Low Regeneration Temperature Sorbent for Direct Air Capture of CO_2

DE-FE0031965

Dr. S. James Zhou

Susteon Inc.

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Management and Natural Gas & Oil Research Project Review Meeting
Virtual Meetings August 2 through August 31, 2021

Program Overview

- **Funding**: DOE: $799,687 **Cost-Share**: $200,000
- **Overall Project Performance Dates**: 10/2020 – 03/2022
- **Overall Project Objective**: Development of catalyzed amine-based solid sorbents with fast kinetics and low regeneration temperature for direct air capture of CO_2. The catalyst is designed to improve sorbent's working CO_2 capacity, reduce CAPEX and reduce energy consumption for sorbent regeneration resulting in lower cost of DAC.

Team and Facilities

Susteon

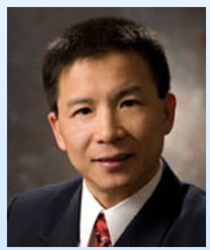
Raghubir Gupta
President

S. James Zhou
Senior Director

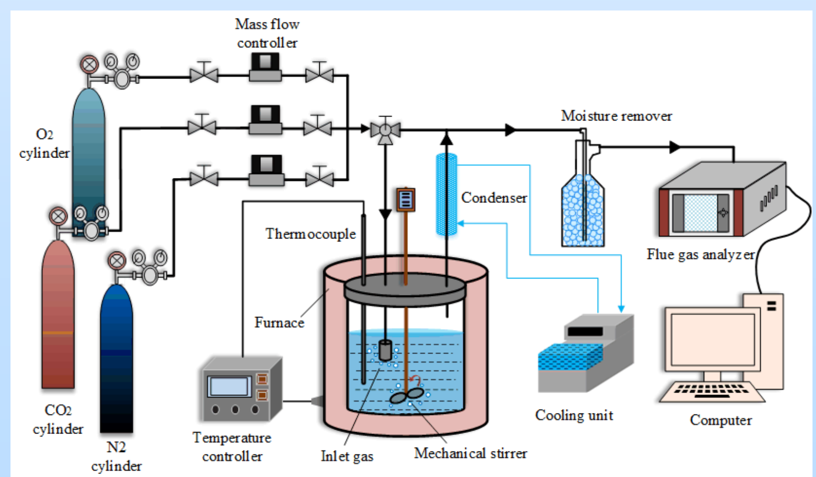
Cory Sanderson
Process Technologist

Jian Zheng
Sr. Engineer

UNIVERSITY OF WYOMING



Professor Maohong Fan

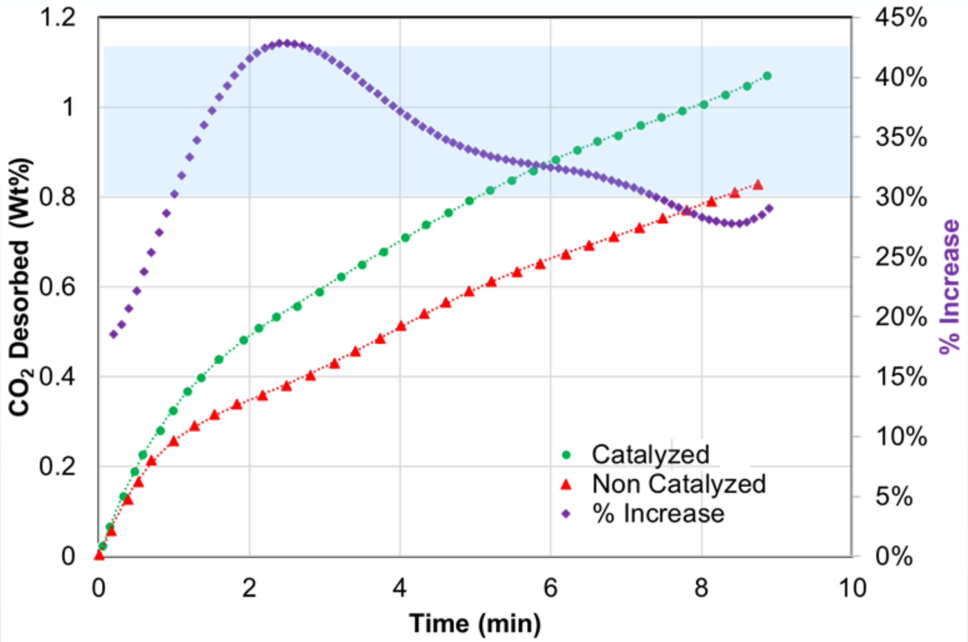


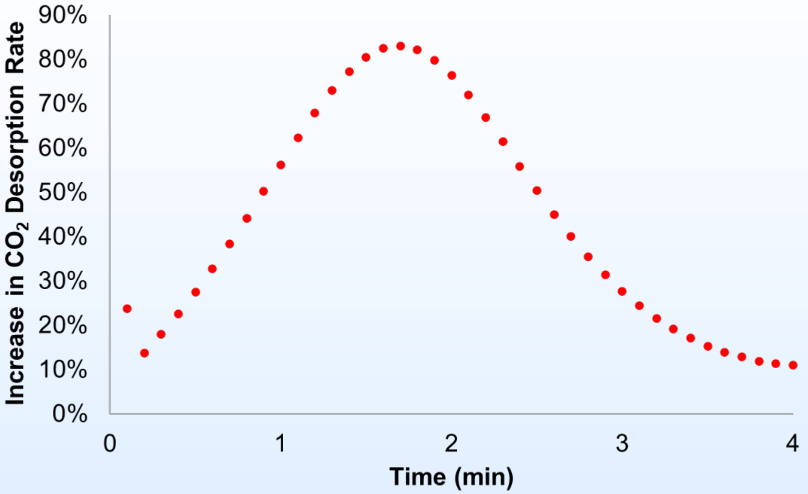
Technology Background

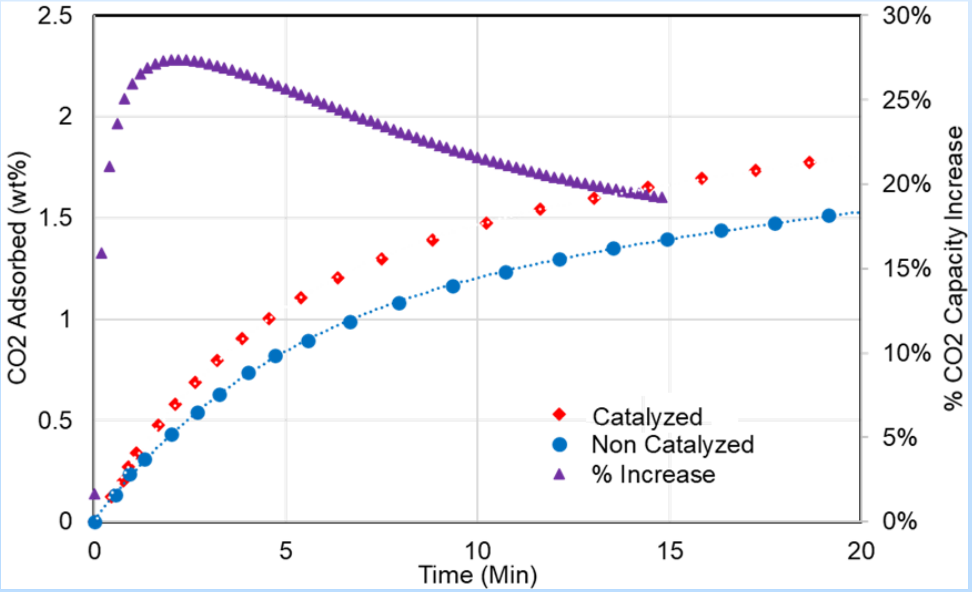
- Susteon's ionic liquid catalyst demonstrated improved CO_2 sorption and desorption rates by several orders of magnitudes for amine solvent/sorbent based CO_2 capture applications.
- Only ppm quantities of the catalyst need to be added to amine-based adsorbents. This has a potential to reduce the regeneration temperature to as low as 80°C, thus lowering the overall cost of CO_2 capture.
- A number of patent applications have been filed on this technology.

Metric	State-of-Art	Goal
CO_2 Adsorption Kinetics (gmol/min/kg)	1.0	2.0
Temperature of Regeneration (°C)	100-120	80-90
