Scale-Up and Site-Specific Engineering Design for Global Thermostat Direct Air Capture Technology

primary project goal

Black & Veatch Corporation is partnering with Global Thermostat (GT), Sargent & Lundy, ExxonMobil Research and Engineering, Southern Company Services, and Elysian Ventures LLC to execute an initial engineering design of a commercial-scale carbon capture, utilization, and storage direct air capture (CCUS-DAC) system that captures at least 100,000 net tonnes/year of carbon dioxide (CO_2) from the atmosphere. The lead system, designated as DAC+, consists of a DAC unit utilizing GT's sorbent contactor technology coupled with a natural gas-fired combined heat and power (CHP) plant, the DAC+ designation indicating modification of the DAC system to enable capture of the CHP unit flue gas.

technical goals

- Complete the baseline design of the commercial-scale DAC+ unit that captures CO_2 from both the air and the associated natural gas-fed CHP unit, for a *net* removal of 100,000 tonnes of CO_2 per year from the atmosphere.
- Conduct site-specific studies for three proposed plant site locations: Odessa, Texas; Bucks, Alabama; and Goose Creek, Illinois.
- Conduct a comparative study of DAC+ versus DAC combined with a traditional post-combustion carbon capture system for at least one of the potential host sites.
- Develop a techno-economic analysis (TEA), life cycle analysis (LCA), and environmental health and safety (EH&S) analysis to compare the cost, emissions, and performance metrics between all three proposed site locations.

technical content

The project utilizes a polymer-based adsorbent system developed by GT in 2009. The process container for the GT system, displayed in Figure 1, uses a temperature-vacuum swing adsorption (TVSA) regeneration cycle to remove CO_2 from both the air and flue gas. Steam is used as a direct phase-change heat transfer fluid to remove the CO_2 from the adsorbent. The proprietary adsorbent material uses a honeycomb geometry, which has been experimentally verified to have a very low pressure drop, which helps minimize energy cost. The system is designed to be modular: each module is about 250 cubic feet in size (2,000 cubes that are 6 by 6 by 6 inches), and scale-up can be achieved by adding more modules in an array.

The complete absorption-regeneration cycle is designed to operate in DAC+ mode, where air and flue gas are passed through the adsorbent filter honeycomb sections sequentially to maximize carbon capture capacity. The overall process targets about 1,000 seconds to complete cycle for a single module, as indicated in Figure 2. The illustrated unit contains 10 sorbent panels, which move in a counter-clockwise manner to enable stationary positioning in the regeneration box (shown as gray area in the figure).

program area:
Carbon Dioxide Removal

ending scale:
pre-FEED

application:
Direct Air Capture

key technology:
Sorbents

project focus:
Sorbent-Based DAC+ System Integrated with Combined Heat and Power (CHP) Plant

participant:
Black & Veatch

project number:
FE0032101

predecessor projects:
N/A

NETL project manager:
Nicole Shamitko-Klingensmith
nicole.shamitko-klingensmith@netl.doe.gov

principal investigator:
Mark Steutermann
Black & Veatch
steutermannmg@bv.com

partners:
Global Thermostat; Sargent & Lundy; Southern Company; Elysian Ventures; ExxonMobil

