Low Regeneration Temperature Sorbent for Direct Air Capture of CO_2

DE-FE0031965

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Susteon

U.S. Department of Energy

National Energy Technology Laboratory

Carbon Management Project Review Meeting

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Project Overview

Title	**Low Regeneration Temperature Sorbents for Direct Air Capture of CO_2**
Award No.	DE-FE0031965
Period of Performance	10/01/2020 – 09/30/2022
Project Funding	DOE: $799,687 Cost-Share: $200,000
Overall Project Goal	Development of solid sorbents with fast kinetics and low regeneration temperature catalyzed by an ionic liquid for direct air capture of CO_2 to reduce energy consumption for sorbent regeneration and hence lower the cost of DAC
Project Participants	Susteon Inc., University of Wyoming, and SoCalGas
DOE/NETL Project Manager	Mr. Carl Laird

Technology Background

- The pioneering research work on this discovery was published by University of Wyoming's (UW's) in Nature Communications (2018, Vol 9, PP 2672-2678).
- UW's CO_2 capture and utilization research has been supported by Siemens, NSF, and DOE.
- UW has extensive laboratory facilities for sorbent/catalyst synthesis, characterization, and testing.
- Susteon acquired a license to UW's IP on ionic liquids.

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ARTICLE

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Catalyst-$TiO(OH)_2$ could drastically reduce the energy consumption of CO_2 capture

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Implementing Paris Climate Accord is inhibited by the high energy consumption of the state-of-the-art CO_2 capture technologies due to the notoriously slow kinetics in CO_2 desorption step of CO_2 capture. To address the challenge, here we report that nanostructured $TiO(OH)_2$ as a catalyst is capable of drastically increasing the rates of CO_2 desorption from spent monoethanolamine (MEA) by over 4500%. This discovery makes CO_2 capture successful at much lower temperatures, which not only dramatically reduces energy consumption but also amine losses and prevents emission of carcinogenic amine-decomposition byproducts. The catalytic effect of $TiO(OH)_2$ is observed with Raman characterization. The stabilities of the catalyst and MEA are confirmed with 50 cyclic CO_2 sorption and sorption. A possible mechanism is proposed for the $TiO(OH)_2$-catalyzed CO_2 capture. $TiO(OH)_2$ could be a key to the future success of Paris Climat e Accord.

Technical Approach

- **Scale up Ionic Liquid Catalyst Production**
  - Characterization of large batch produced and compare it with the lab scale IL catalyst
- **Synthesis of IL Catalyzed Amine-based Sorbents on Various Supports**
  - Increase sorbent CO_2 working capacity
  - Higher process productivity in tons of CO_2/day/m^3 structured sorbent volume
  - Significantly enhance adsorption and desorption kinetics
  - Lower the sorbent desorption temperature
  - Lower energy for sorbent regeneration
- **Testing of IL Catalyzed and Non-Catalyzed Sorbents**
  - Performance comparison
- **Process Design**
  - Determine overall cost of DAC and cost reduction from the current and emerging technologies

Our Approach for Reduction of Regeneration Energy

- By increasing the desorption rate significantly at temperatures below 100ºC, we can lower the sorbent regeneration temperature
- Lower regeneration temperatures (~85ºC) will
  - Open a pathway to use waste heat to regenerate the sorbent
  - Reduce the amount of water evaporated from the sorbent
  - Reduce the degradation of amine by oxidation
  - Consequently, reduce the overall DAC cost
- Addition of ppm quantities of ionic liquid to amine solvents/sorbents has been demonstrated to significantly enhance the CO_2 adsorption and desorption rates
- These findings were published in Nature Communications.
- Four patents have been filed on this technology.

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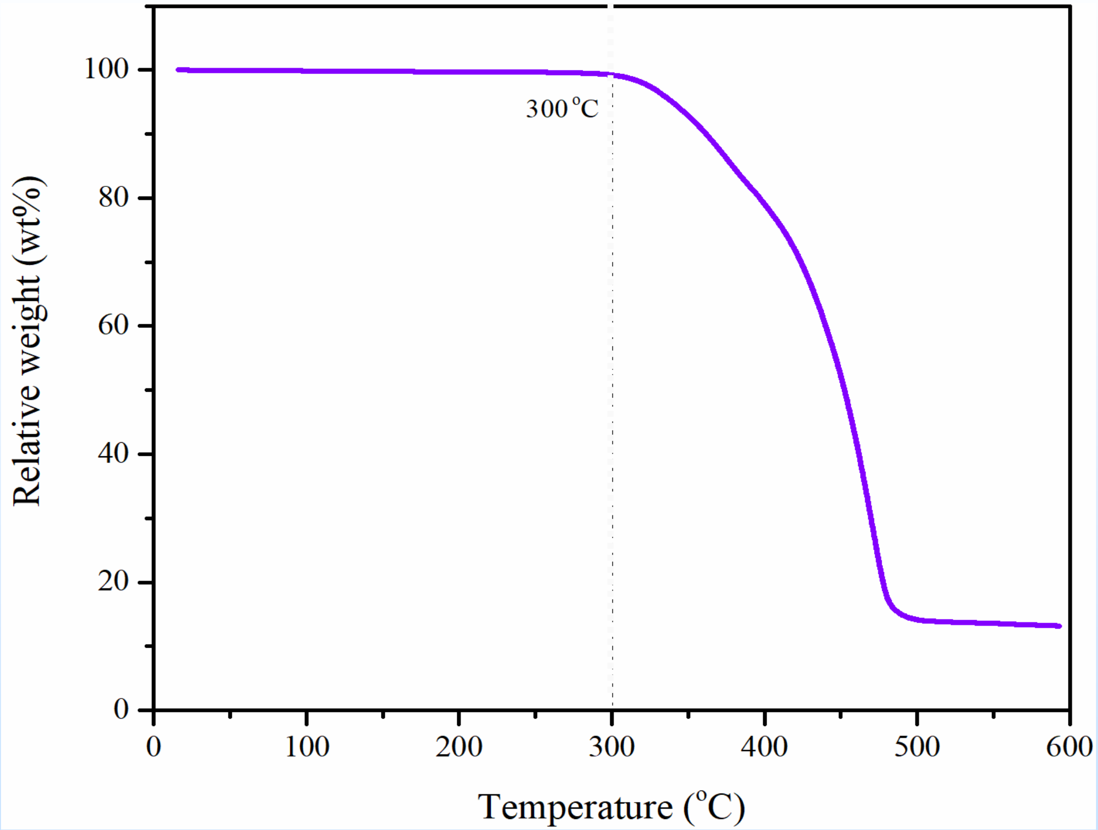
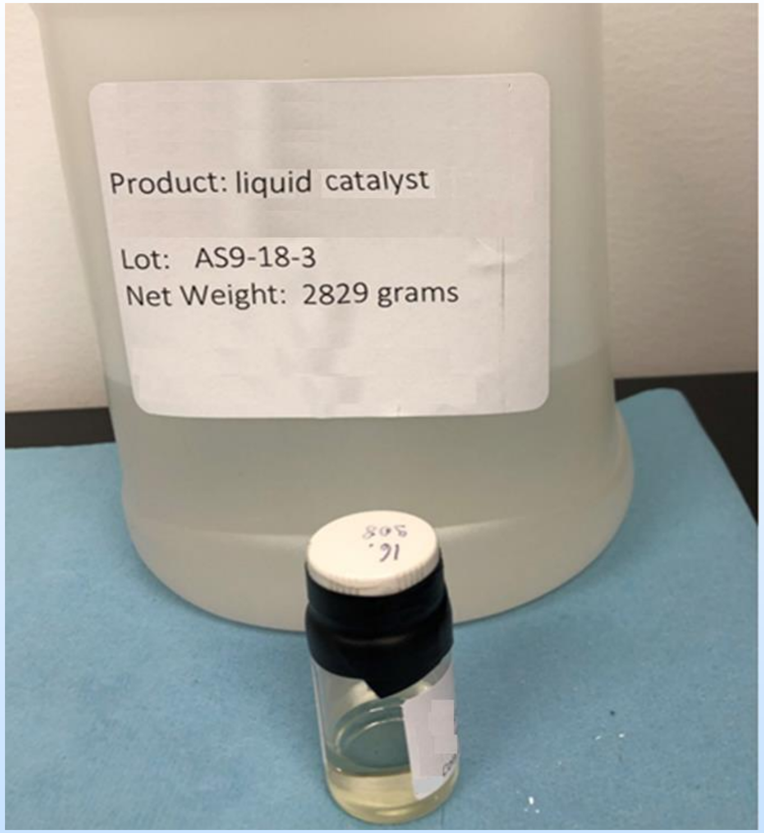
Catalyst Scale Up and Characterization





- The catalyst synthesis method was scaled up from gram quantity in the lab to kilogram quantities.
- 10 kg of catalyst were synthesized for larger scale testing and laboratory use by a US manufacturer.
- The catalyst was characterized using FT-IR, NMR (^{1}H, ^{13}C), and MS
- Results show that the large batch IL is identical with the lab synthesized IL catalyst
- The catalyst is stable up to 300°C.