Energy of Regeneration (%)	100%	80%

Technology Background







- Desorption rate increase can be as high as **80%** with catalyzed sorbent at 85°C.
- At least 30% increase in the desorption amount
- At least 20% increase in the adsorption amount

Technical Approach/Project Scope

Planned Experimental and Process Modeling Work

- Synthesis, characterization and testing of catalysts and sorbents
  - ✓ Use existing industrial amine-based sorbents
  - ✓ Synthesize various amine/support sorbents
  - ✓ Addition of catalyst during or after sorbent synthesis
  - ✓ Amount of catalyst
  - ✓ Synthesis methods
- Determine rates of adsorption and desorption
- Determine CO_2 working capacity
- Determine heat of sorbent regeneration
- Develop a process model, TEA, and LCA

Technical Approach/Project Scope

Major Milestones

M#/Task#	Milestone Description	Planned Completion Date
M3/T1	Technology Maturation Plan (TMP)	12/31/2020
M4/T2	Successful preparation and characterization ionic liquid catalyst	3/31/2021
M5/T3	Successful preparation and characterization of catalyzed and un-catalyzed sorbents	8/31/2021
M6/T4	Successful completion of CO_2 adsorption isotherm and kinetics measurements	12/31/2021

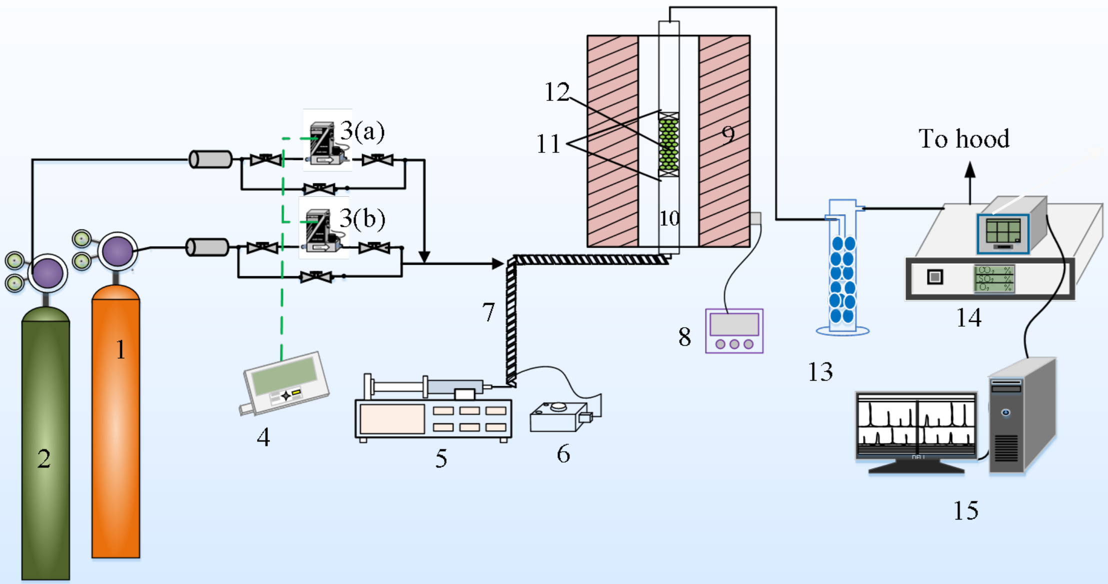
Success criteria

1. Development of a catalyst that can be added to amine doped DAC sorbents to increase adsorption and desorption kinetics
2. An increase of at least 30% in adsorption and desorption rates as compared with un-catalyzed state-of-art sorbents

Technical risks and mitigation plans

1. Low catalyzed sorbent performance - Extensive preliminary results, and alternative catalysts
2. Poor catalyzed sorbent stability – Stable amine + stable catalyst, and lower temperature of sorbent regeneration

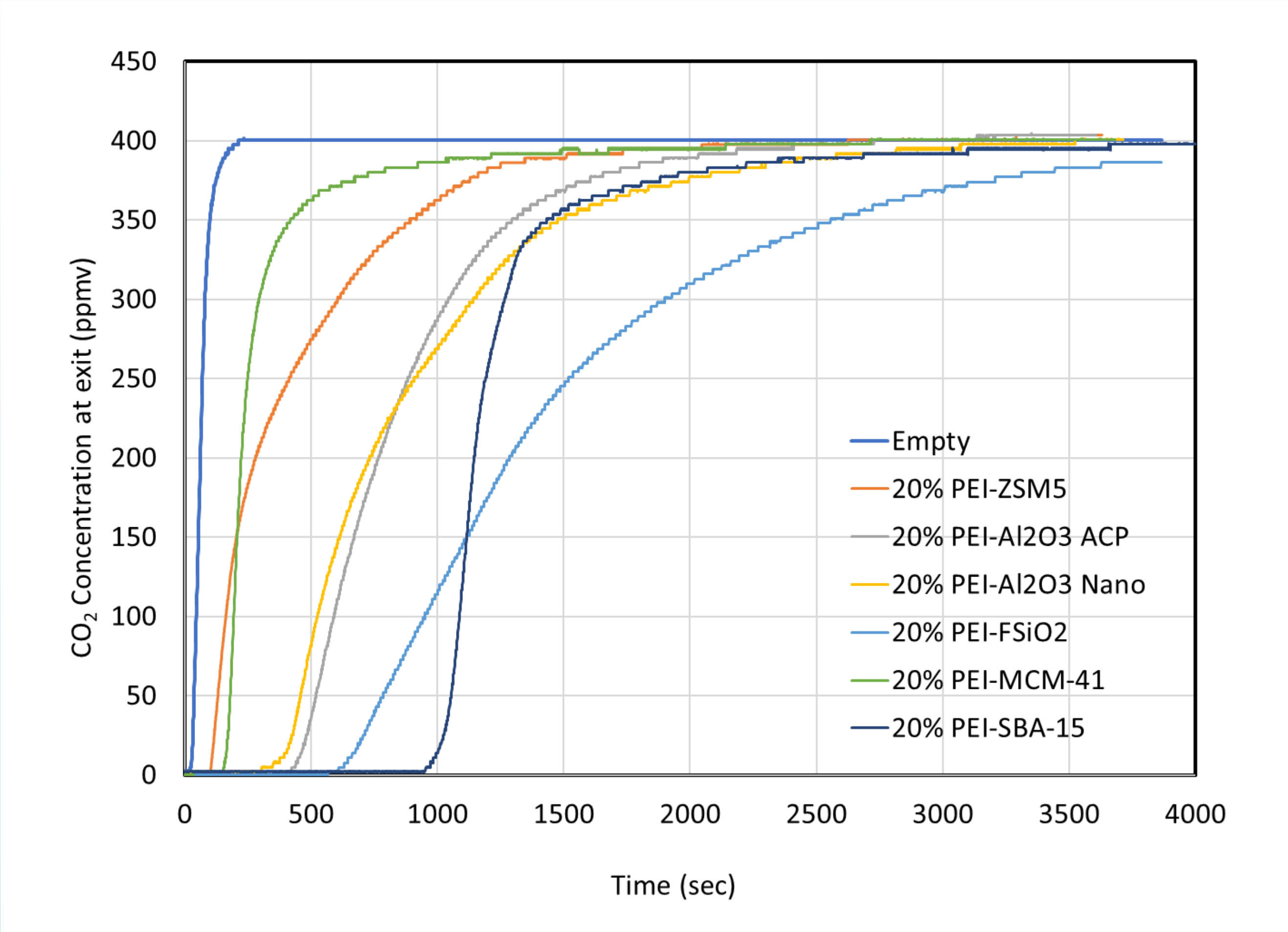
Direct Air Capture Test Setup



Schematic diagram of Air capture setup:

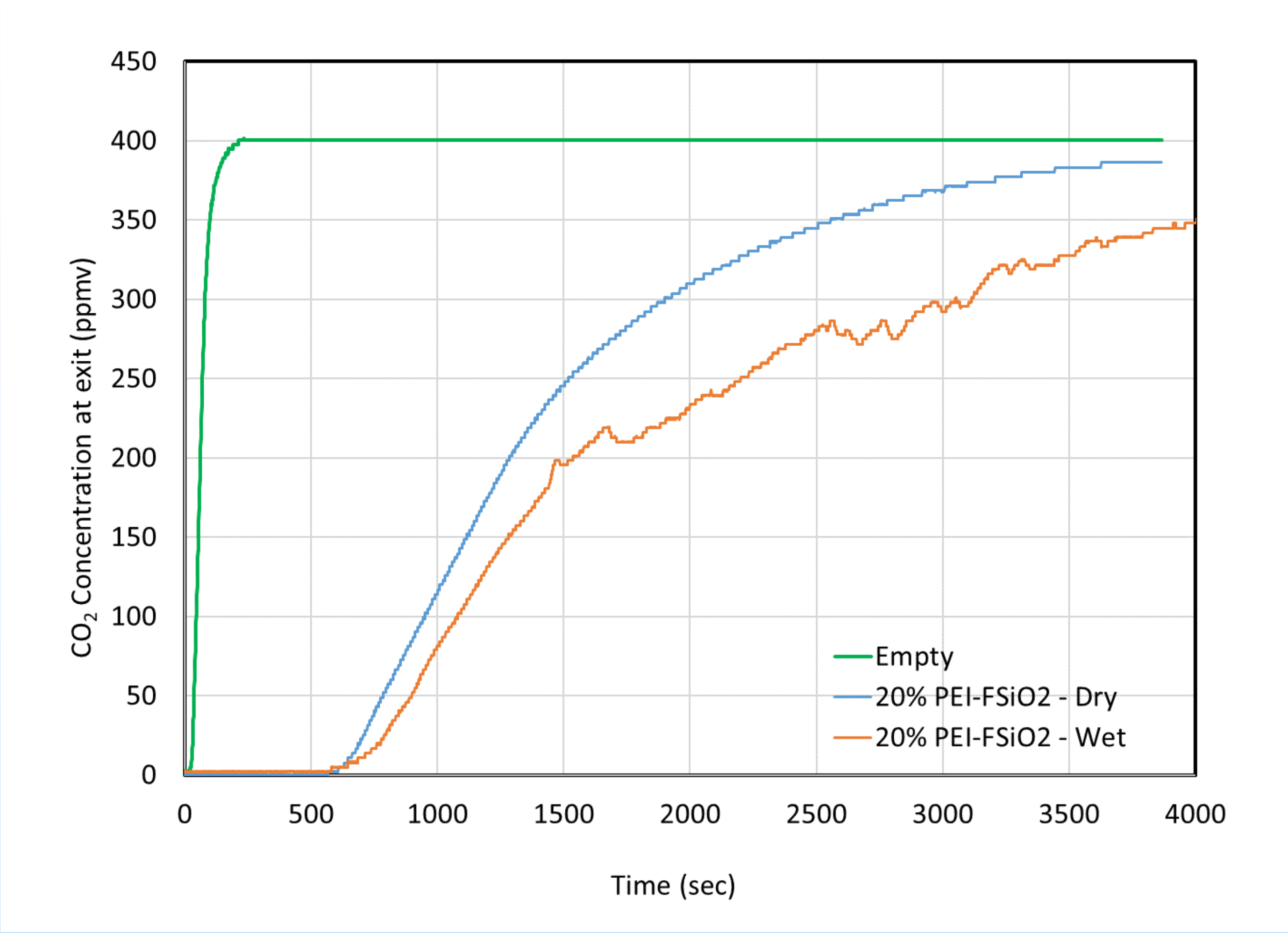
1, 1 vol% CO_2 gas cylinder;
2, nitrogen cylinder;
3(a) and 3(b), mass flow controllers;
4, control module of mass flow controller;
5, syringe pump;
6, temperature controller of heating tape;
7, heating tape;
8, temperature controller of the tube furnace;
9, tube furnace;
10, quartz tube reactor;
11, quartz wool;
12, sorbent bed;
13, moisture removal unit;
14, gas analyzer;
15, data acquisition unit.