start date:
10/01/2021

percent complete:
10%

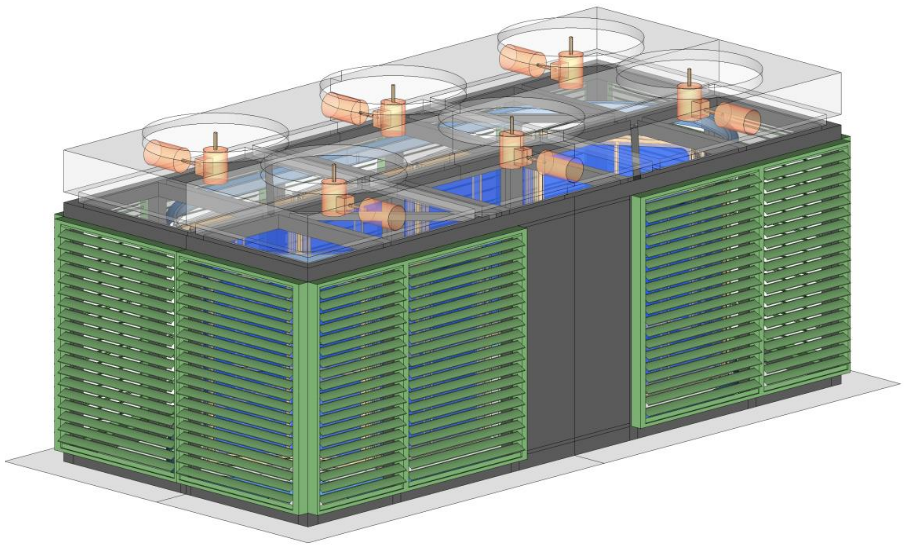

Figure 1: 3D rendering of GT's DAC system, with nine stations for sorption and one station for harvest/regeneration (gray area in Figure).

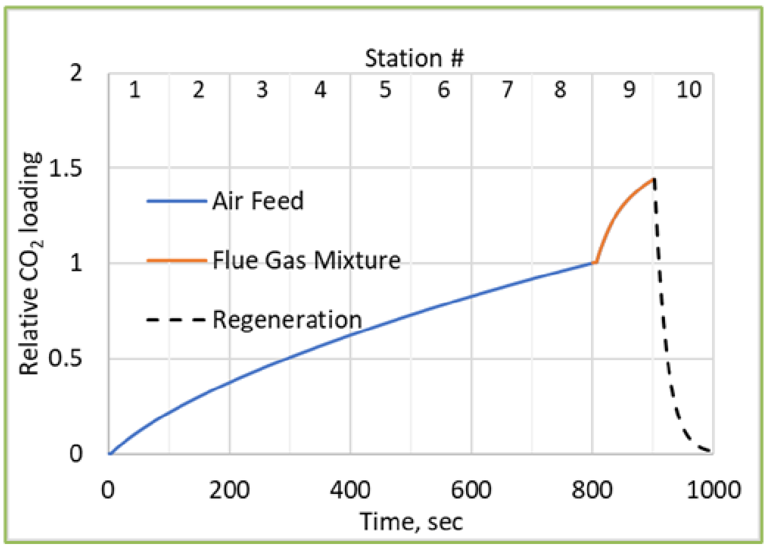

Figure 2: Laboratory adsorption data as a demonstration of the operation of a DAC+ unit. Air feed is 400 ppm; flue gas mixture is 10,000 ppm.

The proprietary adsorbent material's known properties and the operating parameters of the adsorption-regeneration system are shown in Table 1. The TVSA system works by manipulating the temperature and pressure of the adsorbent material in order to change the adsorptivity of the material to prioritize either adsorption or desorption at the right time, selectively removing CO_2 from the feed gas or releasing the CO_2 in order to transport it to the storage site.

A number of modules will be installed at three specifically chosen locations in the continental United States: one in Odessa, Texas (warm, dry climate); one in Bucks, Alabama (warm, wet climate); and one in Goose Creek, Illinois (temperate climate). Each site's proposed plant design will utilize a natural gas-fired CHP plant to provide the energy to run the DAC unit. The resulting combined system will capture more than 100,000 tonnes of CO_2 from the atmosphere (*after* accounting for the CO_2 produced by the CHP plant). This concept is referred to as DAC+, as it is able to accomplish all of these tasks from within a single facility. The Alabama site's results will be compared to those of a standard amine-based absorption system as a means of better highlighting the strength of GT's adsorption technology for at least one of the sites.

TABLE 1: SORBENT PROCESS PARAMETERS

Sorbent	Units	Project Value**
True Density @ STP	kg/m^3	2,300
Bulk Density	kg/m^3	500
Average Particle Diameter	mm	0.23
Particle Void Fraction	m^3/m^3	0.78
Packing Density	m^2/m^3	1,800
Solid Heat Capacity @ STP	kJ/kg-K	0.81
Crush Strength	kg$_f$	4
Thermal Conductivity	W/(m-K)	0.4
Adsorption		
Pressure	bar	1.0
Temperature	°C	25
Equilibrium Loading	g mol CO_2/kg	2.5
Heat of Adsorption	kJ/mol CO_2	85-95
CO_2 Adsorption Kinetics	mol/kg-min	0.043
Desorption		
Pressure	bar	1.0
Temperature	°C	100
Equilibrium CO_2 Loading	g mol CO_2/kg	<0.05
Heat of Desorption	kJ/mol CO_2	85-95
CO_2 Desorption Kinetics	mol/kg-min	0.3
Proposed Module Design		
Flow Arrangement/Operation	—	Honeycomb Monolith
Air Feed Approach Velocity	m/sec	5
Space Velocity	hr^{-1}	120
Volumetric Productivity	mol$_{CO2}$/(hr-kg$_{sorbent}$)	2.7
CO_2 Recovery, Purity, and Pressure	% / % / bar	50/95/1.0
Adsorber Pressure Drop	bar	0.002
Degradation	% capacity fade/yr	5%

**Development in materials properties is prohibited within this project area of interest (AOI) and therefore project-derived changes to these numbers is out of scope and not anticipated.

