Bench-Scale Development of a Novel Direct Air Capture Technology Using High-Capacity Structured Sorbents

primary project goal

Susteon Inc., in partnership with Cormetech Inc. and Columbia University, is conducting bench-scale testing on a novel structured sorbent system for direct air capture (DAC). The project team is developing a structured material system (SMS) that integrates a highly dispersed sorbent with in situ desorption by direct electric heating and a low pressure drop structured support in order to reduce the overall cost of DAC by lowering energy consumption by approximately 50%.

technical goals

- Advance the novel SMS from the current Technology Readiness Level (TRL) 3 to TRL 4 to justify its scale-up and pilot test in a subsequent program.
- Optimize the sorbent and structured support to maximize CO_2 working capacity, capture/adsorption rate, and adsorbent stability.
- Design and build a bench-scale test unit to evaluate the SMS and determine engineering factors and scale-up parameters such as CO_2 working capacity, adsorption and desorption rates, desorption energy requirements, and cycle times.
- Evaluate desorption method and refine the current COMSOL-based desorption heating method model to design an energy-efficient, facile, and cost-effective means to integrate desorption energy into the SMS.
- Develop and validate a process model using lab- and bench-scale data.
- Perform techno-economic analysis (TEA) and life cycle analysis (LCA) studies to assess the potential of the novel structured sorbent to reduce the cost of DAC by more than 20% compared to current technologies.

technical content

DAC is a potentially scalable negative CO_2 emissions technology. Beyond the benefit of negative emissions, DAC technologies can use CO_2 for a wide variety of applications, ranging from CO_2 conversion to value-added products to geologic storage without expensive pipelines. The U.S. Department of Energy (DOE)—Office of Fossil Energy and Carbon Management (FECM)/National Energy Technology Laboratory (NETL), Office of Energy Efficiency and Renewable Energy (EERE), and Advanced Research Projects Agency-Energy (ARPA-E)—and industry are making significant investments in the development of these technologies. With the exception of those developed by three major providers (Carbon Engineering, Climeworks, and Global Thermostat), most DAC technologies are under bench-scale development. A majority of these are based on solid adsorbents, primarily containing amine (e.g., polyethylene imine [PEI]) as a reactive chemical agent for CO_2, and almost all of them are supported on a high surface area support material, like a silica and/or a metal organic framework (MOF). These materials are scientifically intriguing, but their scale-up to commercial quantities at a reasonable production cost and their limited selectivity

program area:
Carbon Dioxide Removal

ending scale:
Bench Scale

application:
Direct Air Capture

key technology:
Sorbents

project focus:
Structured Sorbent System with Direct Electric Heating for Desorption in DAC Process

participant:
Susteon Inc.

project number:
FE0032118

predecessor projects:
N/A

NETL project manager:
Dustin Brown
dustin.brown@netl.doe.gov

principal investigator:
Cory Sanderson
Susteon Inc.
ces@susteon.com

partners:
Cormetech Inc.;
Columbia University

start date:
10.01.2021

percent complete:
17%

for adsorbing CO_2 over water (H_2O) from air are major challenges standing in the way of commercialization for DAC applications. This project's technology uses alkali sorbents, primarily sodium-based materials on an alumina support. The CO_2 in this process is captured by the synergistic combination of physical adsorption by high surface area alumina support followed by chemisorption by sodium carbonate (Na_2CO_3).

At ambient temperatures, CO_2 chemisorption on Na_2CO_3 is highly favorable, bringing CO_2 concentration in air down from 415 to less than 25 parts per million-volume (ppmv), while at higher temperatures the reverse reaction is favored, decomposing sodium bicarbonate ($NaHCO_3$) into Na_2CO_3 and CO_2.