Baseline Sorbent Performance



- 300 mg sorbent was used for each test.
- 400 ppm CO_2 in air with a total flow of 1030 ml/min used.
- 3 ml/h H_2O for moist conditions.
- Adsorption at ~ 26°C

Baseline Sorbent Performance



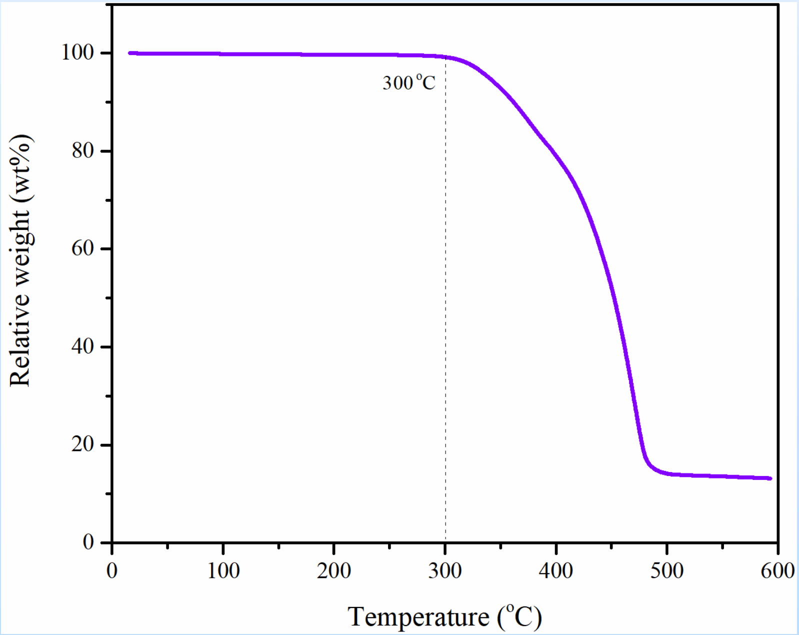
- 300 mg sorbent was used for each test.
- 400 ppm CO_2 in air with a total flow of 1030 ml/min
- 3 ml/h H_2O for moist conditions.
- Adsorption at ~ 26°C

Baseline Sorbent Performance

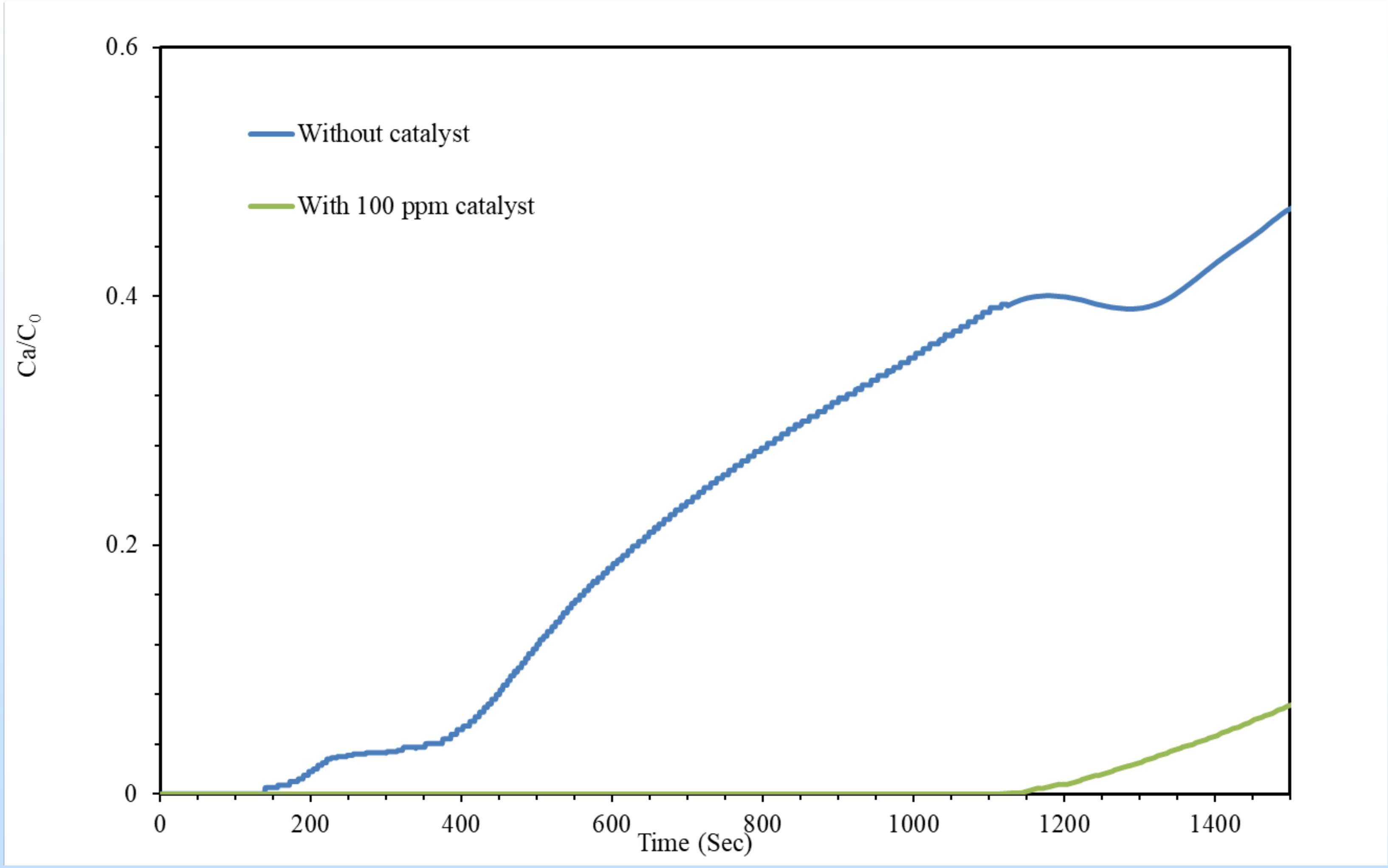
Sorbent Composition	CO_2 Capacity (µmol/g)	CO_2 Capacity (wt%)
20% PEI/$FSiO_2$	1.05	4.62
20% PEI/$FSiO_2$ (Humid conditions)	1.36	5.98
20 % PEI/SBA15	0.86	3.78
20% PEI/MCM-41	0.18	0.79
20% PEI/γ-Al_2O_3-nano	0.61	2.68
20% PEI/ γ-Al_2O_3-ACP	0.58	2.55
20% PEI/ZSM-5	0.26	1.14

Catalyst Scale Up and Characterization

- The catalyst synthesis method was scaled up from gram quantity in the lab to kilogram quantities.
- 3 kg of catalyst were synthesized for larger scale testing and laboratory use.
- The catalyst was compared with lab synthesized catalyst and found to be identical.
- The catalyst is stable up to 300°C.

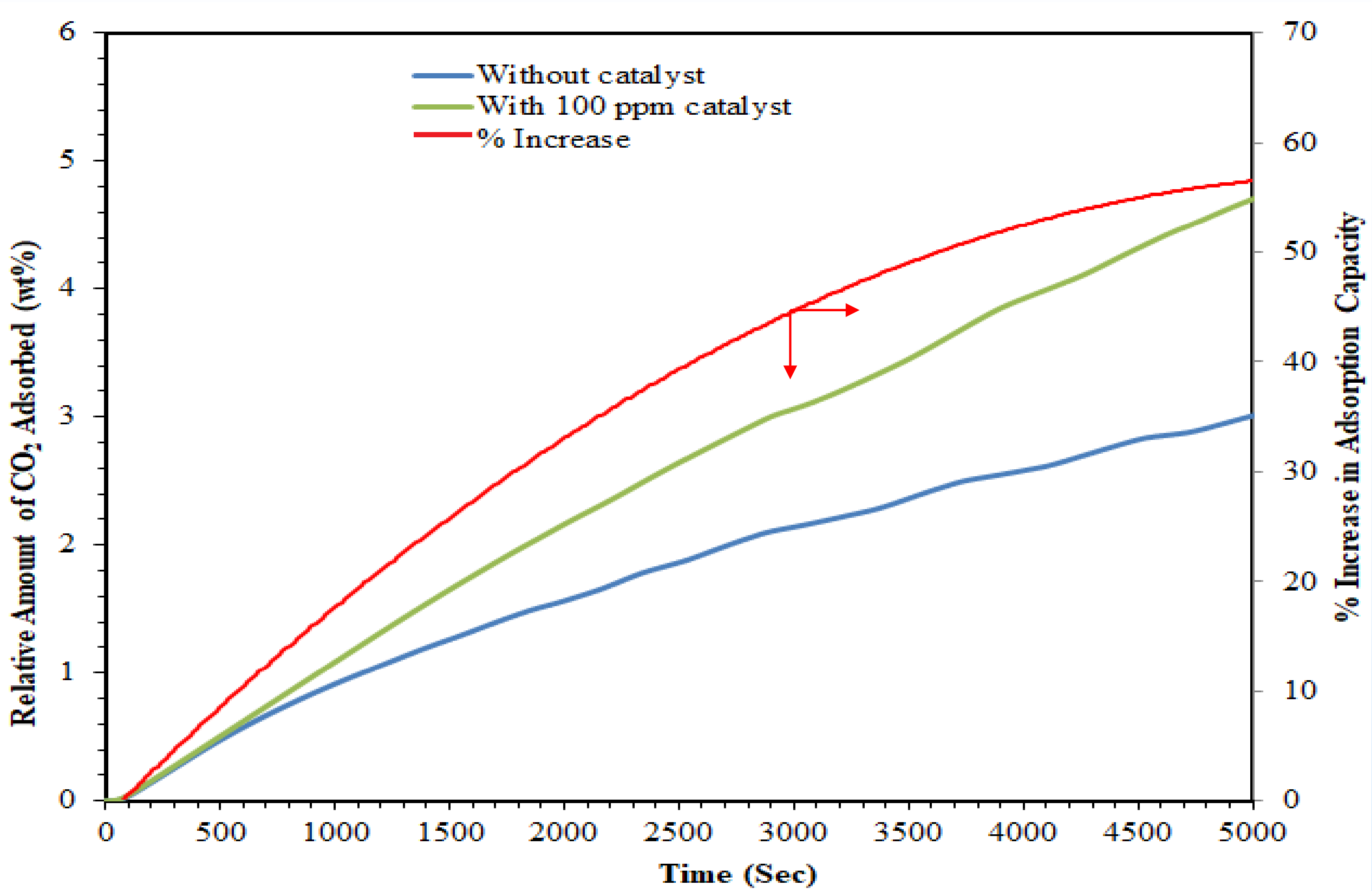


Catalyst Addition to an Industrial Amine-based Sorbent



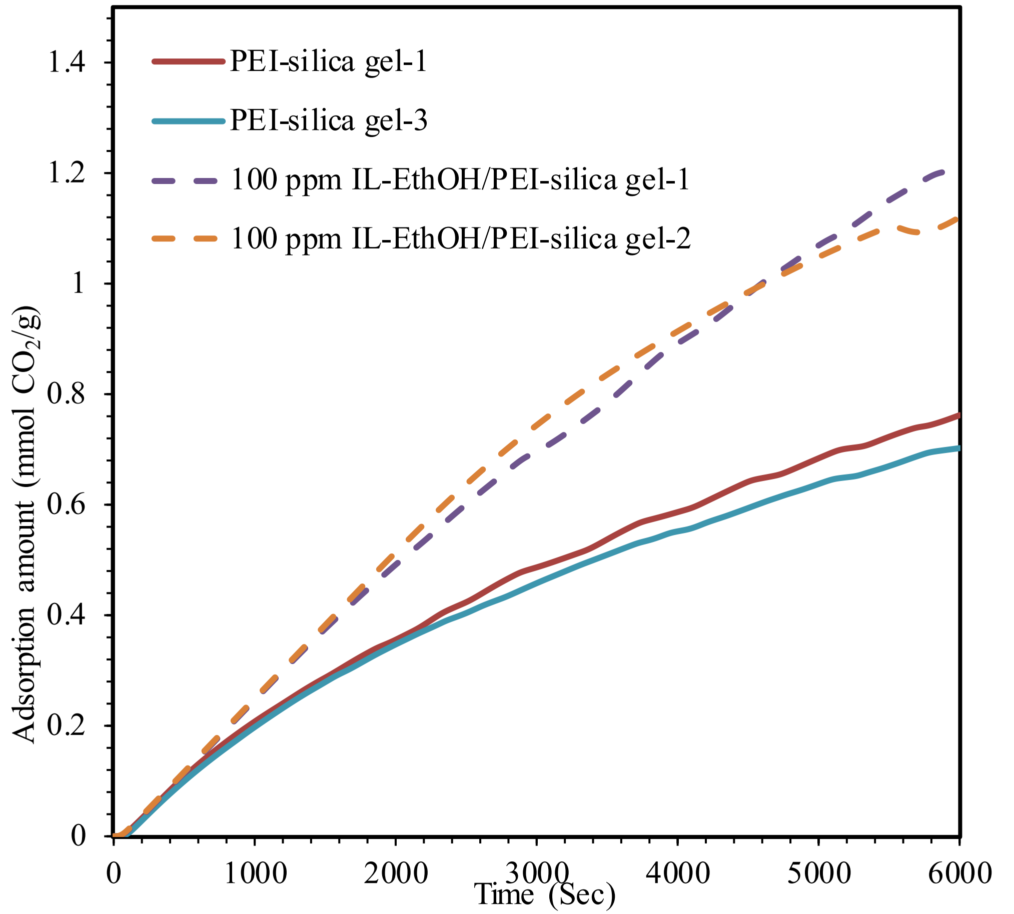
- More than 5 times longer breakthrough time

