Low Regeneration Temperature Sorbent for Direct Air Capture of CO₂
DE-FE0031965
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U.S. Department of Energy
National Energy Technology Laboratory
Carbon Management Project Review Meeting
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# Project Overview

<table>
<thead>
<tr>
<th>Title</th>
<th>Low Regeneration Temperature Sorbents for Direct Air Capture of CO$_2$</th>
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</thead>
<tbody>
<tr>
<td>Award No.</td>
<td>DE-FE0031965</td>
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<tr>
<td>Period of Performance</td>
<td>10/01/2020 – 09/30/2022</td>
</tr>
<tr>
<td>Project Funding</td>
<td>DOE: $799,687 Cost-Share: $200,000</td>
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<tr>
<td>Overall Project Goal</td>
<td>Development of solid sorbents with fast kinetics and low regeneration temperature catalyzed by an ionic liquid for direct air capture of CO$_2$ to reduce energy consumption for sorbent regeneration and hence lower the cost of DAC</td>
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<tr>
<td>Project Participants</td>
<td>Susteon Inc., University of Wyoming, and SoCalGas</td>
</tr>
<tr>
<td>DOE/NETL Project Manager</td>
<td>Mr. Carl Laird</td>
</tr>
</tbody>
</table>
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 CO₂ 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.
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 CO₂ adsorption and desorption rates

• These findings were published in Nature Communications.

• Four patents have been filed on this technology.
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.
Direct Air Capture Test Apparatus
Baseline Sorbent Performance

- 20% PEI/FSiO₂ shows the highest CO₂ adsorption capacity.
- 20% PEI/SBA-15 shows the longest breakthrough time.
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\textsubscript{2} Adsorption

- Sorbent with 100ppm IL catalyst showed the best CO\textsubscript{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.
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
Effect of Humidity on CO$_2$ Adsorption

Time (s)

$\frac{c_f}{c_0}$

- 0% RH
- 75% RH
- 100% RH

200 ppm IL Catalyst
Working Capacity of PEI/Silica DAC Sorbent

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>With IL</th>
<th>Without IL</th>
<th>% Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL Catalyst</td>
<td>ppmw</td>
<td>100</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Breakthrough time</td>
<td>sec</td>
<td>5800</td>
<td>3000</td>
<td>93%</td>
</tr>
<tr>
<td>CO₂ capacity at breakthrough at 0 ppm</td>
<td>wt%</td>
<td>9.49%</td>
<td>4.91%</td>
<td>93%</td>
</tr>
<tr>
<td>Rate of CO₂ adsorption</td>
<td>mol/kg/min</td>
<td>0.014</td>
<td>0.010</td>
<td>40%</td>
</tr>
</tbody>
</table>
• 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
Catalyzed Sorbent Cyclic Stability

CO$_2$ Breakthrough Capacity (wt%) vs Cycle

- 100% RH Adsorption
- 100% RH Desorption
- 0% RH Adsorption
- 0% RH Desorption

100 ppm IL-FS-PEI 50, 0.4 g + 0.8 g sand
Catalyzed Sorbent CO$_2$ Desorption Rate Stability

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Desorption Rate g CO$_2$/g Sorbent s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle 1</td>
<td>9.96E-05</td>
</tr>
<tr>
<td>Cycle 2</td>
<td>1.14E-04</td>
</tr>
<tr>
<td>Cycle 20</td>
<td>1.09E-04</td>
</tr>
</tbody>
</table>
Cost Reduction with IL Catalyzed Sorbent

- CAPEX: -36.8%
- F-OPEX: -0.9%
- V-OPEX: -11.9%
- CO2 Capture Cost: -19.4%
Summary and Conclusions

• Susteon’s patented ionic liquid catalyst demonstrated improvement in CO₂ 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 CO₂ working capacity up to 11 wt%.
• The catalyst has been successfully scaled up to kilogram scale.
• Catalyzed sorbents have stable cyclic CO₂ 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
Acknowledgement

Financial and Technical Support

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

- SoCalGas

- University of Wyoming
Acknowledgement
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Appendix

- These slides will not be discussed during the presentation but are mandatory.
Organization Chart

DOE Project Manager
Mr. Carl Laird

Susteon Inc.
Dr. S. James Zhou
Senior Director
Principal Investigator

Susteon Inc.
Dr. Raghubir Gupta
President

University of Wyoming
Prof. Maohong Fan
Prof. Khaled Gasem
Prof. Gang Tan

SoCalGas
Dr. Flavio da Cruz
Dr. Ethan Simonoff

Susteon Inc.
Dr. Aravind Rabindran
Dr. JP Shen
### Project Timeline

#### Tasks and Milestones

| Task 1 - Project Management and Planning | Assigned Resources | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Subtask 1.1 - Project Management        | Susteon            |    |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 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

| Subtask 2.1 – Catalyst Preparation | UWy |    |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Subtask 2.2 – Catalyst Characterization | |    |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Milestone 4: Successful preparation and characterization of ionic liquid catalyst | |    |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

#### Task 3.0 - Sorbent Synthesis and Characterization

| Subtask 3.1 - Sorbent Synthesis | UWy/Susteon |    |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Subtask 3.2 - Sorbent Characterization | |    |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Milestone 5: Successful preparation and characterization of catalyzed and uncatalyzed sorbents | |    |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

#### Task 4.0 - Sorbent Testing

| Subtask 4.1 - Sorbent CO2 Adsorption Isotherm Measurements | UWy |    |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Subtask 4.2 - Sorbent CO2 Adsorption and Desorption Kinetics Measurements | |    |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Milestone 6: Successful completion of CO2 adsorption isotherm and kinetics measurements | |    |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

#### Task 5.0 - Data, Heat, and Material Transfer Analyses

| Subtask 5.1 - Data Analysis | Susteon |    |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 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

| Subtask 6.1 - Process Design | Susteon |    |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Subtask 6.2 - EH&S Assessment | |    |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |