low Dielectric Loss (Poor Microwave Absorbance)**
- **Stainless-Steel TC Sheath Requires External Grounding**
- **Gas Inlet/Outlet Via Teflon Tubing with Bulkhead Fittings in Microwave Wall**

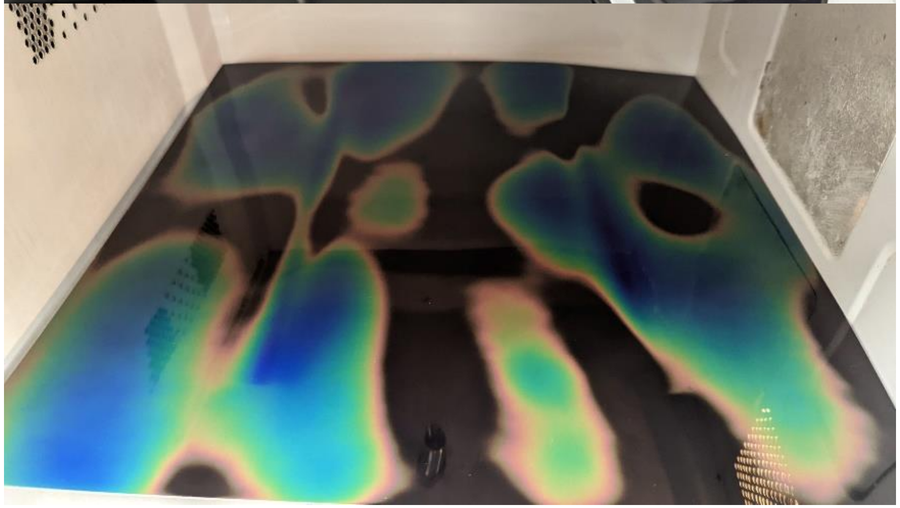
Node Characterization

- Commercial microwaves operate by creating a standing wave inside the microwave cavity
- This standing wave creates 'hotspots' or nodes
- The distance between nodes is given by:

$$d = \frac{\lambda}{2}$$

- For a frequency of 2450 MHz we expect d ~6.1 cm
- When nodes are experimentally verified we see both the expected distance and more random heating depending on vertical position in cavity





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