Catalyst Addition to Industrial Sorbent



- Up to 55% increase in CO_2 capacity

Catalyst Addition to PEI/Silica Sorbent

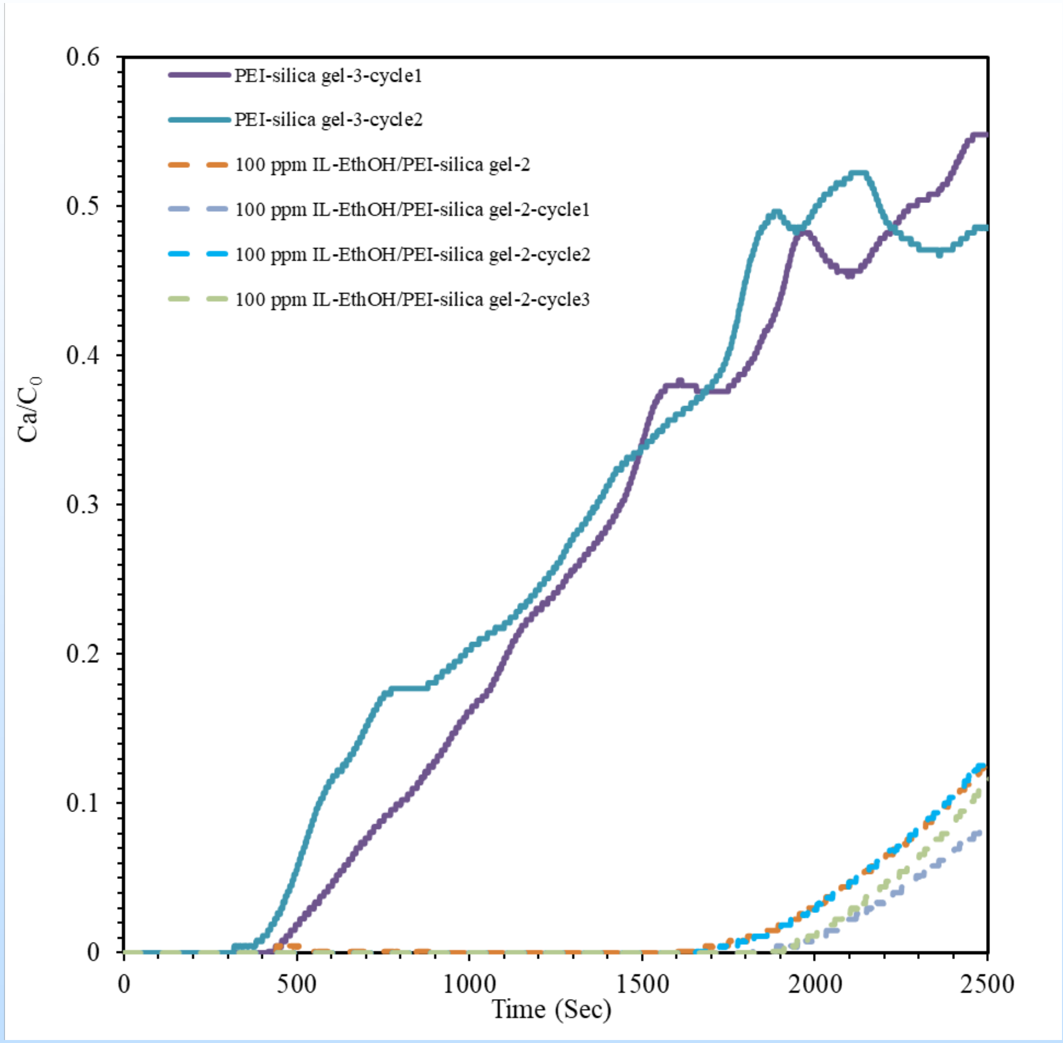


Absorption conditions:

- Sorbent : 0.4 g;
- 400 ppm CO_2;
- Flow rate of gas: 500 mL/min; Absorption T: 25^{o}C; water: 60% humidity at 20^{o}C;
- Desorption T: 110^{o}C

– Addition of catalyst greatly increases the adsorption amount.

Catalyst Addition to PEI/Silica Sorbent



Absorption conditions:

- Sorbent : 0.4 g;
- 400 ppm CO_2;
- Flow rate of gas: 500 mL/min; Absorption T: 25^{o}C; water: 60% humidity at 20^{o}C;
- Desorption T: 110^{o}C

– Addition of catalyst greatly improve DAC sorbent performance

– Catalyzed sorbents have 4 to 5 times longer breakthrough time

Plans for Future Testing and Development

- Synthesis of catalyzed baseline sorbents with varying amount of catalyst
- Sorbent DAC performance testing
- DAC process design
- TEA and EH&S Analysis

Plans for Commercialization

- Develop process design using catalyzed sorbents
- Conduct bench and pilot testing with catalyzed sorbents for DAC
- Scale-up of the catalyst to multi-kilogram scale (already in progress)
- Explore pilot testing of catalyst with amines-based systems
- Develop a compelling value proposition
- Set up partnerships with leading amine solvent/sorbent technology providers

Summary and Conclusions

- Susteon's patented ionic liquid catalyst demonstrated improvement in CO_2 adsorption capacity of amine sorbents by ~50% with much longer breakthrough times.
- This catalyst improves a desorption rate by up to 80%.
- This catalyst has been successfully scaled up to kilogram scale.
- **Catalyst can be added to any amine-based sorbents or solvents for improved sorption and desorption kinetics.**