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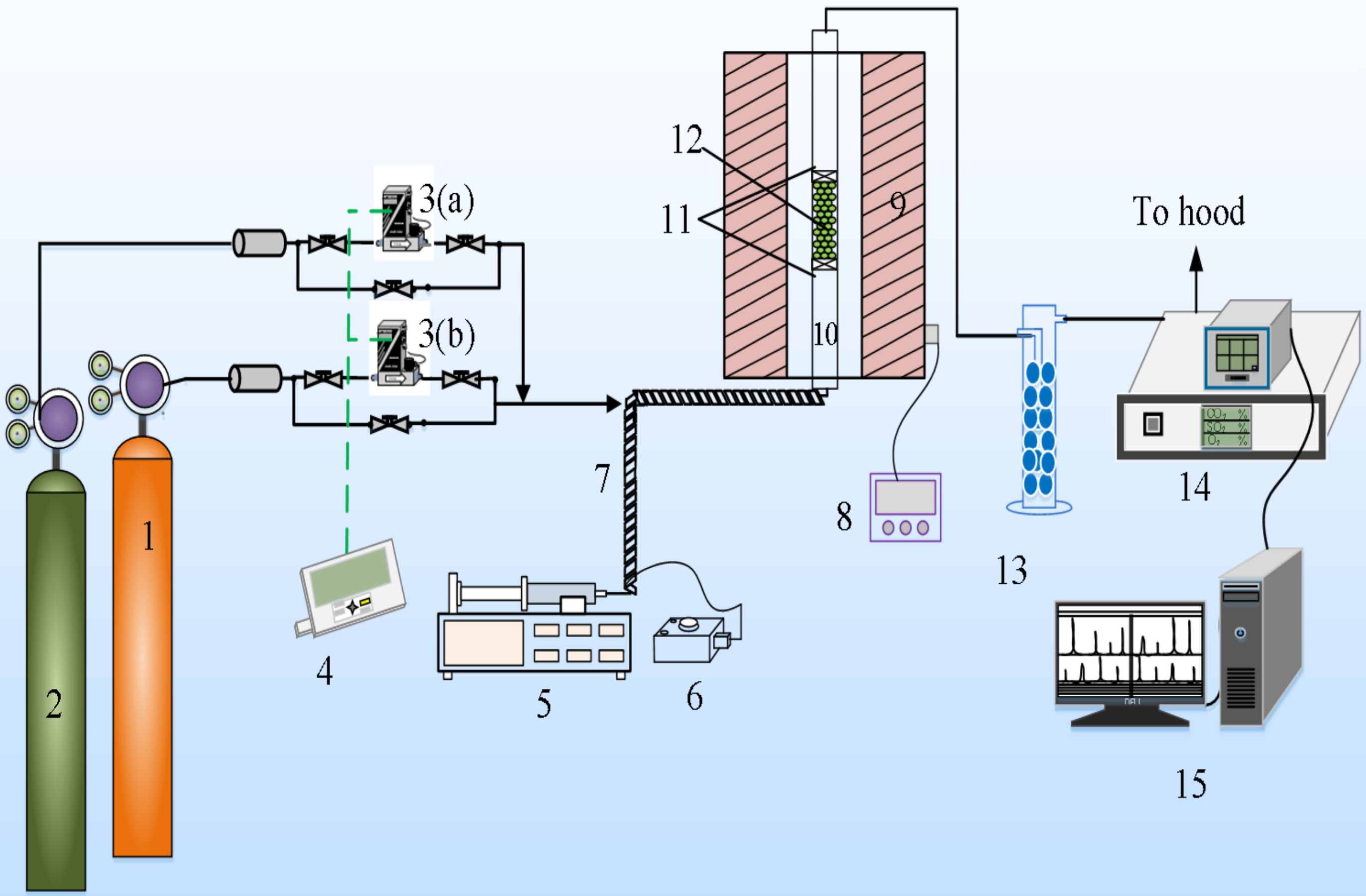
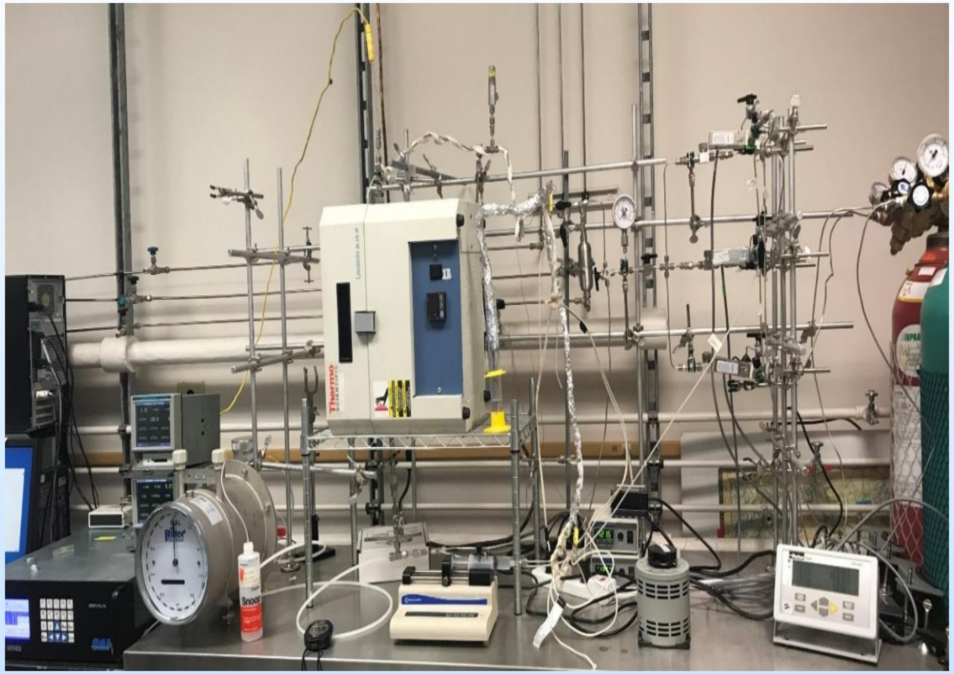
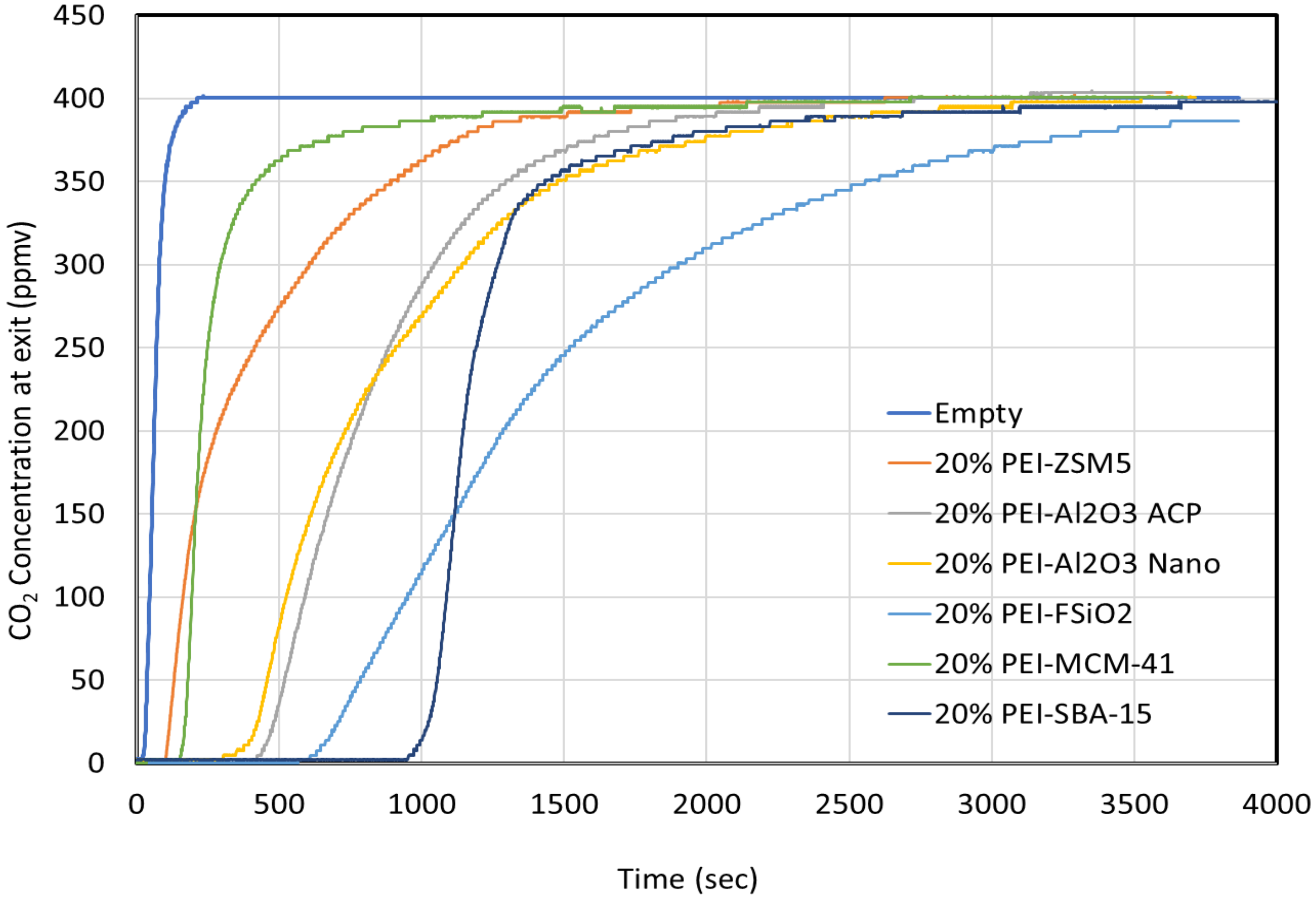
Direct Air Capture Test Apparatus





Baseline Sorbent Performance



- 20% PEI/$FSiO_2$ shows the highest CO_2 adsorption capacity.
- 20% PEI/SBA-15 shows the longest breakthrough time.

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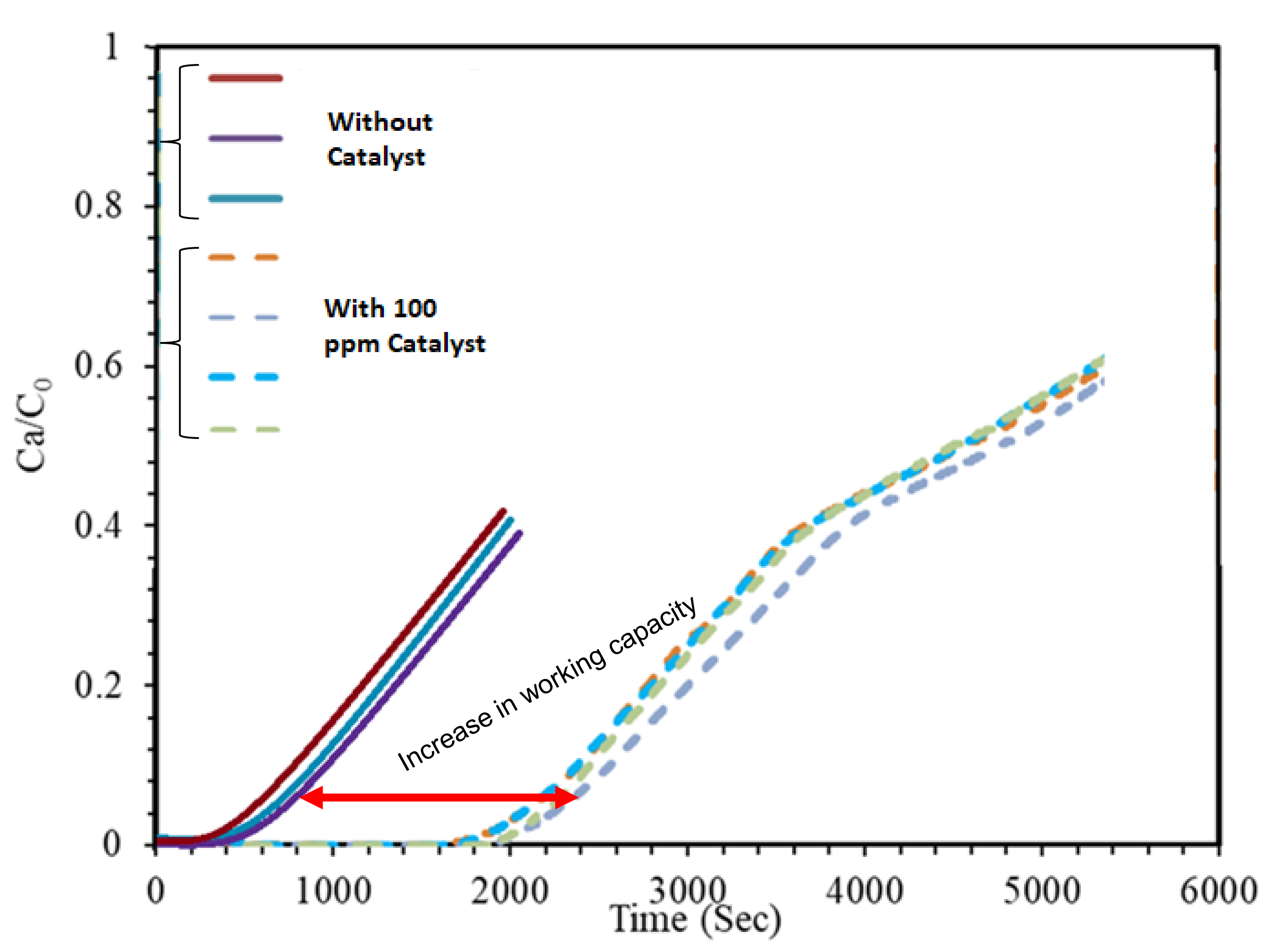
IL Catalyst Addition to Commercial PEI/Silica Sorbent



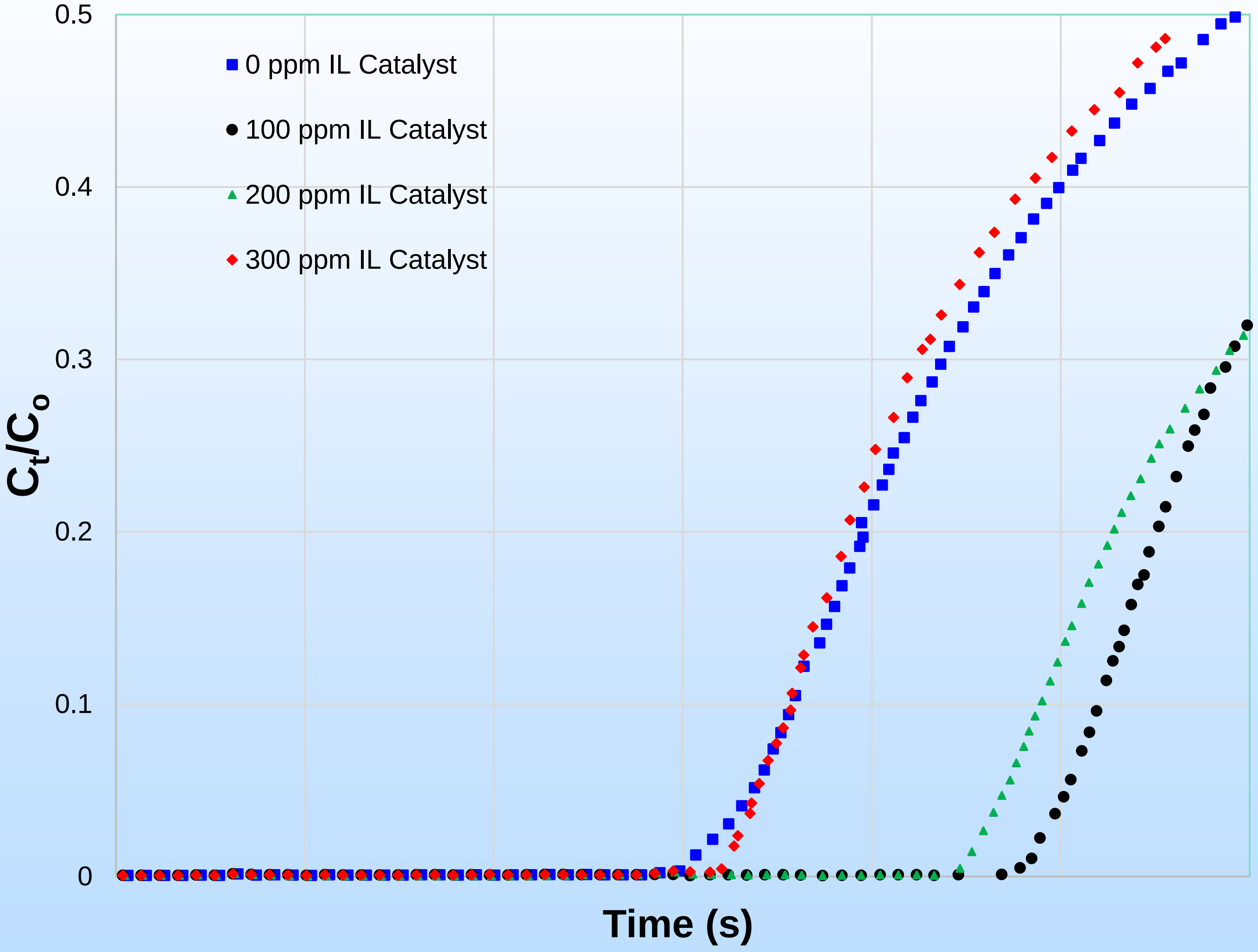
Absorption conditions:

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

– Addition of catalyst greatly improved DAC sorbent performance.

– Catalyzed sorbents have 8 times longer breakthrough time and hence higher working capacity.

Effect of Catalyst Concentration on CO_2 Adsorption



- Sorbent with 100ppm IL catalyst showed the best CO_2 adsorption performance.
- The increase of the catalyst loading from 100ppm to 200ppm slightly decreased the adsorption performance.
- The increase of the catalyst loading to 300ppm further decreased the adsorption performance.

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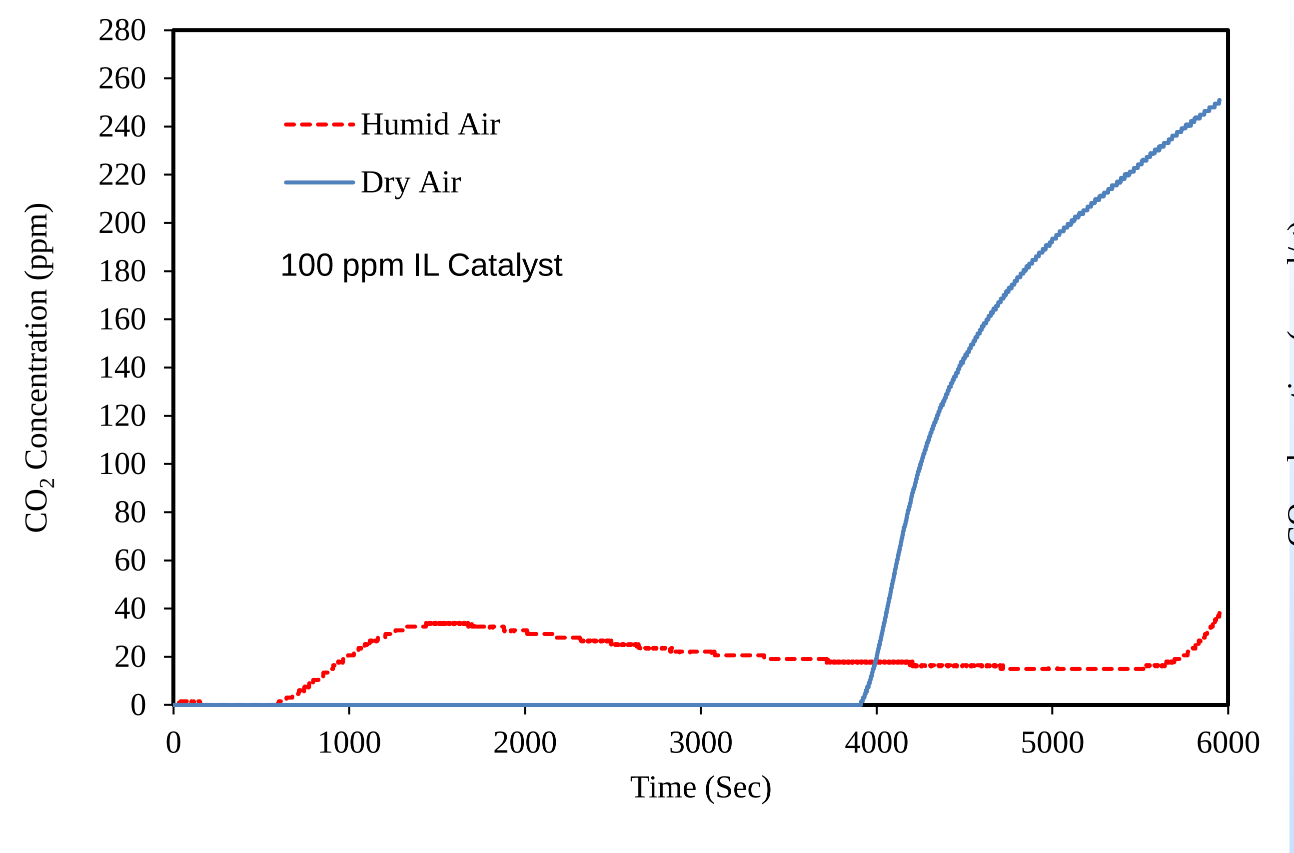
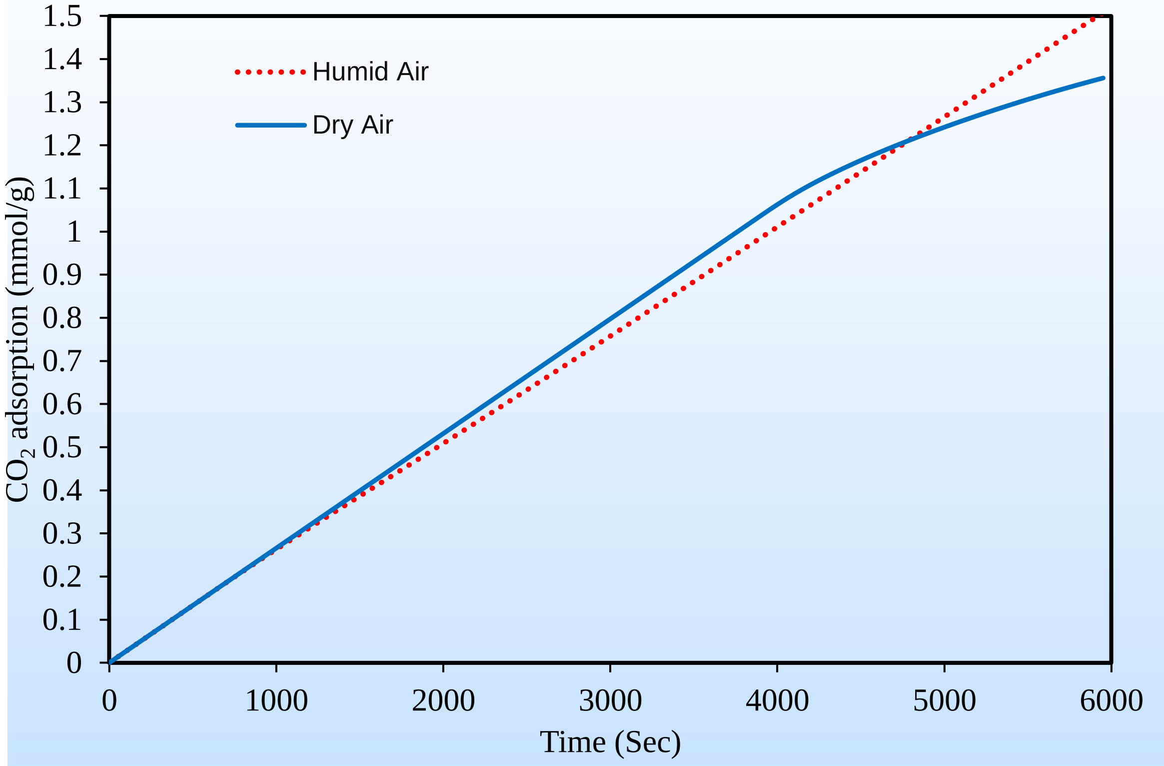
Effect of Humidity on CO_2 Adsorption





- Humid air (~100% RH) significantly increased (by >90%) IL catalyzed DAC sorbent CO_2 capture efficiency
- IL catalyzed sorbent has 2X CO_2 working capacity

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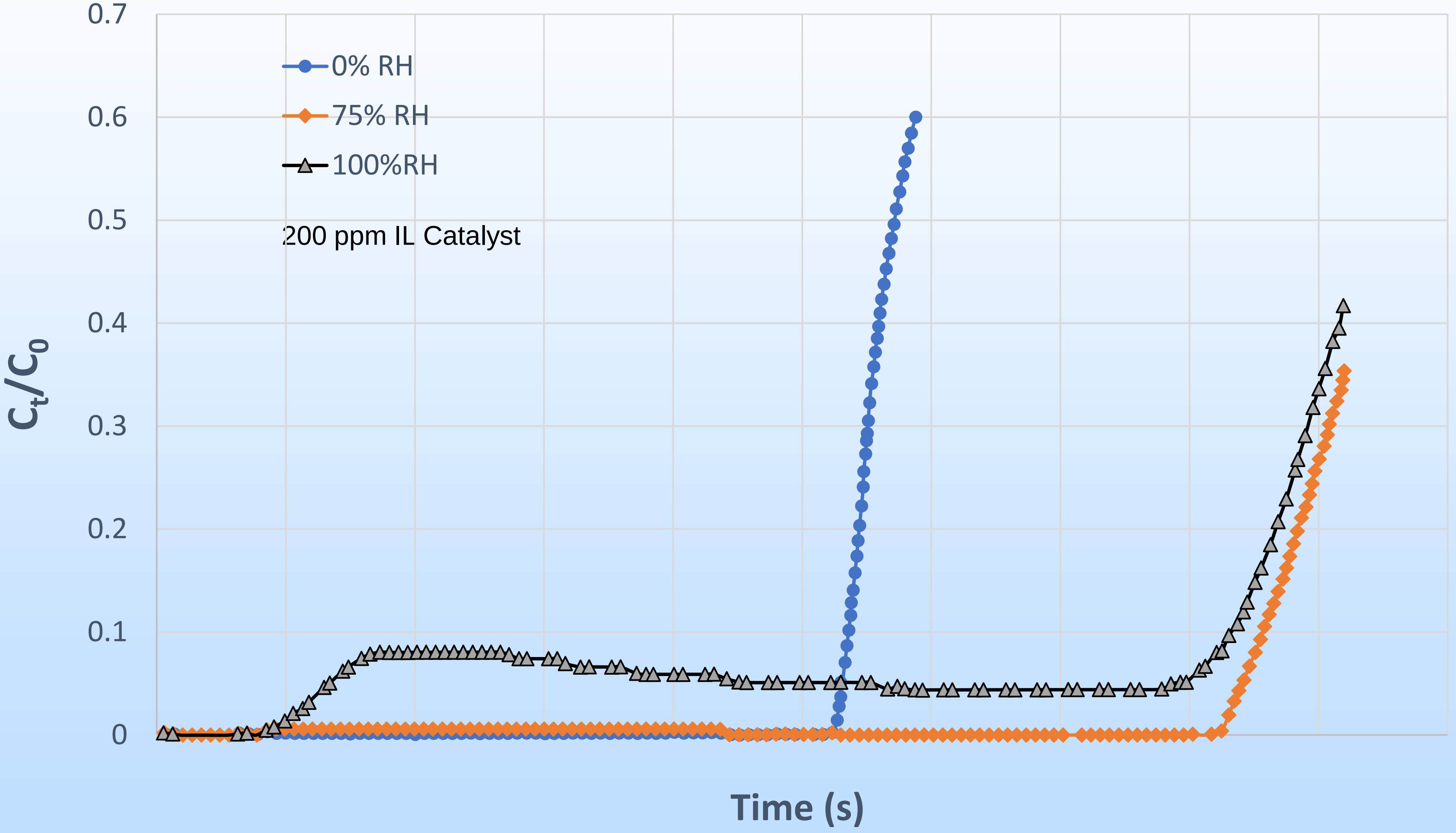
Effect of Humidity on CO_2 Adsorption



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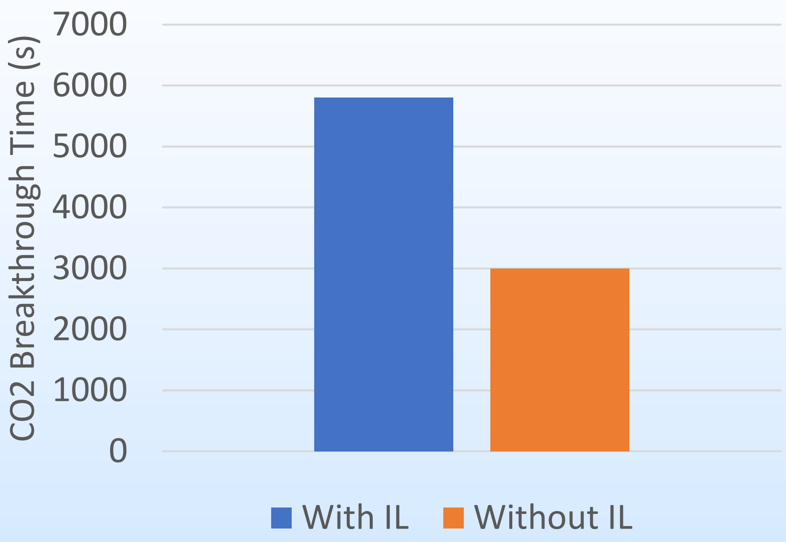
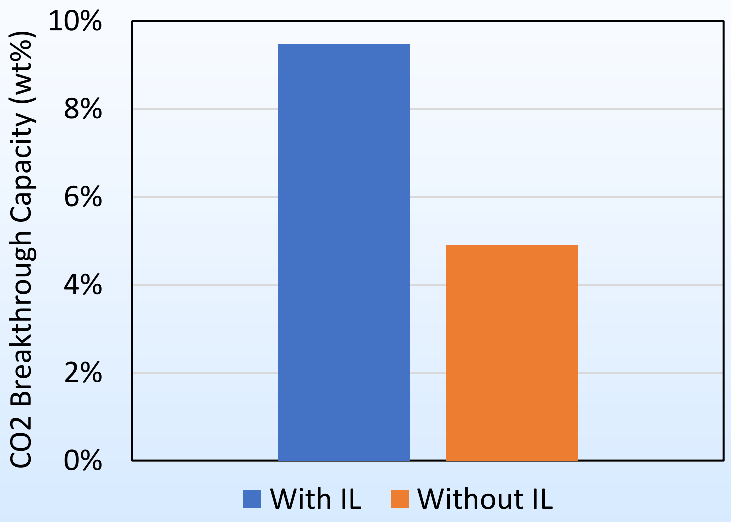
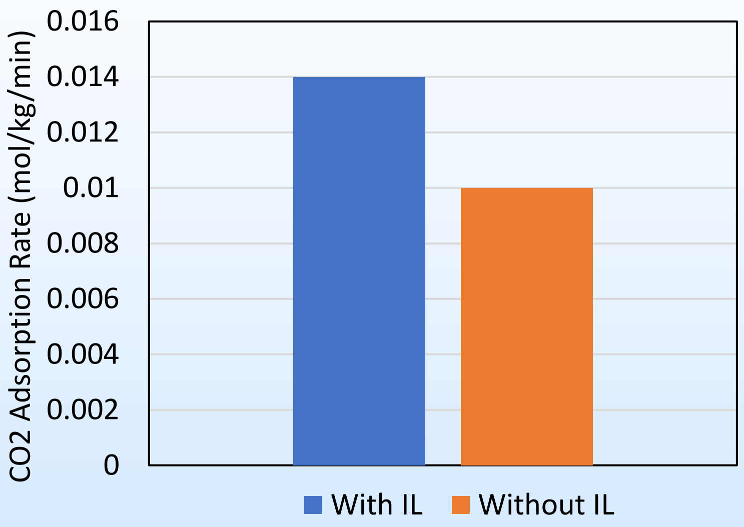
Working Capacity of PEI/Silica DAC Sorbent



