Bench Scale Test of a Polyethyleneimine Monolith Carbon Capture Process for NGCC Point Sources

DE-FE0032138

Dr. Christopher Bertole

CORMETECH, Inc.

U.S. Department of Energy

National Energy Technology Laboratory
Carbon Management Project Review Meeting
August 15 - 19, 2022

Funding and Performance Dates

- Three years total period, in three budget periods.
- Total Federal Share = $2,500,000.
- Cost share = 20%.

BUDGET	Budget Period 1 2/1/2022 – 1/31/2023			Budget Period 2 2/1/2023 – 1/31/2024			Budget Period 3 2/1/2024– 1/31/2025			Total 2/1/2022 – 1/31/2025		
	Federal Share	Cost Share	Total	Federal Share	Cost Share	Total	Federal Share	Cost Share	Total	Federal Share	Cost Share	Total
Total	$666,234	$166,560	$832,794	$1,230,566	$307,640	$1,538,206	$603,200	$150,800	$754,000	$2,500,000	$625,000	$3,125,000
Cost Share %	20%			20%			20%			20%		

Project Participants

Prime Recipient

CORMETECH

RELIABILITY. DELIVERED.

Global Thermostat

The Carbon Negative Solution

Southern Company

NC NATIONAL CARBON CAPTURE CENTER

MIDDLE RIVER POWER

Zero Carbon Partners, LLC

Cormetech Background

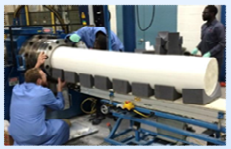
CORMETECH, Inc. is a world leader in manufacturing of high-quality monolithic environmental catalysts, providing catalyst regeneration and engineering services for the power, marine, mobile retrofit, industrial-process, refinery, and petrochemical markets. The company has leveraged more than 30 years of field experience, catalysis, and ceramic extrusion technology to create innovative catalyst and adsorber products and services that meet our customer's needs in the United States and abroad.

Charlotte, NC

Cleveland, TN

Kings Mountain, NC

Durham, NC



1989 — Founding

CORMETECH

JV of CORNING and MHI.

1991 — Durham, NC

Production Plant 1.

SCR catalyst for NOx control.

2001 — Cleveland, TN

Production Plant 2.

SCR catalyst for NOx control.

NOx SIP Call, CAIR, CSAPR, MATS

2015 — Durham, NC

Major Plant upgrade for 300cpsi catalyst manufacture.

+ Oxidation catalyst for CO/VOC/HAP control.

2017 — Charlotte & KM, NC

Merged with STEAG SCR-Tech.

JV of STEAG and Energy Capital Partners.

+ Catalyst regeneration.

2019 — Durham, NC

JDA established with Global Thermostat.

+ **Monolithic CO_2 adsorbers.**

2022 — Charlotte, NC

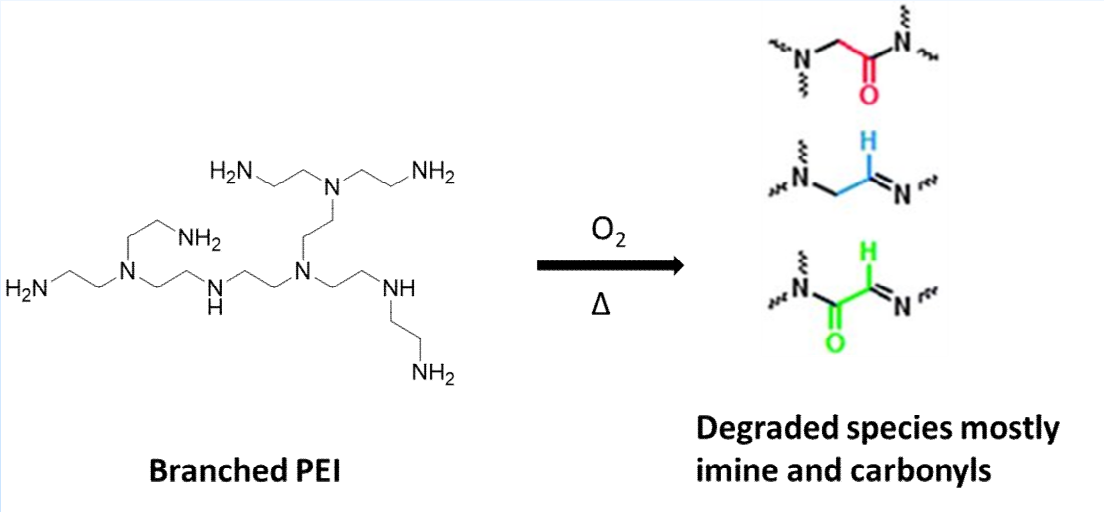
Acquired by Innovative Emissions Control, Inc.

Overall Project Objectives

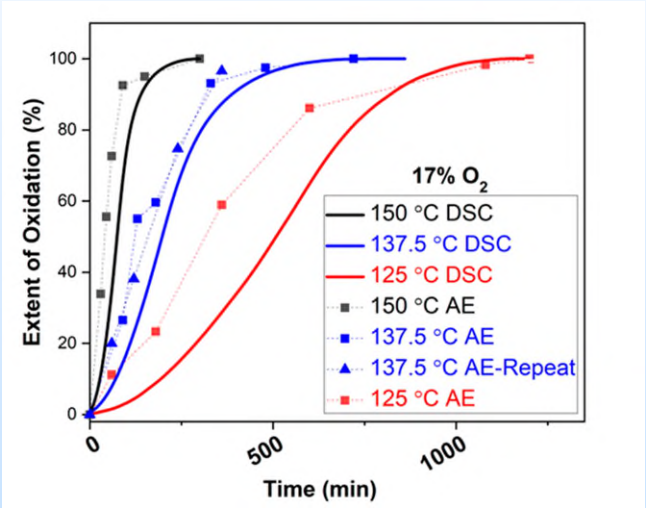
- Develop and validate a high performance, lower cost integrated process for NGCC point source CO_2 capture incorporating an **oxide monolith + amine structured contactor** (achieve TRL 5).
- Refine the process model with experimental data (for capture performance and accelerated life-cycle tests performed under relevant process conditions) collected during the project to optimize the process prior to the bench-scale system test and to support the techno-economic analysis.
- Refine the process techno-economic analysis, with multiple stakeholder inputs, to outline the roadmap towards achieving a 20% cost reduction with the new integrated process relative to the NETL benchmark carbon capture process.