Susteon

Acknowledgement

- Department of Energy (DOE/NETL)
- DOE Project Manager: Carl Laird

NATIONAL ENERGY TECHNOLOGY LABORATORY

- SoCalGas

SoCalGas
A Sempra Energy utility

- University of Wyoming

UNIVERSITY OF WYOMING

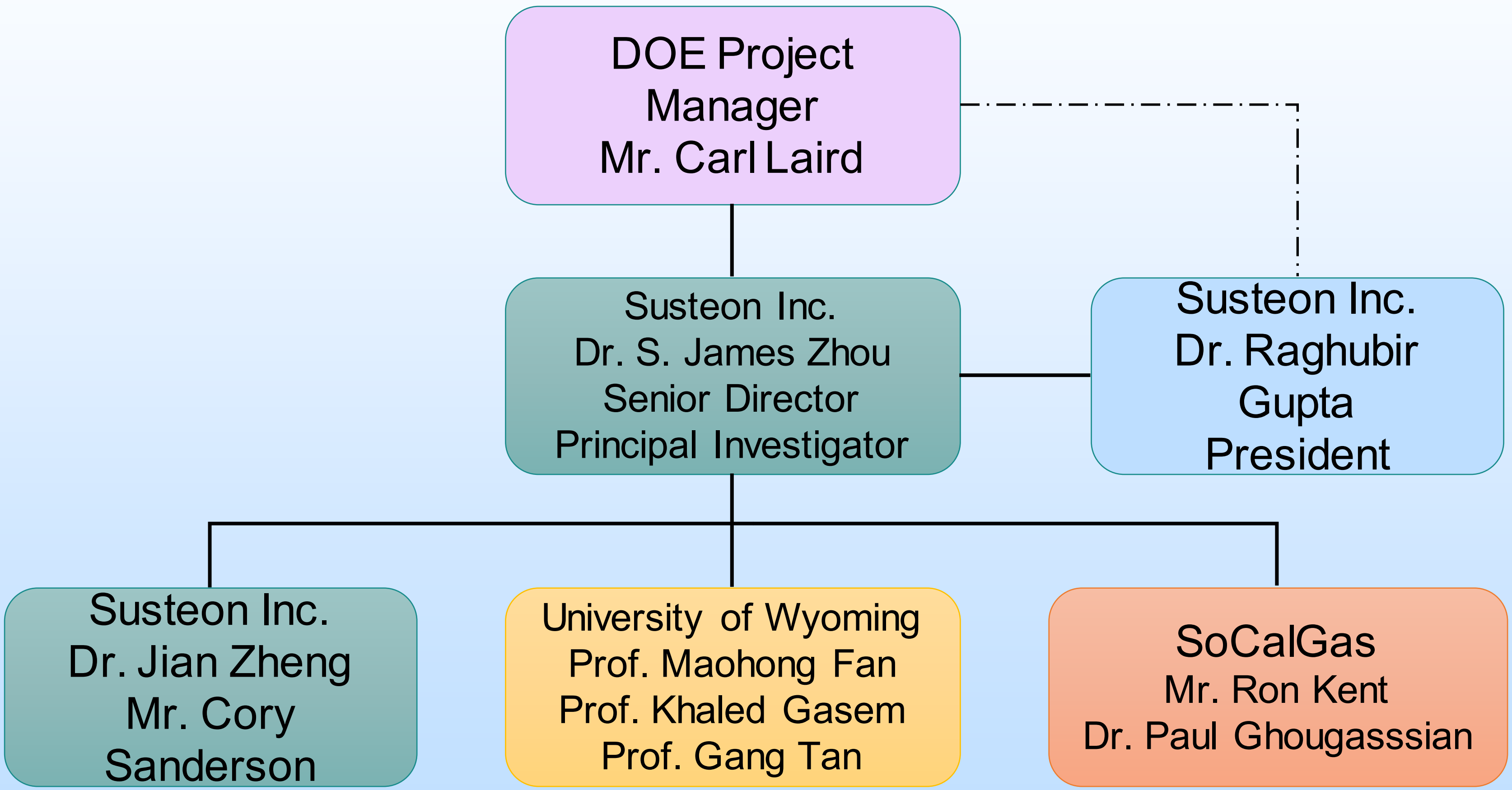
Acknowledgement
This material is based upon work supported by the Department of Energy under Award Number DE-FE0031965.