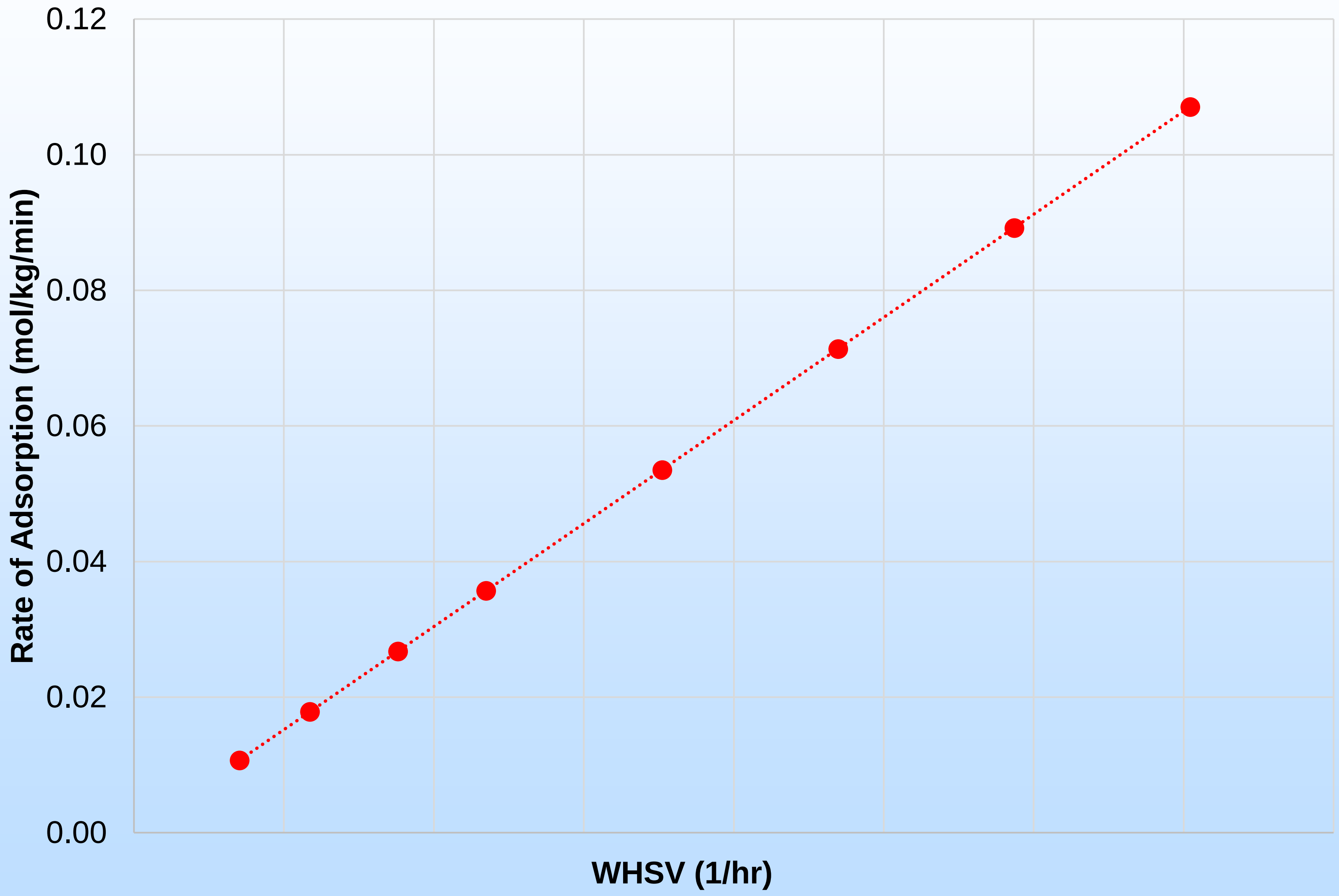




Parameters	Unit	With IL	Without IL	% Increase
IL Catalyst	*ppmw*	100	0	-
Breakthrough time	*sec*	5800	3000	93%
CO_2 capacity at breakthrough at 0 ppm	*wt%*	9.49%	4.91%	93%
Rate of CO_2 adsorption	*mol/kg/min*	0.014	0.010	40%

Catalyzed Sorbent CO_2 Adsorption Rate

- Rate of adsorption is mass transfer limited
- Reaction of CO_2 with sorbent is fast and not limiting
- Rate of adsorption is thus only limited by pressure drop through air contactor



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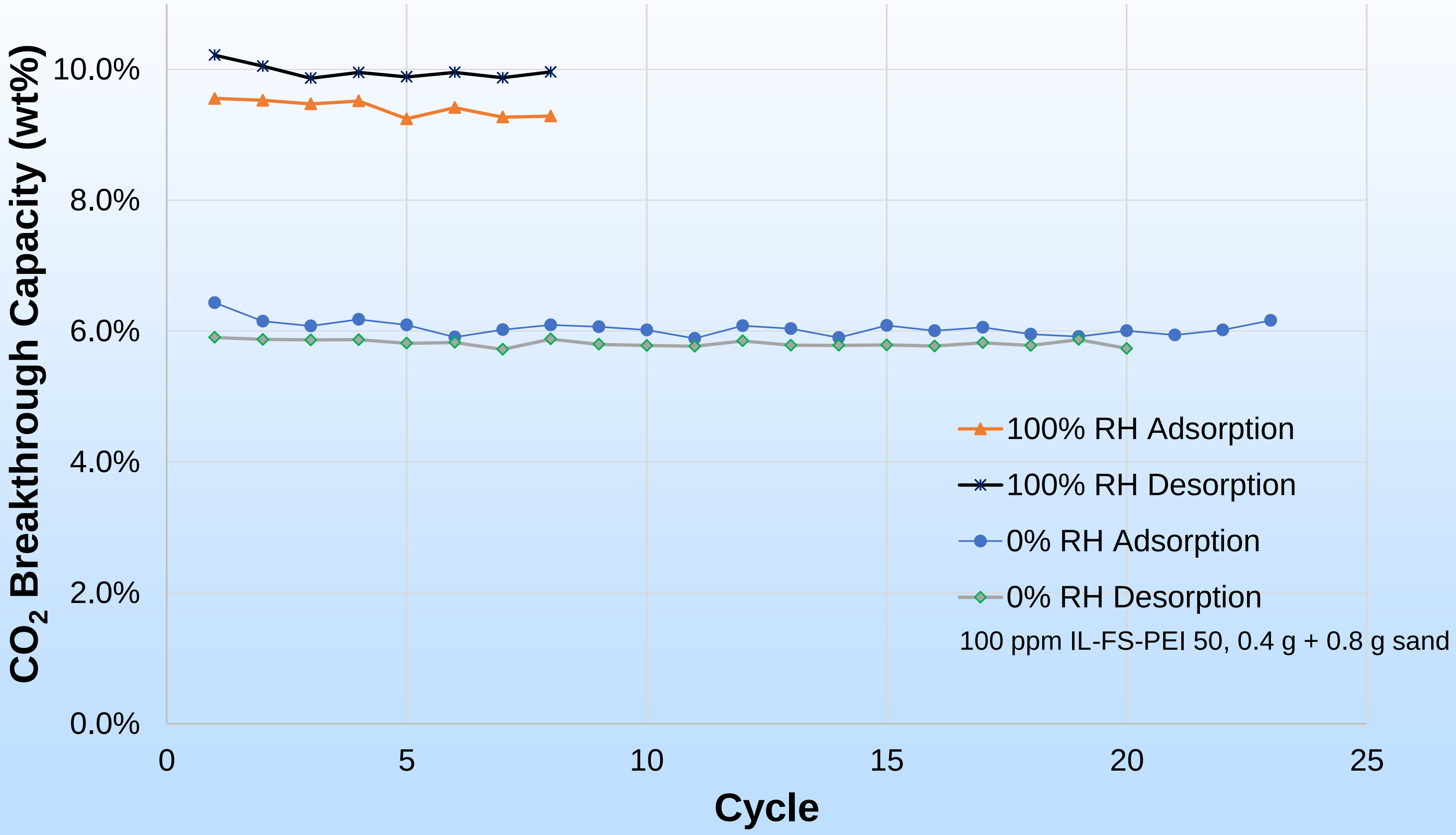
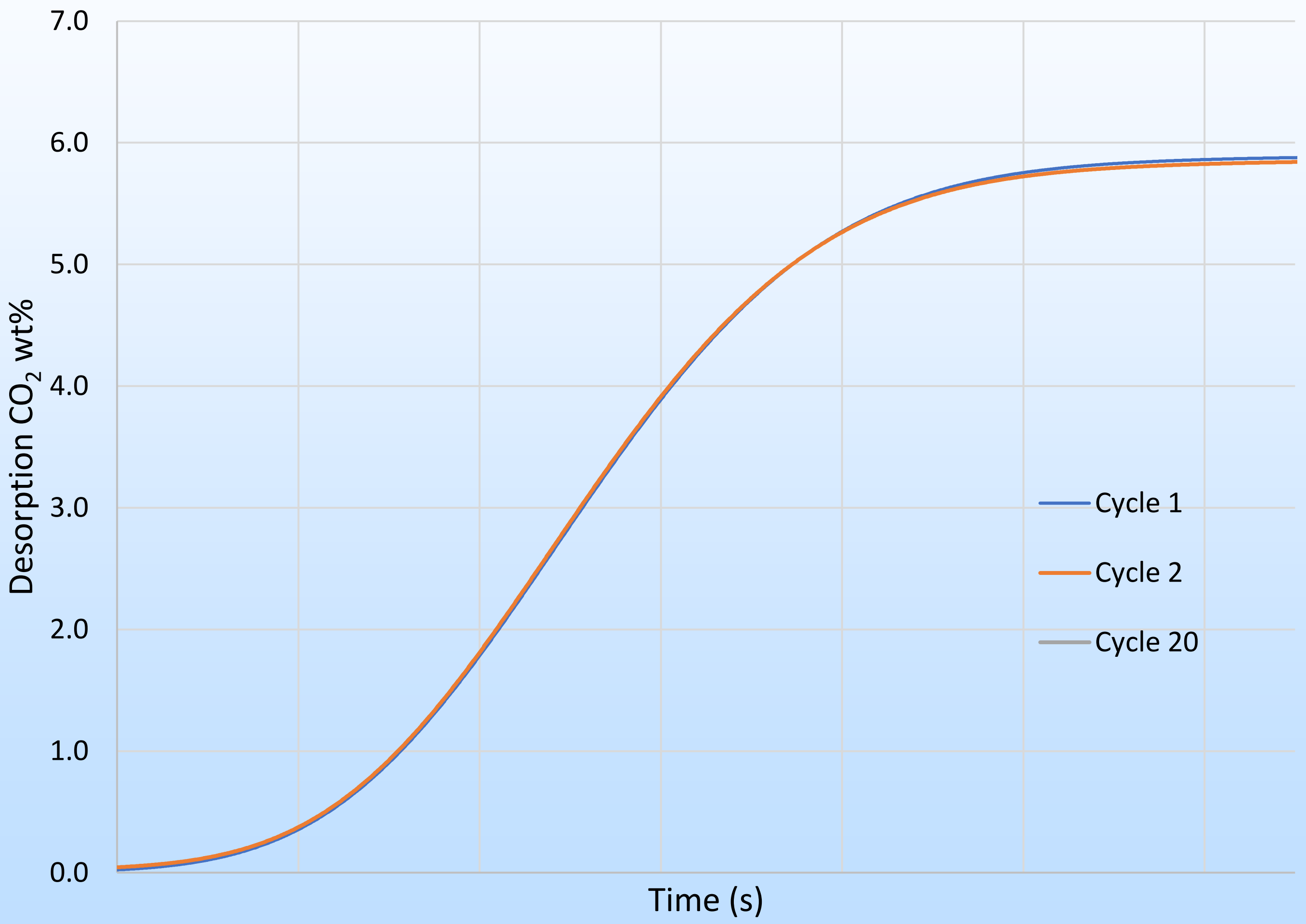
Catalyzed Sorbent Cyclic Stability