Technology Background
Oxidative Stability of PEI

- Poly(ethylenimine) is known to degrade in the presence of O_2.



Phys.Chem.Chem.Phys. 2014, 16, 1529-1535



ACS Sustainable Chem. Eng. 2021, 9, 25, 8477–8486

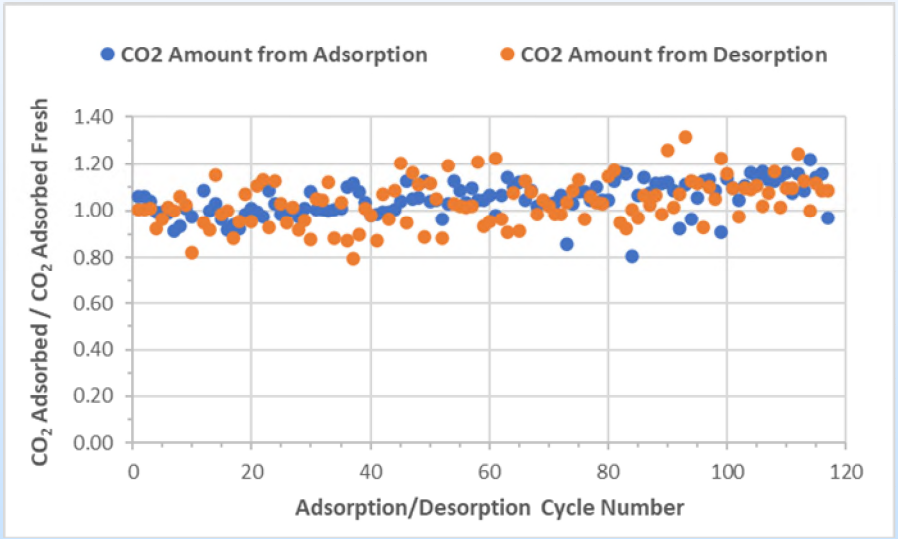
- PEI degradation rate = function (t, T, P_{O2}).
  - GT's base DAC process is designed to mitigate high temperature oxygen exposure.

Technology Background

Adsorber Component Data for NGCC PSC Conditions

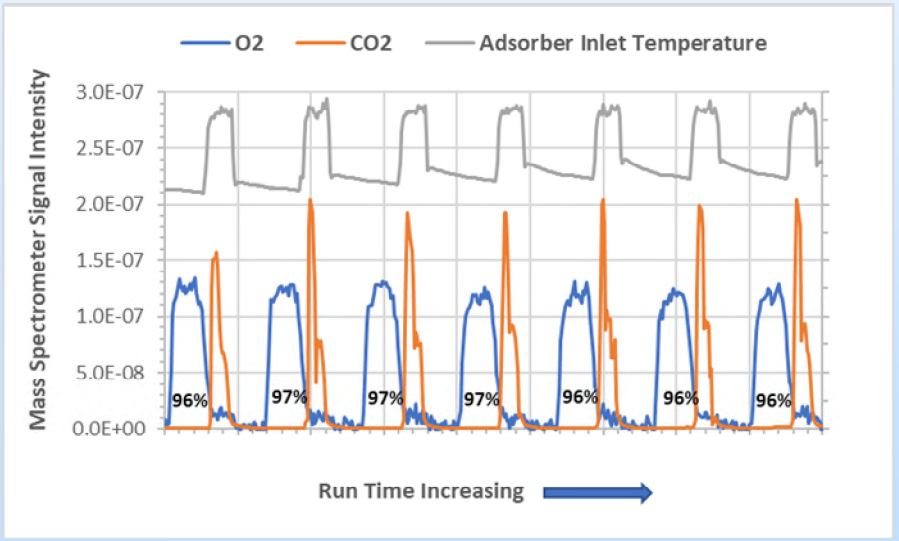
PSC conditions:

Rate of oxidative degradation is slow.



CO_2 ads/des cycling test showing capacity retention

Capture effectiveness > 95%.



Multi-cycle adsorption test showing capture effectiveness

Technology Background

Anticipated Benefits

Design Vision: PEI-monolith contactor, with steam as desorbing medium.

Simple unit design. No vacuum stage used. Efficient. Scalable. Low capital cost.
Monolith PEI adsorbers **utilizes existing amine supported substrate technology**.
Monolith PEI adsorbers operate with **low pressure drop** (<200Pa). Low-cost fans.
High contact area between flue gas and the monolith PEI adsorbers. Efficient.
Amine (PEI) **is contained in a fixed position** within the monolith's internal porous structure: there is no physical movement of the amine. Negligible expected stack emissions of the amine, no operational loss of amine, no need to recirculate the amine, no equipment corrosion issues.
Monolith PEI adsorber only **requires low quality steam** to regenerate (desorb CO_2).
Energy efficient. No need to heat large amounts of excess water during steam regeneration. Minimal sensible heat is required to heat the system for desorption. Low energy requirement for regeneration.
Manageable life cycle costs. CORMETECH has the **expertise and capability for monolith regeneration** (commercial process for the regeneration of SCR catalyst) such that the monolith substrates can be reused (degraded amine stripped, and fresh amine reapplied) to manage potential amine oxidative degradation. Process can accept **future monolithic-amine adsorber innovations** to improve capacity and lifetime.