Disclaimer
This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

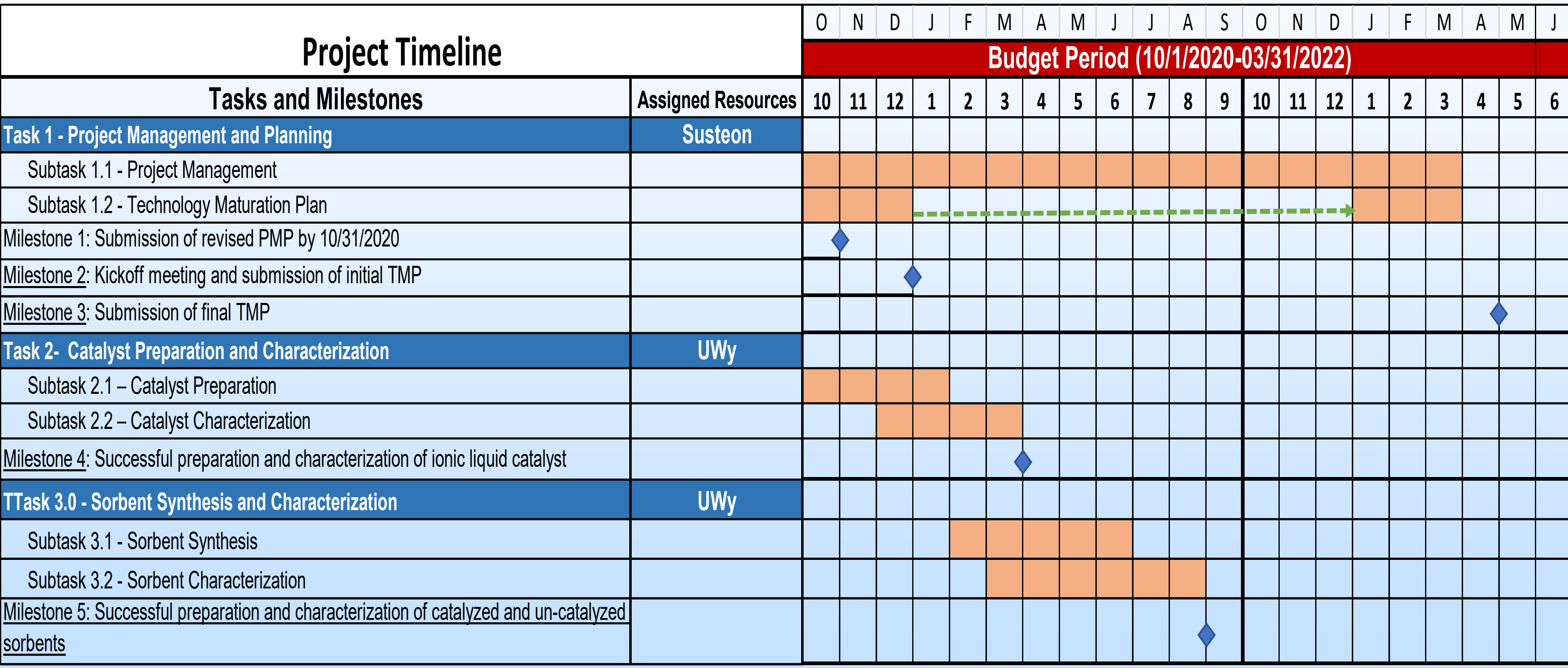
Appendix

– These slides will not be discussed during the presentation but are mandatory.

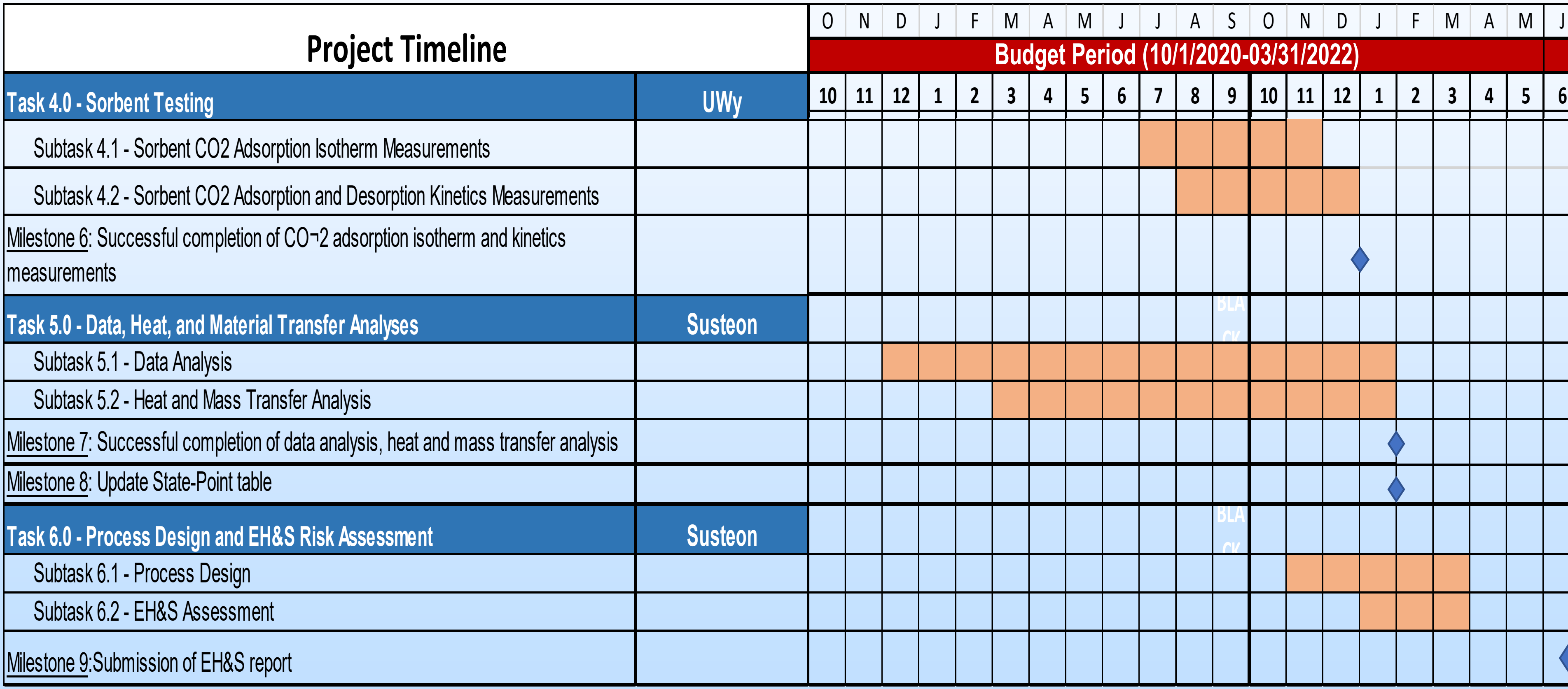
Organization Chart



Gantt Chart


Project Timeline
O N D J F M A M J J A S O N D J F M A M J
Budget Period (10/1/2020-03/31/2022)
Tasks and Milestones
Assigned Resources
10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6
Task 1 - Project Management and Planning
Susteon
Subtask 1.1 - Project Management
Subtask 1.2 - Technology Maturation Plan
Milestone 1: Submission of revised PMP by 10/31/2020
Milestone 2: Kickoff meeting and submission of initial TMP
Milestone 3: Submission of final TMP
Task 2- Catalyst Preparation and Characterization
UWy
Subtask 2.1 – Catalyst Preparation
Subtask 2.2 – Catalyst Characterization
Milestone 4: Successful preparation and characterization of ionic liquid catalyst
TTask 3.0 - Sorbent Synthesis and Characterization
UWy
Subtask 3.1 - Sorbent Synthesis
Subtask 3.2 - Sorbent Characterization
Milestone 5: Successful preparation and characterization of catalyzed and un-catalyzed sorbents

Gantt Chart



Project Timeline
O N D J F M A M J J A S O N D J F M A M J
Budget Period (10/1/2020-03/31/2022)
Task 4.0 - Sorbent Testing
UWy
10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6
Subtask 4.1 - Sorbent CO2 Adsorption Isotherm Measurements
Subtask 4.2 - Sorbent CO2 Adsorption and Desorption Kinetics Measurements
Milestone 6: Successful completion of CO¬2 adsorption isotherm and kinetics measurements
Task 5.0 - Data, Heat, and Material Transfer Analyses
Susteon
Subtask 5.1 - Data Analysis
Subtask 5.2 - Heat and Mass Transfer Analysis
Milestone 7: Successful completion of data analysis, heat and mass transfer analysis
Milestone 8: Update State-Point table
Task 6.0 - Process Design and EH&S Risk Assessment
Susteon
Subtask 6.1 - Process Design
Subtask 6.2 - EH&S Assessment
Milestone 9:Submission of EH&S report