Catalyzed Sorbent CO_2 Desorption Rate Stability



	Desorption Rate
	g CO_2/(g Sorbent x s)
Cycle 1	9.96E-05
Cycle 2	1.14E-04
Cycle 20	1.09E-04

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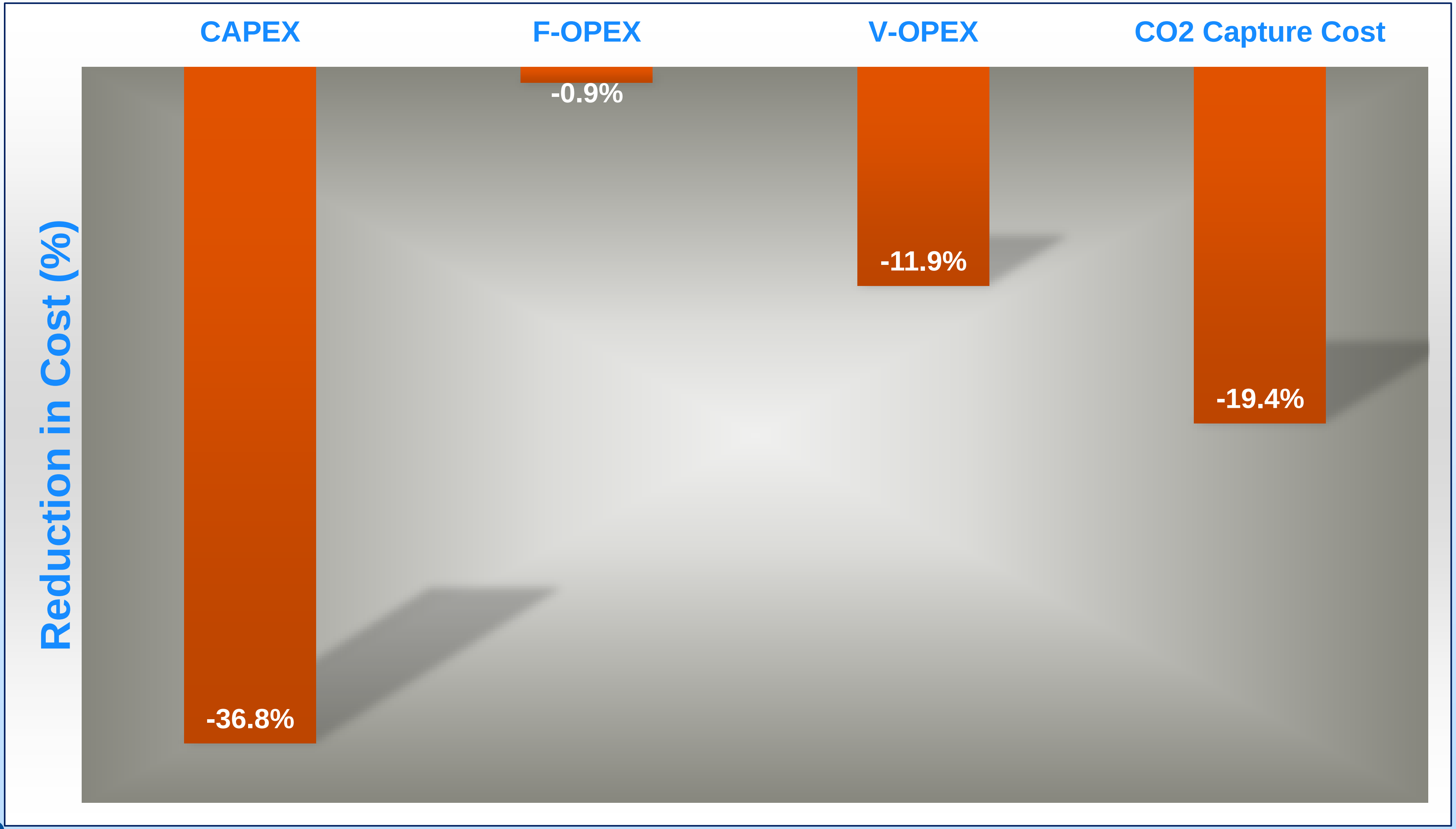
Cost Reduction with IL Catalyzed Sorbent



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Summary and Conclusions

- Susteon's patented ionic liquid catalyst demonstrated improvement in CO_2 adsorption capacity of amine sorbents by ~50 to 100% with much longer breakthrough times.
- The catalyst improves adsorption and desorption rates by up to 80%.
- Catalyzed sorbents have much higher cyclic CO_2 working capacity up to 11 wt%.
- The catalyst has been successfully scaled up to kilogram scale.
- Catalyzed sorbents have stable cyclic CO_2 capacity

- **Catalyst can be added to any amine-based sorbents or solvents for improved sorption and desorption kinetics.**

