Spatiotemporal Adaptive Passive Direct Air Capture

primary project goal

Carbon Collect Inc., along with the Electric Power Research Institute (EPRI), Arizona State University (ASU), Trimeric Corporation, and PM Group, is performing an initial design of a commercial-scale, passive direct air capture (DAC) system termed "Carbon Trees" to capture, separate, and store or utilize a nominal capacity of 1,000 tonnes per day of carbon dioxide (CO_2) from air.

technical goals

- Prepare an initial engineering design package for carbon farms based on the Carbon Tree technology at each of three geographically diverse host sites throughout the United States to better understand the effect of local/regional ambient conditions on DAC system performance and project costs.
- Complete a techno-economic analysis (TEA), life cycle analysis (LCA), business case analysis, and an environmental, health, and safety risk assessment for each of the three geographically diverse host sites.

technical content

Passive DAC is unique among DAC technologies in that passive air delivery by wind avoids the energy penalty of forced convection. The passive DAC Carbon Tree system includes a passive collector that absorbs wind-delivered CO_2 and an integrated regenerator that releases CO_2 into a confined chamber. During CO_2 collection, the leaves of the Carbon Tree take the form of large horizontal disks arranged in a vertical column over a cylindrical regeneration chamber. For sorbent regeneration, the column lowers into the chamber; a combination of steam, low-grade heat, and vacuum releases the CO_2, which is extracted from the chamber and then purified and compressed.

Uniquely, this system readily accommodates alternative hybrid cycles—temperature vacuum swing absorption (TVSA), moisture vacuum swing absorption (MVSA), moisture temperature vacuum swing absorption (MTVSA), and their associated alternate sorbents—such that the collector system is adaptable to broadly different climate conditions. This study will illustrate and emphasize this unique advantage, employing both TVSA and MTVSA cycles as appropriate for the three study sites. For both of these cycles, the collector effluent gas is a mixture of CO_2 and water (H_2O) with trace residual air. The collector effluent is compressed and purified to storage-ready specifications by a compression and purification unit (CPU). The CPU comprises conventional unit operations that are configured to recapture nearly 100% of heat and water for a nearly closed cycle integration with the collector and optimal energy efficiency. The Carbon Tree design represents a radical departure from other forced-air DAC systems. Instead of using fans and blowers to force air, the contactor in its fully open position (Figure 1, right) stands in the native wind to capture CO_2 directly from passing ambient air onto leaf-like structures containing sorbent. The system's vertical column incorporates a stack of 150 1.5-decimeter (dm) disks that hang freely on straps, forming a 7.5-meter column above the regenerator chamber. Wind flows freely through gaps between these disks while about 30% of the CO_2 is fractionally skimmed from the air stream.

program area:
Carbon Dioxide Removal

ending scale:
pre-FEED

application:
Direct Air Capture

key technology:
Sorbents

project focus:
Dynamic Performance of Passive "Carbon Tree" DAC Technology

participant:
Carbon Collect Inc.

project number:
FE0032097

predecessor projects:
N/A

NETL project manager:
David Lang
david.lang@netl.doe.gov

principal investigator:
Mike Austell
Carbon Collect Inc.
mike.austell@carboncollect.com

partners:
Arizona State University; Electric Power Research; Institute; PM Group; Trimeric Corporation

start date:
10.01.2021

percent complete:
12%

Figure 1: Carbon Tree in capture (right) and regeneration modes (left).

The disk frames shown in Figure 2 provide support structure to hold a variety of sorbent materials and form factors with high surface area exposure. For regeneration, the column is lowered into the regeneration chamber, collapsing the disk stack. The chamber is pre-evacuated to rough vacuum to remove bulk air contamination and heated with sub-atmospheric steam to between 40–100°C, releasing CO_2 at a vapor pressure of about 5 kPa. The MTVSA cycle uses steam principally as a sweep gas to carry liquid water droplets as an aerosol to the MTVSA sorbent. In both TVSA and MTVSA cycles, the steam increases the total pressure during regeneration to significantly reduce the vacuum requirement. Steam is the condensed from the regeneration effluent for energy recovery and bulk water removal. The remaining gas comprising CO_2 with residual water and air is subsequently compressed and purified in the CPU as described below.

Figure 2: Top head and disks of Carbon Tree.

Starting with a durable sorbent that has been demonstrated in outdoor operation for more than a year, the temperature tolerance of the sorbent was increased so as to take better advantage of the heat of condensation of the water used to deliver these sorbents. The current sorbent receives a substantial boost from the increase in moisture, but by raising the temperature, this project can reach even higher concentrations and forgo the moisture boost in humid climates. ASU and, more recently Carbon Collect Limited (CCL), have worked over the past 10 years to build a library of sorbents and form factors to allow the fine-tuning of the Carbon Tree system for geographically diverse host sites. Without major hardware changes, sorbent selection, and the application of heat, vacuum and moisture can be optimized (patents pending). Detailed thermodynamic analyses of the role of water and heat in these sorbents have been developed. An MVTSA commercial system will require less than 70 kJe/mol or 440 kWh per tonne of final product CO_2.

technology advantages

- Passive DAC uses wind delivery of air which lowers operating expenses (OPEX).
- Reduction in capital expenditure (CAPEX) using economies of mass production of inexpensive modular equipment.

R&D challenges

- Optimizing collector to minimize temperature, thermal mass, and void space.
- Cycle optimization for efficient water and thermal energy recovery.

status

Trimeric is currently beginning the process design basis and initial development of the engineering design of the process. This includes the establishment of site-specific data, design specifications, ambient conditions, potential permitting requirements, process targets for CO_2 capture, and purity. The PM Group is beginning site planning, layout, and tree design. EPRI is beginning the geological storage assessment of the three site locations (Southern San Joaquin Valley; Citronelle, Alabama; and Gillette, Wyoming), estimating capital operating costs of injecting and storing CO_2 for project scenarios, etc.

available reports/technical papers/presentations

Mike Austell, "Spatiotemporal Adaptive Passive Direct Air Capture," Project kickoff meeting presentation, Pittsburgh, PA, November 2021. *http://www.netl.doe.gov/projects/plp-download.aspx?id=12348&filename=Spatiotemporal+Adaptive+Passive+Direct+Air+Capture.pdf*.