Technology Background
State before Start of Project

- **Monolithic PEI adsorbers have been utilized for DAC units:**
  - Adsorption at ambient T, RH conditions, with 400-600ppm CO_2.
  - TVSA for CO_2 collection, using steam as the heating medium.
  - Susceptible to capacity fade by oxidative degradation. Impact is mitigated through DAC process design.

- **Their performance under NGCC PSC conditions was known:**
  - Core sample test conditions,
  - with thermal humidified N_2 (up to 30% H_2O) desorption conditions,
  - and the oxidative durability evaluated to ~120 cycles.

Project Steps

Tasks and Schedule

ID	Task Name	Resource Names
1	**Task 1 - Project Management and Planning**	**CM**
2	Subtask 1.1 - Project Management Plan (PMP)	CM
3	Deliverable 1 - PMP Update (100% Complete)	CM
4	Subtask 1.2 - Technology Maturation Plan (TMP)	TEAM
5	Deliverable 2 - Initial TMP (100% Complete)	TEAM
6	Deliverable 5 - Final TMP	TEAM
7	**Task 2 - PEI Durability Validation Testing**	**GT**
8	Subtask 2.1 - PEI Oxidative Degradation Rate Testing (25% Complete)	GT,CM
9	Subtask 2.2 - PEI Nox Exposure Degradation Rate Testing (0% Complete)	CM,GT
10	Subtask 2.3 - PEI SOx Exposure Degradation Rate Testing (0% Complete)	CM,GT
11	Deliverable 3 - Report on PEI Durability under NGCC PSC Conditions (Including Mitigation Options)	GT,CM
12	**Task 3 - Integrated Process Unit: Basic Engineering**	**CM**
13	Subtask 3.1 - Specifications Document (100% Complete)	CM,GT
14	Subtask 3.2 - Basic Engineering Design (40% Complete)	CM,GT
15	**Milestone 1 - PEI Stability Under Point Source Capture NGCC Flue Gas Conditions Validated.**	TEAM
16	**Milestone 2 - Basic Engineering Design Package Completed (with Fixed Price and Process Unit Delivery Timing Established).**	TEAM
17	**Task 4 - Integrated Process Unit: Detailed Engineering, Procurement, and Build**	**CM**
18	Subtask 4.1 - Detailed Engineering Design	CM,GT
19	**Milestone 3 - Detailed Engineering Design Package Completed (Ready to Procure and Build).**	CM
20	Subtask 4.2 - Procurement and Build	CM
21	Subtask 4.3 - Factory Acceptance Testing (FAT)	CM
22	**Task 5 - Host Site Planning**	**CM**
23	Subtask 5.1– Execute Technology Collaboration Agreement (TCA) with NCCC	CM
24	Subtask 5.2 – Hazard Review with NCCC	CM
25	Deliverable 4 - Copy of TCA and documented NCCC acceptance of detailed engineering design and hazard review	CM
26	**Task 6 - Sorbent Manufacture for Integrated Process Unit**	**CM**
27	Subtask 6.1 - Batch, Extrude and Activate Monolithic PEI Sorbent	CM
28	**Task 7 - Parametric Testing and Modeling Refinement to Optimize Process Performance**	**GT**
29	Subtask 7.1 - Parametric Experiments for CO2 Cycling (with Input from Task 2 Results)	GT,CM
30	Subtask 7.2 - Adsorber and Process Model Refinement	CM
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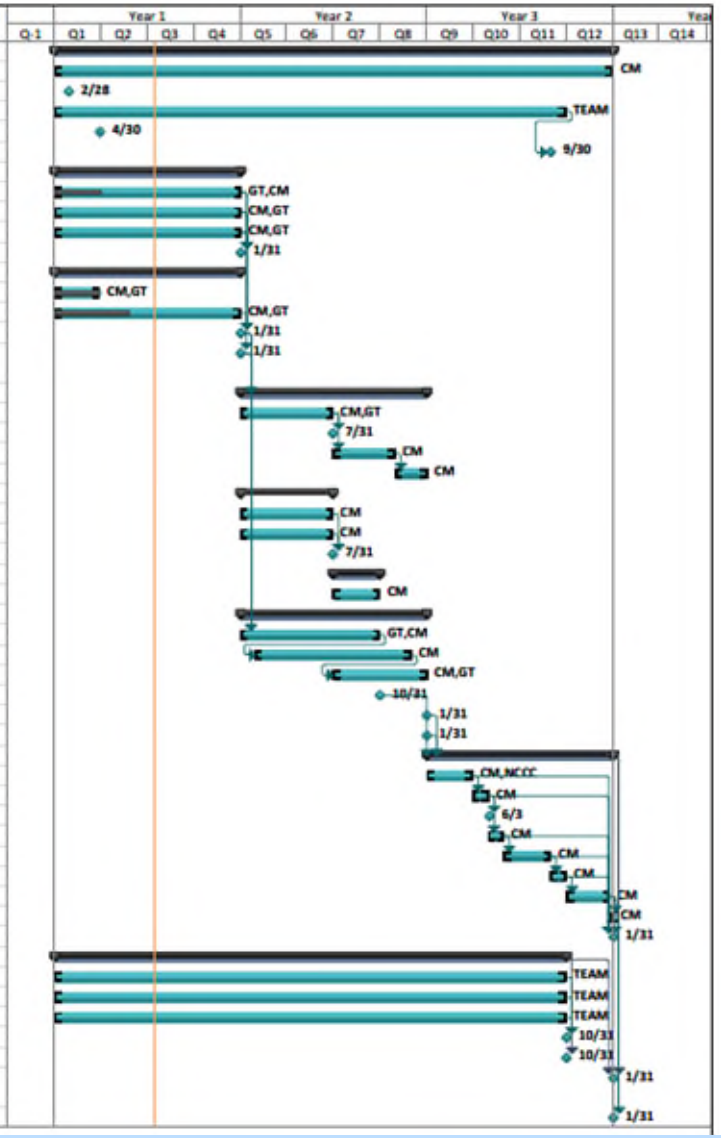
32	**Milestone 4 - Monolithic PEI Sorbent Ready for Test Campaign.**	TEAM
33	**Milestone 5 - FAT complete and unit ready to ship to NCCC site.**	TEAM
34	**Milestone 6 - Optimized Process Operating Cycle Parameters Established to Guide Test Campaign.**	TEAM
35	**Task 8 - Bench Test Campaign at NCCC**	**CM**
36	Subtask 8.1 - Installation of Integrated Process Unit at NCCC Site Location	CM,NCCC
37	Subtask 8.2 - Unit Commissioning	CM
38	**Milestone 7 - Unit Installed and Commissioned at NCCC Site.**	CM
39	Subtask 8.3 - Parametric Testing (Impact of Flow Rate)	CM
40	Subtask 8.4 - Continuous Operation Test	CM
41	Subtask 8.5 - Parametric Testing (Impact of Flow Rate)	CM
42	Subtask 8.6 - Parametric Testing (Impact of Flue Gas Contaminants)	CM
43	Subtask 8.7 – Removal of Integrated Process Unit from NCCC Site Location	CM
44	Deliverable 6 - Final Bench Test Campaign Report	CM
45	**Task 9 - Techno-Economic Analysis (TEA), Life Cycle Analysis (LCA), and Technology EH&S Assessment**	**TEAM**
46	Subtask 9.1 - Techno-Economic Analysis (TEA)	TEAM
47	Subtask 9.2 - Life Cycle Analysis (LCA)	TEAM
48	Subtask 9.3 - Technology EH&S Risk Assessment	TEAM
49	Deliverable 7 - Final TEA/LCA/EH&S Risk Assessment	TEAM
50	**Milestone 8 - Final TEA/LCA and TMP Complete.**	TEAM
51	**Milestone 9 - Bench Test Campaign Complete. >95% Carbon Capture Efficiency Demonstrated for Minimum 1 Month Continuous Operation. Parametric Testing Complete.**	TEAM
52	**Milestone 10 -Unit Decommissioned and Removed from NCCC Site Location**	CM



Project Steps – BP1

Bench-Scale Test PEI-Monolith NGCC PSC Process

BP1 activities (2/1/2022 – 1/31/2023; in Tasks 2 & 3)

- **Further characterize the durability of the PEI monolithic adsorber under NGCC PSC conditions to improve the certainty of the adsorber lifetime estimation.**
  - Oxidative degradation. Impact of NOx and SO_2.
- **Improve the durability of the PEI monolithic adsorber as feasible to further increase adsorber lifetime.**
- **Complete the basic engineering design for the bench-scale integrated process unit (IPU).**
  - Technical & functional specifications.
  - Design & sizing of major components.
- **Develop an ASPEN process model to simulate performance.**

Project Steps – BP2

Bench-Scale Test PEI-Monolith NGCC PSC Process

<u>BP2 activities (2/1/2023 – 1/31/2024; in Tasks 4, 5, 6, & 7)</u>

- **Complete, for the bench-scale IPU:**
  - Detailed engineering design.
  - Adsorber manufacture.
  - Procurement, build and FAT.
- **Complete the TCA and Hazards Review with NCCC.**
- **Perform process optimization work for the bench-scale IPU:**
  - Run process parametric experiments (on SBST), and use the data to…
  - refine the ASPEN process model, and then…
  - run process simulations to optimize performance,

  to prepare for the bench-scale testing campaign at NCCC in BP3.

Project Steps – BP3

Bench-Scale Test PEI-Monolith NGCC PSC Process

BP3 activities (2/1/2024 – 1/31/2025; in Tasks 8 & 9)

- **Complete the test campaign for the bench-scale IPU at NCCC.**
- **Complete the TEA, LCA, and Technology EH&S Risk Assessment.**

Project – Success Criteria

Decision Point	Date	Success Criteria
Completion of BP1	1/31/2023	❑ PEI durability meets specified target before adsorber amine regeneration [i.e., adsorber can still achieve the carbon capture efficiency goal (95%) and CO_2 purity goal (95%)]. ❑ Fixed price (±10%) and process unit delivery timing established.
Completion of BP2	1/31/2024	❑ Capacity of durability optimized PEI-monolith meets specified target for PSC conditions. ❑ Process optimized to meet and exceed carbon capture efficiency goal (95%) and CO_2 purity goal (95%) in bench test. ❑ NCCC Technology Collaboration Agreement with letter indicating acceptance of hazard review and design. ❑ FAT complete and unit ready to ship to NCCC site.
Project Completion	1/31/2025	❑ >95% carbon capture efficiency and >95% CO_2 purity demonstrated for minimum 1-month continuous operation. ❑ Impact of flue gas contaminants (NOx, SOx) on system performance / durability quantified, to yield <20% adsorber degradation. ❑ The TEA/LCA show advantages of novel PSC system and road map towards 20% reduction in carbon capture cost relative to the NETL standard CANSOLV system. ❑ EH&S risk assessment shows no issues for commercial deployment.