Susteon has been working with Columbia University for the last two years to develop dual-function materials for reactive CO_2 capture, both from flue gas and for reactive DAC applications (Small Business Innovation Research [SBIR] grant DE-SC0020795). This collaboration has led to the identification of unique sorbent materials that exhibit very desirable characteristics for DAC applications. It was found that moisture in the air significantly enhances the performance and stability of the sorbent, unlike MOF-based sorbents, which selectively adsorb H_2O over CO_2. A high degree of dispersion of Na_2CO_3 on high surface area alumina allows rapid adsorption and desorption rates. Using the sorbent compositions identified, a structured DAC sorbent system capable of capturing CO_2 from air at a rapid rate and high dynamic capacity was developed by washcoating a low pressure-drop monolithic structure while minimizing heat/energy needed to desorb the captured CO_2. In this project, the sorbent is being incorporated on commercially available monolith supports (for low-cost fabrication) to minimize pressure drop.

The major cost contributor to DAC is the high regeneration temperature and energy input requirement for CO_2 desorption. In the case of Susteon's DAC technology, favorable sorbent characteristics enable CO_2 to be desorbed below 120°C with heat generated using renewable electricity. Relying purely upon temperature-swing adsorption, this technology does not require partial pressure difference as a driving force for desorption, as is the case with other amine-based DAC sorbents that use steam to lower the CO_2 partial pressure. This enables energy savings via lowered temperature requirements for sorbent regeneration and a reduction in auxiliary energy requirements such as vacuum and steam generation.

One of the key components of the SMS in Susteon's DAC technology is an electrical heating component that enables selective heating of the sorbent to facilitate CO_2 desorption. Selective heating leads to minimal wasted heat and high energy efficiency, while the overall low temperature requirement for sorbent regeneration enables Susteon's engineered DAC solution to be powered entirely by carbon-free energy (e.g., solar, wind). Other advantages of the SMS relative to other leading DAC sorbents include high sorbent working capacity (~3 wt%) and long-term stability, sorbent resistance to atmospheric oxygen and humid conditions, fast adsorption and desorption rates, and the environmentally benign nature of the sorbent materials.

Figure 1 shows a process flow diagram for a fully engineered DAC technology, which includes both the sorbent-containing SMS and supporting downstream systems. During the adsorption step at ambient conditions, CO_2 is adsorbed onto the sorbent contained within channels in the SMS, with air drawn into the system using a fan. The SMS is then closed to the air, and a fan evacuates CO_2-lean air from the system. Renewable electricity is used to selectively heat the sorbent whereupon the CO_2 is desorbed, regenerating the sorbent. A vacuum pump pulls high-concentration CO_2 (containing some water vapor) from the system. Water is condensed out and the pure CO_2 is compressed and sent for storage.

