Advancing a Low-Temperature, Low-Cost Direct Air Capture System Based on Organic Chemistry (FE0032269)

Anca Timofte, CEO & CO-FOUNDER

HOLOCENE

2024 FECM & NETL Carbon Management Research Project Review Meeting

HOLOCENE – OUR COMPANY "AT-A-GLANCE"

LINEAGE

climeworks, Stanford, CO280 Carbon Negative Solutions, ETH zürich, McKinsey & Company, Patch

Founded from a historic lineage of CDR R&D + commercial homes

COMPANY

13

Employees, across 5,000 square feet of industrial space

CAPACITY

10s

Of tonnes of carbon removal capacity from our pilot facility

FUNDING

>$6M

Dollars ($) in up-front, non-dilutive funding awarded to-date

CUSTOMERS

>$10M

Secured customer contracts supporting our future CDR facilities

SUPPORTERS

Breakthrough Energy Fellows, TVA, Oak Ridge National Laboratory, Frontier, XPRIZE Carbon Removal, U.S. Department of Energy

A deep, diverse, and steadfast bench of supporters

GRANT OVERVIEW: DE-FE0032269

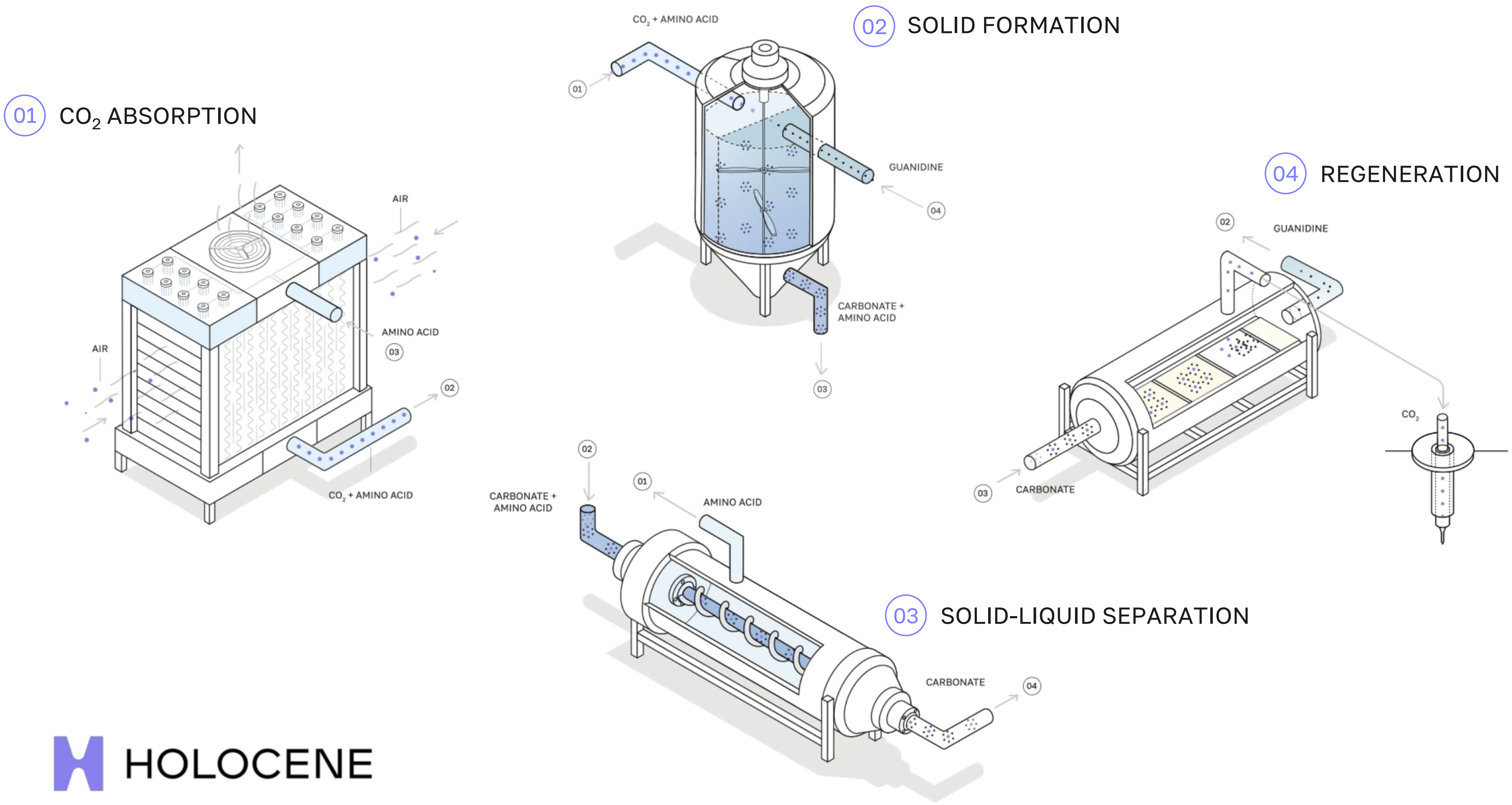
Advancing a Low-Temperature, Low-Cost Direct Air Capture System Based on Organic Chemistry