Project – Risks and Mitigations

- **Risk 1: delay of hiring personnel.**
  - Key position (project engineer for IPU design & build) was vacant at start of project (2/1/2022).
  - **Status: complete. Sr Development Engineer joined Cormetech team in April 2022.**

- **Risk 2: cost of bench unit > budget.**
  - Mitigation: initial budget plan used a preliminary P&ID sketch & equipment list to estimate pricing from catalogs & past quotes, with the automation & assembly pricing estimated from previous projects. Basic engineering (task 3.2) focuses on setting a fixed price proposal ($\pm$10%).
  - **Status: work in-progress; end of BP1 deliverable.**

Project – Risks and Mitigations

- **Risk 3: delayed delivery of equipment and parts.**
  - Mitigation: main procurement activity starts in 2023 (in BP2); order well in advance and follow up with vendors to assure timely delivery.
  - **Status: monitoring as needed.**

- **Risk 4: unreliable bench test unit does not work for required field campaign duration.**
  - Mitigation: Cormetech has experience with building bench test skids. Unit will be well-designed (with specifications document and acceptance criteria ready before build) and FAT completed before shipping to site.
  - **Status: BP2 task.**

Project – Risks and Mitigations

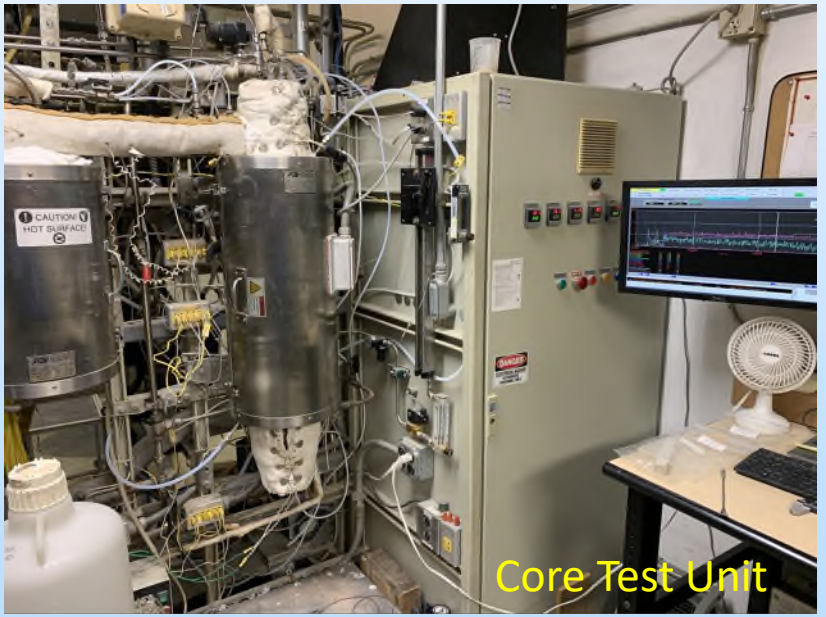
- **Risk 5: monolith damage/failure during field test campaign.**
  - Mitigation: spare charges will be produced for the bench IPU testing in case issues arise. NOx and SOx impact testing will be run at the campaign's end, since it will likely have a negative impact on adsorber.
  - **Status: BP2 task.**
- **Risk 6: PEI monolithic adsorber degrades too quickly under PSC conditions.**
  - Mitigation: Lab-scale tests have shown promising oxidative durability to date under NGCC PSC conditions. Planned process and substrate properties experiments will reveal optimization pathways to extend PEI monolith lifetime.
  - **Status: work currently in-progress.**

Task 2 – Update
PEI Durability Validation Testing

- **Completed ~1000-cycle stability tests, at multiple temperatures.**
  - Ran testing in core sample test unit. Used fresh PEI-monolith core samples.
  - One "cycle": adsorb for "x" time / desorb for "y" time.

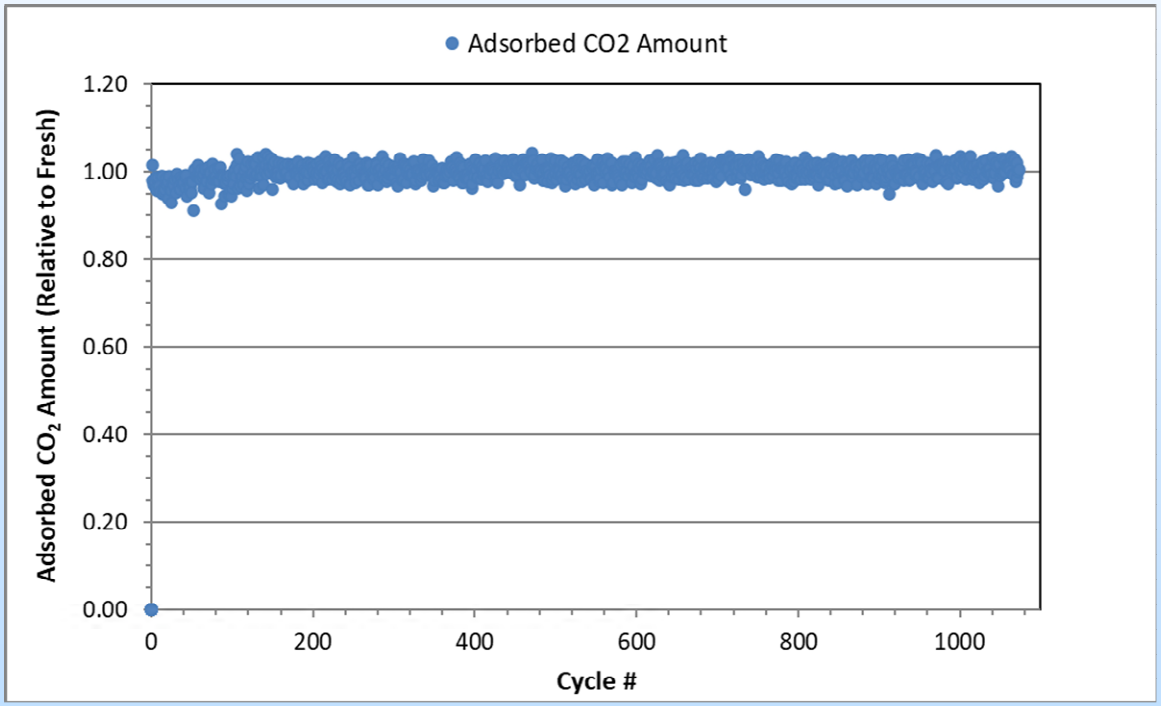
Adsorption gas:
4% CO_2, 15% O_2, 9% H_2O, balance N_2.