Remaining Work

- Complete process design and process model
- Process material and energy balance
- Process EH&S analysis
- Final TMP

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Acknowledgement

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

- SoCalGas

- University of Wyoming

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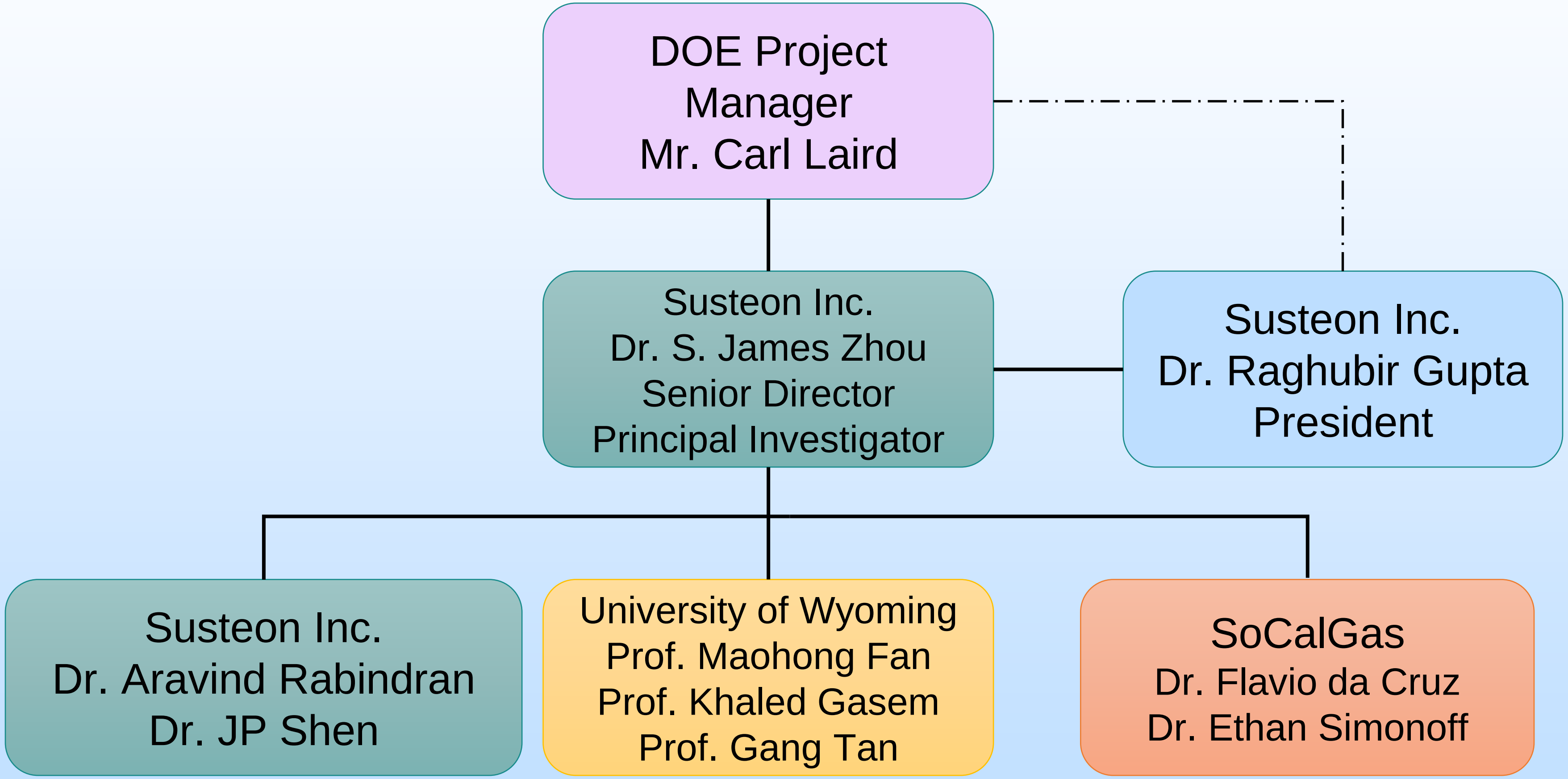
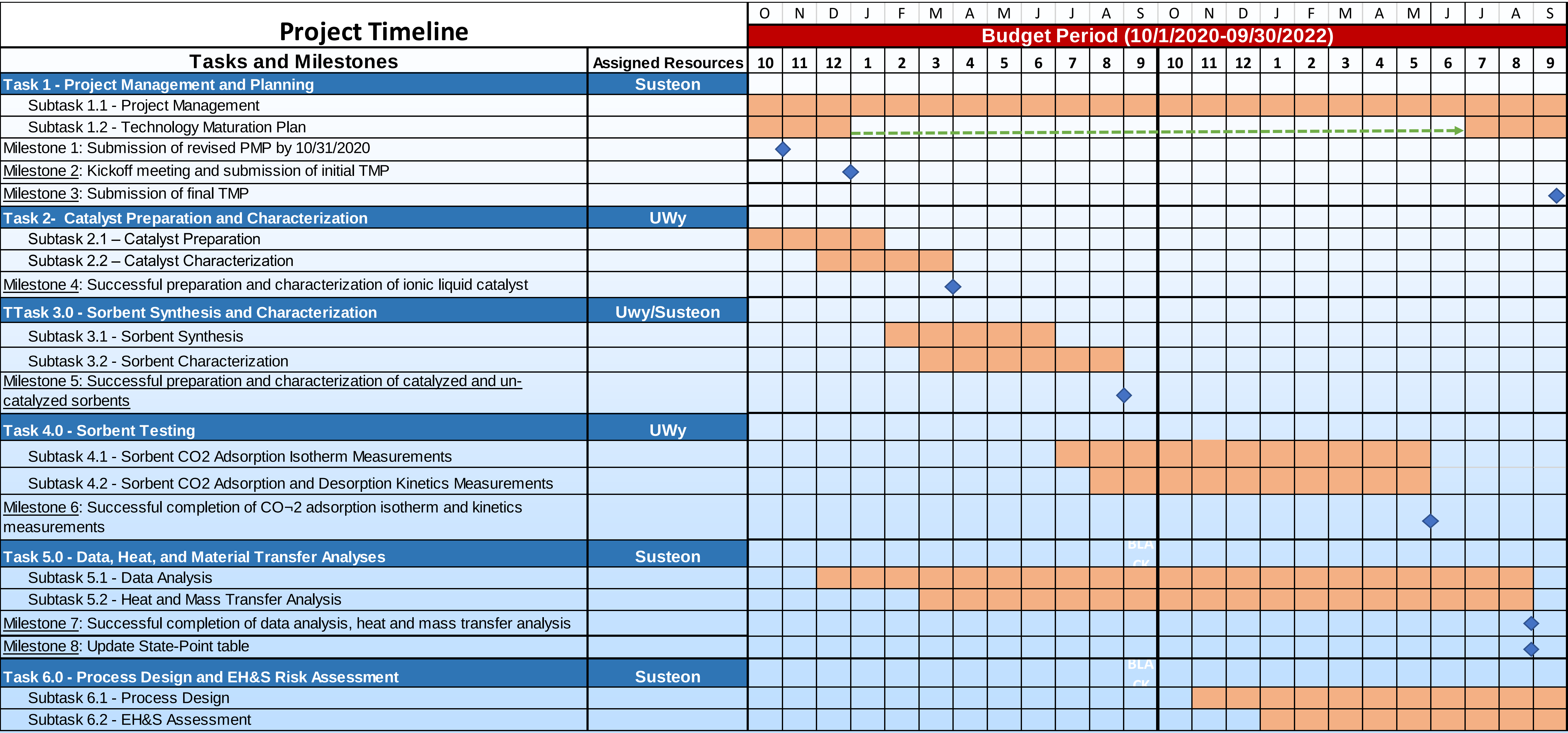
Appendix

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

Organization Chart



Gantt Chart


Project Timeline
Budget Period (10/1/2020-09/30/2022)
O N D J F M A M J J A S O N D J F M A M J J A S
10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9
Tasks and Milestones
Assigned Resources
Task 1 - Project Management and Planning
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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/Susteon
Subtask 3.1 - Sorbent Synthesis
Subtask 3.2 - Sorbent Characterization
Milestone 5: Successful preparation and characterization of catalyzed and un-catalyzed sorbents
Task 4.0 - Sorbent Testing
UWy
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
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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
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Subtask 6.1 - Process Design
Subtask 6.2 - EH&S Assessment