A complete TEA and LCA is being performed as a part of this study. Preliminary capture cost estimates for the DAC+ carbon capture system installed with a CHP plant are shown in Table 2.

TABLE 2: DAC+ ECONOMICS

Economic Values	Units	Target Project Value
Cost of Carbon Captured	\$/tonne CO_2	90-150
Cost of Carbon Captured (Net Removal Basis)	\$/tonne CO_2	130-240
Capital Expenditures (annualized at 10%)	\$/tonne (net)	70-130
Operating Expenditures	\$/tonne (net)	60-110

Definitions:

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

Cost of Carbon (Net Removal Basis) – Projected cost of capture per mass of CO_2 under expected operating conditions for net removal from the atmosphere

Capital Expenditures – Projected capital expenditures (CAPEX) in dollars per tonne on a net removal basis. Cost estimates use annualized values at 10% of CAPEX.

Operating Expenditures – Projected operating expenditures in dollars per tonne on either a total or a net removal basis.

Sorbent – Adsorbate-free (i.e., CO_2-free) and dry material as used in adsorption/desorption cycle.

Adsorption – The conditions of interest for adsorption are those that prevail at maximum sorbent loading. Measured data are preferable to estimated data.

Desorption – The conditions of interest for desorption are those that prevail at minimum sorbent loading. Operating pressure and temperature for the desorber/stripper are process dependent. Measured data are preferable to estimated data.

Pressure – The pressure of CO_2 in equilibrium with the sorbent. If the vapor phase is pure CO_2, this is the total pressure; if it is a mixture of gases, this is the partial pressure of CO_2.

Loading – The basis for CO_2 loadings is mass of dry, adsorbate-free sorbent.

Kinetics – A characterization of the CO_2 adsorption/desorption trend with respect to time, as complete in the range of time as possible.

Flow Arrangement/Operation – Gas-solid module designs include fixed, fluidized, and moving bed, which result in either *continuous*, *cyclic*, or *semi-regenerative* operation.

Estimated Cost – Basis is $ per tonne of CO_2 in CO_2-rich product and assuming targets are met.

Other Parameter Descriptions:

Chemical/Physical Sorbent Mechanism – The GT DAC system employs a solid-sorbent system.

Sorbent Contaminant Resistance – Air borne contamination mitigated with filters.

Sorbent Attrition and Thermal/Hydrothermal Stability – Targeted lifetime for sorbent is three years.

Flue Gas Pretreatment Requirements – Not established yet.

Sorbent Make-Up Requirements – Replacement after capacity loss tolerance level exceeded.

Waste Streams Generated – Waste gases mostly water.

technology advantages

- Modular design.
- Enables carbon-negative fossil power generation and carbon-neutral synthetic fuels.
- Low pressure drops.
- Future-proof—different adsorbent materials can be slotted into the units, allowing future generations of adsorbents to be used with the design to reduce cost of future upgrades.
- High selectivity—can capture CO_2 at incoming concentrations as low as 400 parts per million (ppm).

R&D challenges

- Integrating DAC+ system with commercial host sites.
- Completing the detailed TEA and LCA for all three sites.

status

Process and equipment design for the host site in Alabama is underway. A comparative analysis of DAC+ and DAC combined with conventional capture from CHP unit flue gas is underway.

available reports/technical papers/presentations

Steutermann, M., "Scaleup and Site-Specific Engineering Design for Global Thermostat Direct Air Capture Technology." Project Kickoff Meeting. Pittsburgh, PA. December 13, 2021. *https://netl.doe.gov/projects/plp-download.aspx?id=12682&filename=Scaleup+and+Site-Specific+Engineering+Design+for+Global+Thermostat+Direct+Air+Capture+Technology.pptx.*