Desorption gas:
~20% H_2O, balance N_2.



Task 2 – Update
PEI Durability Validation Testing

- **Series 1: 1073 cycles, at NGCC PSC relevant temperature.**
  - Capacity is stable.

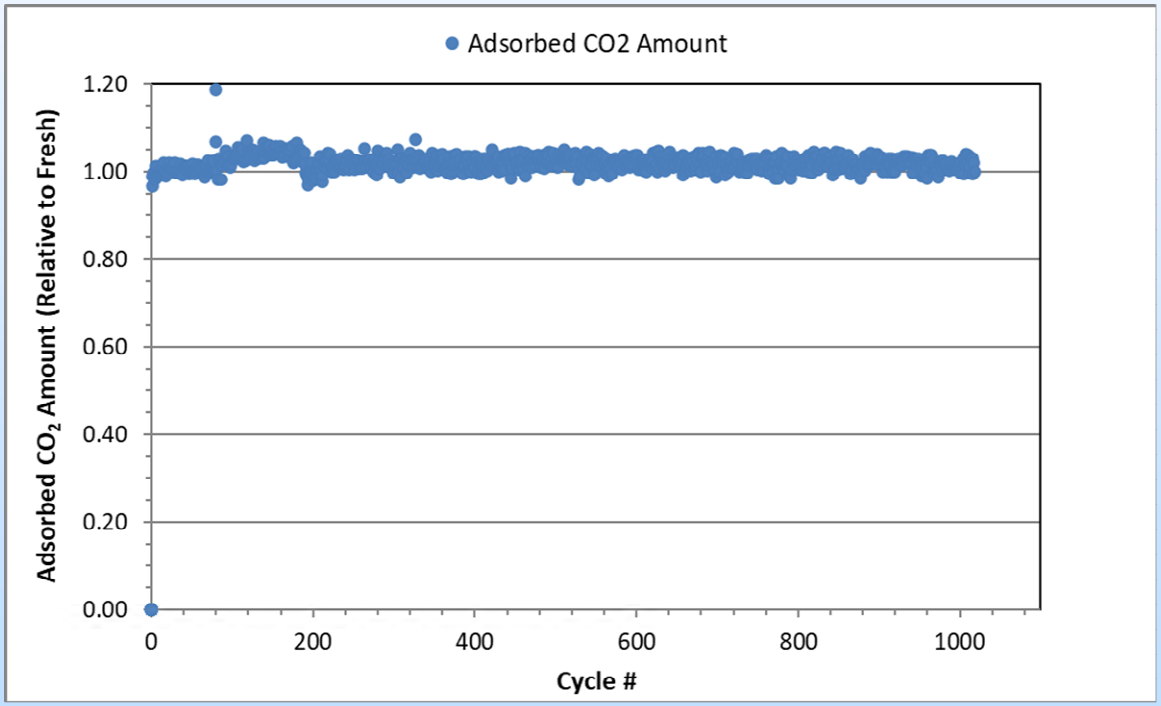


Adsorption gas: 4% CO_2, 15% O_2, 9% H_2O, balance N_2.

Desorption gas: ~20% H_2O, balance N_2.

Task 2 – Update
PEI Durability Validation Testing

- **Series 2: 1018 cycles, at Temperature = series 1 + 10°C.**
  - Capacity is stable.

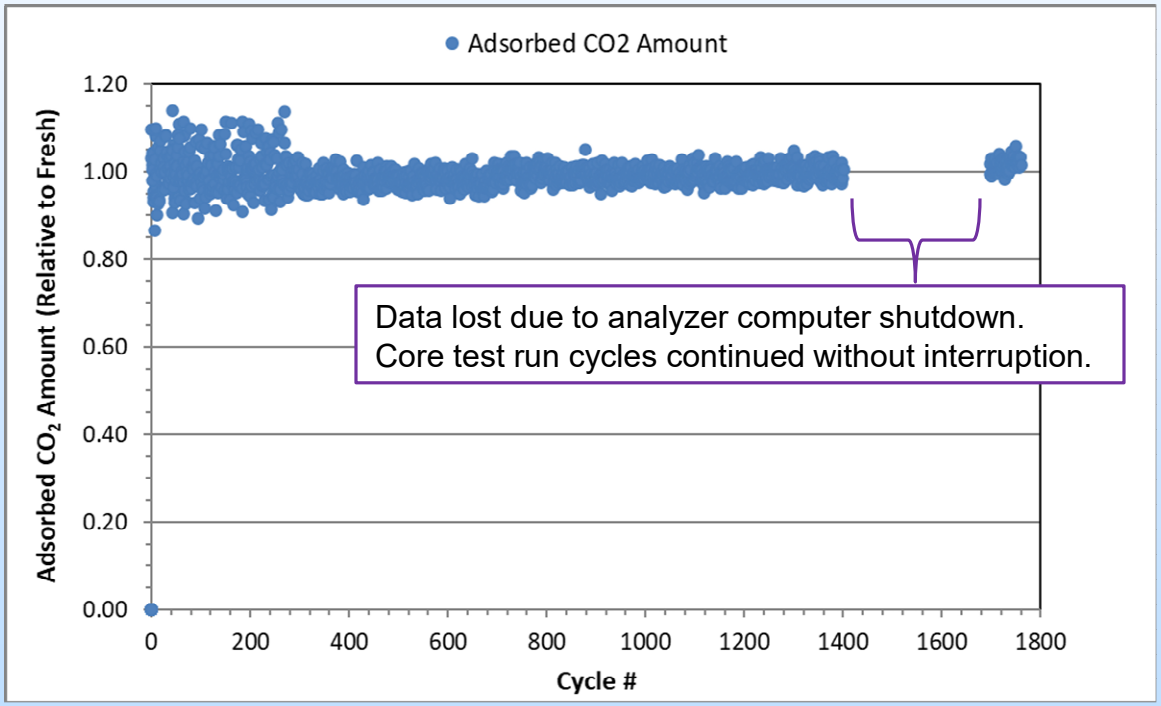


Adsorption gas: 4% CO_2, 15% O_2, 9% H_2O, balance N_2.