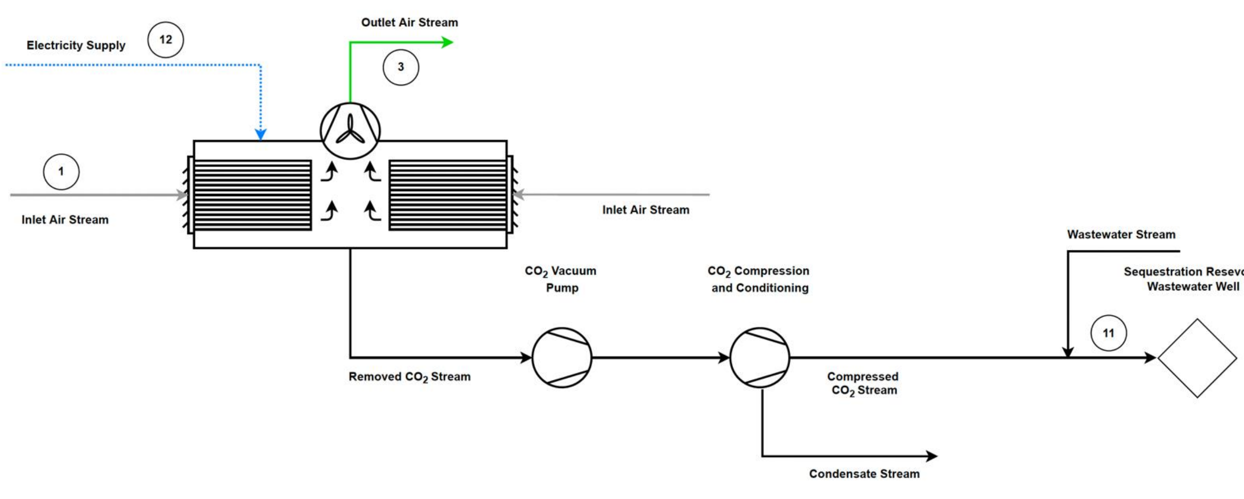

Figure 1: Process flow diagram for the Susteon DAC technology.

Chemical/Physical Sorbent Mechanism – Chemisorption with temperature swing.

Sorbent Contaminant Resistance – High.

Sorbent Attrition and Thermal/Hydrothermal Stability – Proprietary.

Flue Gas Pretreatment Requirements – N/A.

Sorbent Make-Up Requirements – Proprietary.

Waste Streams Generated – N/A.

Process Design Concept – Figure 1 (above) illustrates the process design concept for Susteon's DAC technology.

Proposed Module Design – The key components of Susteon's DAC module include: (i) a solid sorbent, consisting of an alkali carbonate as a CO_2 getter; (ii) a monolith to support the sorbent and allow air flow through the module; (iii) a layer of resistive material to selectively heat the sorbent; (iv) an enclosure to house the supported sorbent; (v) mechanical components such as fans and louvers to draw air into the module and enable a product stream of pure CO_2; (vi) necessary gas handling and process control systems. The module operates by temperature-swing adsorption principles.

TABLE 1: KEY TECHNOLOGY METRICS FOR DIRECT AIR CAPTURE

Values	Units	Current R&D Value	Target R&D Value
Carbon Capture Capacity	w/w % sorbent	2.5	3.5
Heating Rate	°C/min	10	75
Energy Intensity	kWh/tonne CO_2	3,335	<2,500
Capital Expenditure Intensity	$/tonne CO_2	1,050	<800

Definitions:

Cost of Carbon Captured – Projected cost of capture per mass of CO_2 captured under expected operating conditions.

Cost of Carbon Avoided – Projected cost of capture per mass of CO_2 avoided under expected operating conditions.

Capital Expenditures – Projected capital expenditures in dollars per tonne of CO_2 captured.

Operating Expenditures – Projected operating expenditures in dollars per tonne of CO_2 captured.

Calculations Basis – Susteon has performed a preliminary engineering and TEA on its DAC technology at multiple scales, including the present lab scale (~1 kg/day CO_2 removal), 100 tonnes/day CO_2 removal, and 1,000,000 tonnes/year CO_2 removal. Based on this TEA, Susteon believes that there is a reasonable pathway to achieve $100 per tonne of CO_2 capture cost at 1 million tonnes/yr scale assuming electricity price of ~3 cents/kWh and capital intensity of ~$600/tonne-year.

Scale of Validation of Technology Used in TEA – Susteon has validated the key innovations of the proposed DAC technology at the laboratory scale, corresponding roughly to TRL 3.

technology advantages

- Novel electrical heating subsystem to minimize heat losses, lowering regeneration energy penalty.
- Low cost of sorbent and higher CO_2 capture rate and capacity compared to amine-based sorbents.
- Sodium carbonate sorbent has favorable impact of moisture compared to MOF sorbents, and easy regenerability at less than 120°C.

R&D challenges

- Implementation of integrated electrical heating technology in the structured support material.

status

Susteon Inc. has begun sorbent development, optimization, and characterization work. The work focuses upon high surface area sorbent dispersed on the selected support structure to achieve maximum capacity, sorption rate, and adsorbent stability.

available reports/technical papers/presentations

N/A.