Desorption gas: ~20% H_2O, balance N_2.

Task 2 – Update
PEI Durability Validation Testing

- **Series 3: 1773 cycles, at Temperature = series 1 + 18°C.**
  - Capacity is stable.

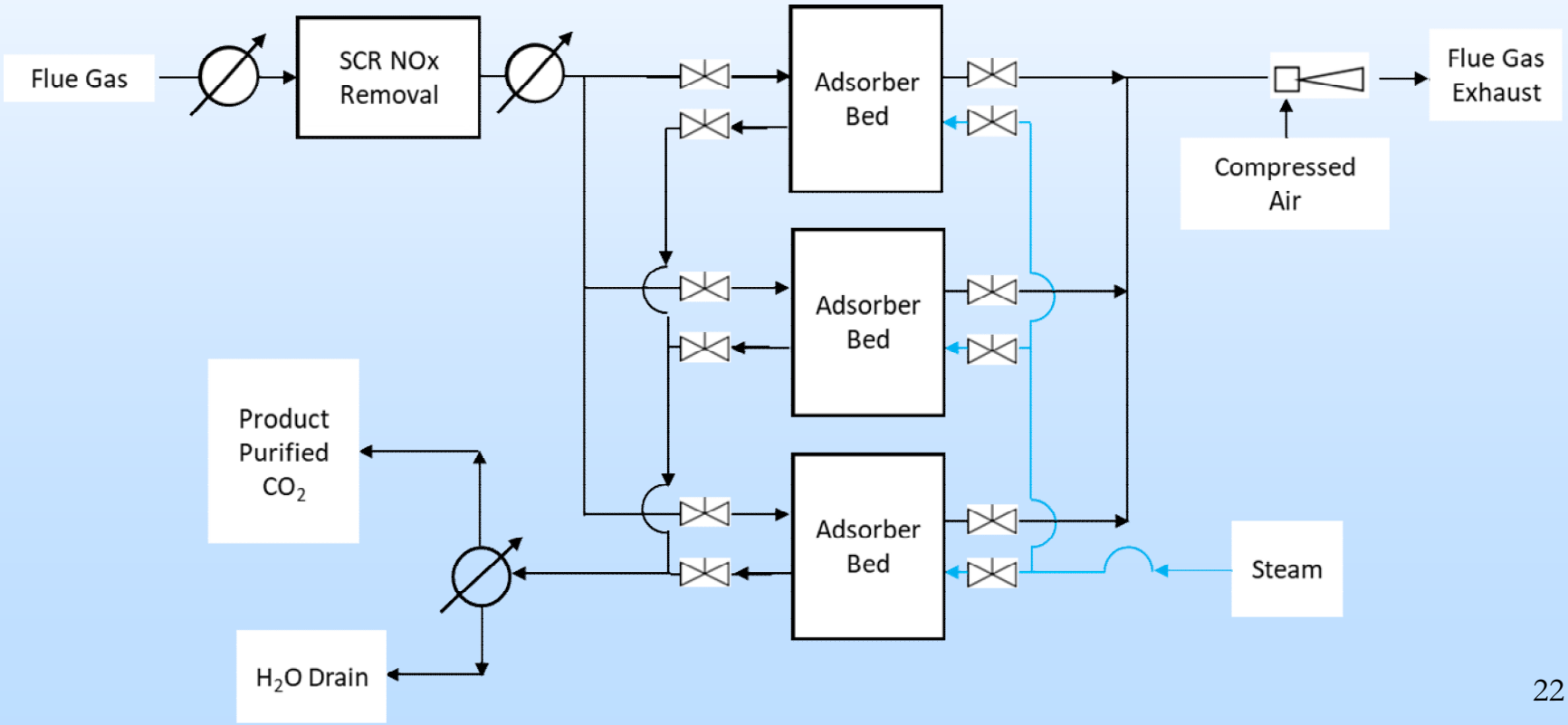


Adsorption gas: 4% CO_2, 15% O_2, 9% H_2O, balance N_2.

Desorption gas: ~20% H_2O, balance N_2.

Task 3 – Update
Basic Engineering for Integrated Process Unit

- **Block diagram of IPU layout: continuous process.**
  - Three adsorber beds for test flexibility on adsorb/desorb times (1:1, 1:2, 2:1).



Task 3 – Update
Basic Engineering for Integrated Process Unit

- **Procured ASPEN and model development is underway.**
- **Established NDA with NCCC and received developers guide.**
- **IPU functional and technical specifications have been set.**
- **Process experiments are underway to finalize equipment sizing (targeting nominal 200 kg/day CO_2 production rate).**
  - Core testing in-progress: generating breakthrough curves as f (SV, temperature).
  - Single-brick testing is planned: currently building SBST 2 to enable NGCC PSC testing. Unit uses steam for CO_2 recovery.

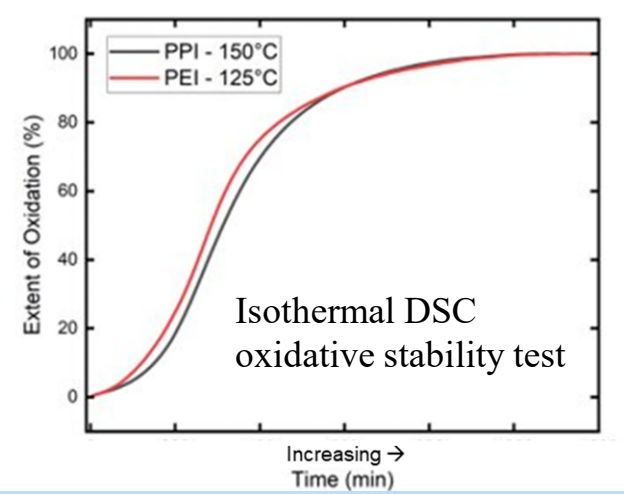
Synergy Opportunities

- Field campaign setup and execution:
  - Cormetech, NCCC, Southern Company
- Techno-economic analysis, with a diverse team:
  - Monolithic adsorber manufacturers
    - Cormetech
  - Carbon capture system developers
    - Cormetech, Global Thermostat
  - NGCC power producers
    - Southern Company, MRP
  - Carbon capture investors
    - ZCP

Synergy Opportunities

Utilizing improved oxidative stability amine-based sorbents:

- Bench-Scale Testing of Monolithic Linear Poly(propyleneimine) Structured Contactors for DAC of CO_2 (DE-FE0032094).
  - CORMETECH (prime), Georgia Tech, Global Thermostat
  - Period of performance: 9/15/2021–9/14/2023. Federal share = $1,500,000.
- Poly(ethylenimine) / PEI: $-(NH-CH_2-CH_2)_{n>1}-NH_2$
- Poly(propyleneimine) / PPI: $-(NH-CH_2-CH_2-CH_2)_{n>1}-NH_2$



Focus of DE-FE0032138 is to develop the process platform, using monolithic PEI adsorbers.

Use of NextGen amine sorbents presents future improvement opportunities.

Next Steps
Testing/Development/Commercialization

- In this project:
  - Continue Task 2 work activities.
    - Complete: PEI durability validation, impact of NOx and SO_2.
  - Continue Task 3 work activities.
    - Complete the basic engineering design package.
  - BP2 and BP3 work activities.

- After this project:
  - Engineering-scale demonstration. We're optimistic!

Summary

- Work has commenced on BP1 activities.
- Progress has been made on validating the durability target for the monolithic-PEI adsorber under NGCC PSC conditions, and on producing the basic engineering design package for the IPU.
- The PEI-monolith NGCC PSC process is a promising technology.

Appendix

Organization Chart – Participants

Prime Recipient

CORMETECH
RELIABILITY. DELIVERED.

Christopher Bertole (PI) – Director, Product and Applications Development
Thomas McDonald – Sr. Development Engineer
Gavin MacInnes – Lead Catalyst Development Engineer
Travis Jones – Manager, Product and Applications Development Laboratory
Drew Cunningham – Sr. Development Scientist
Sam Richardson – R&D Scientist
Casey Huten – Lead R&D Technician
Scot Pritchard – Sr. VP, Sales Engineering

Global Thermostat
The Carbon Negative Solution

Eric Ping – VP, Technology Development
Miles Sakwa-Novak – Director, R&D
Cassandra Hertz – Research Scientist II
Yanhui Yuan – Sr. Development Engineer
Abby Clabaugh – Development Engineer
Joanie Racicot – Research Scientist

Southern Company

Landon Lunsford – Air Quality Program Manager

MIDDLE RIVER POWER

Jeremy Meattey – Director of Financial Planning and Analysis

Zero Carbon Partners, LLC

David Elenowitz – President

Organization Chart – Participants

Prime Recipient

CORMETECH
RELIABILITY. DELIVERED.

- ❑ Engineering design, procurement, build and FAT of the bench-scale IPU.
- ❑ Adsorber manufacture for the bench-scale IPU.
- ❑ Process parametric testing, model refinement, and process optimization.
- ❑ NCCC TCA and hazards review.
- ❑ Bench-scale IPU testing campaign.
- ❑ TEA, LCA, Technology EH&S Risk Assessment.

Global Thermostat
The Carbon Negative Solution

- ❑ PEI oxidative degradation rate resting.
- ❑ PEI NOx and SOx exposure degradation rate testing.
- ❑ TEA, LCA, Technology EH&S Risk Assessment.

Southern Company

- ❑ NCCC TCA and hazards review.
- ❑ TEA, LCA, Technology EH&S Risk Assessment.

MIDDLE RIVER POWER

- ❑ TEA, LCA, Technology EH&S Risk Assessment.

Zero Carbon Partners, LLC

- ❑ TEA, LCA, Technology EH&S Risk Assessment.

Project Schedule – Gannt Chart

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38	**Milestone 7 - Unit Installed and Commissioned at NCCC Site.**	CM
39	Subtask 8.3 - Parametric Testing (Impact of Flow Rate)	CM
40	Subtask 8.4 - Continuous Operation Test	CM
41	Subtask 8.5 - Parametric Testing (Impact of Flow Rate)	CM
42	Subtask 8.6 - Parametric Testing (Impact of Flue Gas Contaminants)	CM
43	Subtask 8.7 – Removal of Integrated Process Unit from NCCC Site Location	CM
44	Deliverable 6 - Final Bench Test Campaign Report	CM
45	**Task 9 - Techno-Economic Analysis (TEA), Life Cycle Analysis (LCA), and Technology EH&S Assessment**	**TEAM**
46	Subtask 9.1 - Techno-Economic Analysis (TEA)	TEAM
47	Subtask 9.2 - Life Cycle Analysis (LCA)	TEAM
48	Subtask 9.3 - Technology EH&S Risk Assessment	TEAM
49	Deliverable 7 - Final TEA/LCA/EH&S Risk Assessment	TEAM
50	**Milestone 8 - Final TEA/LCA and TMP Complete.**	TEAM
51	**Milestone 9 - Bench Test Campaign Complete. >95% Carbon Capture Efficiency Demonstrated for Minimum 1 Month Continuous Operation. Parametric Testing Complete.**	TEAM
52	**Milestone 10 -Unit Decommissioned and Removed from NCCC Site Location**	CM