AGENCY	United States Department of Energy, Office of Fossil Energy and Carbon Management							
TIMELINE	**START DATE**	Oct. 1, 2023	**END BP1**	Sep. 30, 2024	**END BP2**	Sep. 30, 2025		
DESCRIPTION	Holocene Climate Corporation plans to partner with Oak Ridge National Laboratory (ORNL) to conduct bench-scale testing of a new optimized direct air capture system using amino acids and guanidine compounds, a chemical process invented at ORNL. Holocene aims to use ORNL's chemistry to further develop and deploy the technology on a commercial scale.							
BUDGET	**TOTAL**	$1.92MM	**FEDERAL**	$1.50MM	**COST SHARE**	$0.42MM	**HOL %**	55%
LOCATIONS(s)	Knoxville, TN and Oak Ridge, TN							
TASK #1	PROJECT MANAGEMENT & PLANNING: Project management, technology maturation planning, techno-economic analysis (TEA), life cycle assessment (LCA), state-point data tables, DEI & CBP work							
TASK #2	DE-RISKING SORBENT COSTS - STABILITY & PRODUCTION: Test setup, sorbent stability assessment, sorbent production cost de-risking							
TASK #3	DEVELOPMENT OF TRANSFORMATIVE SOLID-LIQUID SEPARATION: Validating crystallization process parameters, conceptual design of crystallization process							
TASK #4	CONTACTOR DESIGN & OPTIMIZATION: Contactor design & build, contactor design evaluation, experimentation, modeling and analysis							
TASK #5	ADVANCED DESORPTION PROCESSES TO REDUCE THERMAL ENERGY: Vacuum-assisted desorption, steam-assisted desorption							

For original grant announcement, please reference this link regarding FOA 2614 selections: https://www.energy.gov/fecm/project-selections-foa-2614-carbon-management-round-1

OUR PROCESS: 4 UNIT OPS, 2 CONTINUOUS LOOPS

Organic chemistry is at the core of our low temperature, aqueous, continuous process.



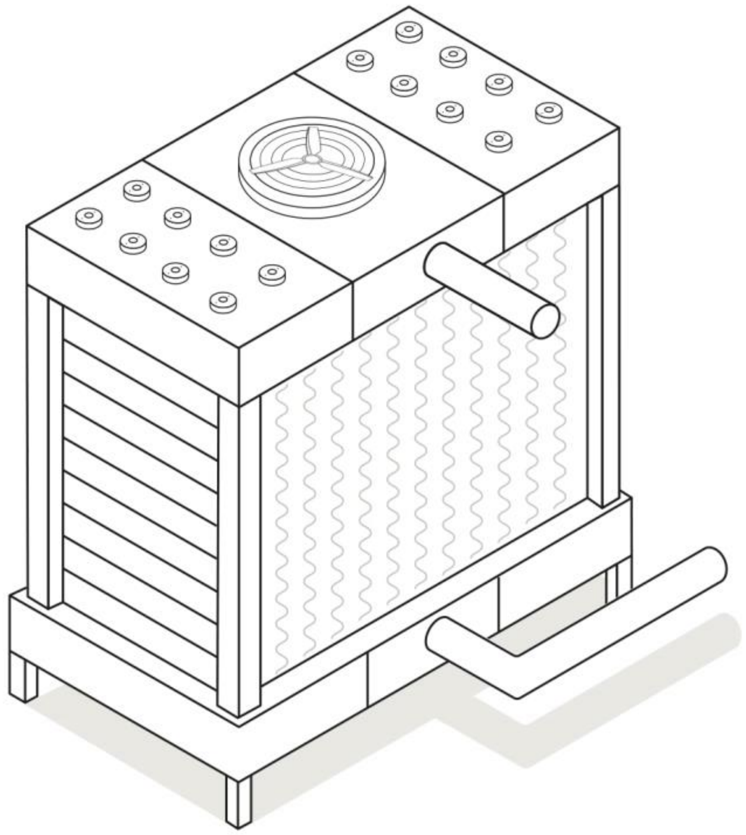
HOLOCENE

An air-liquid contactor facilitates cross-flow absorption via an amino acid solution and ambient air.

Moving CO_2 from air into our system

The first step of our process brings a liquid – an amino acid & water solution – into contact with ambient air that contains CO_2.

We continuously pass air through a thin liquid film via structured packing to enable the CO_2 to react with the amino acid. This binds the CO_2 within our system so it can be sent on to the second stage.



Source: Holocene

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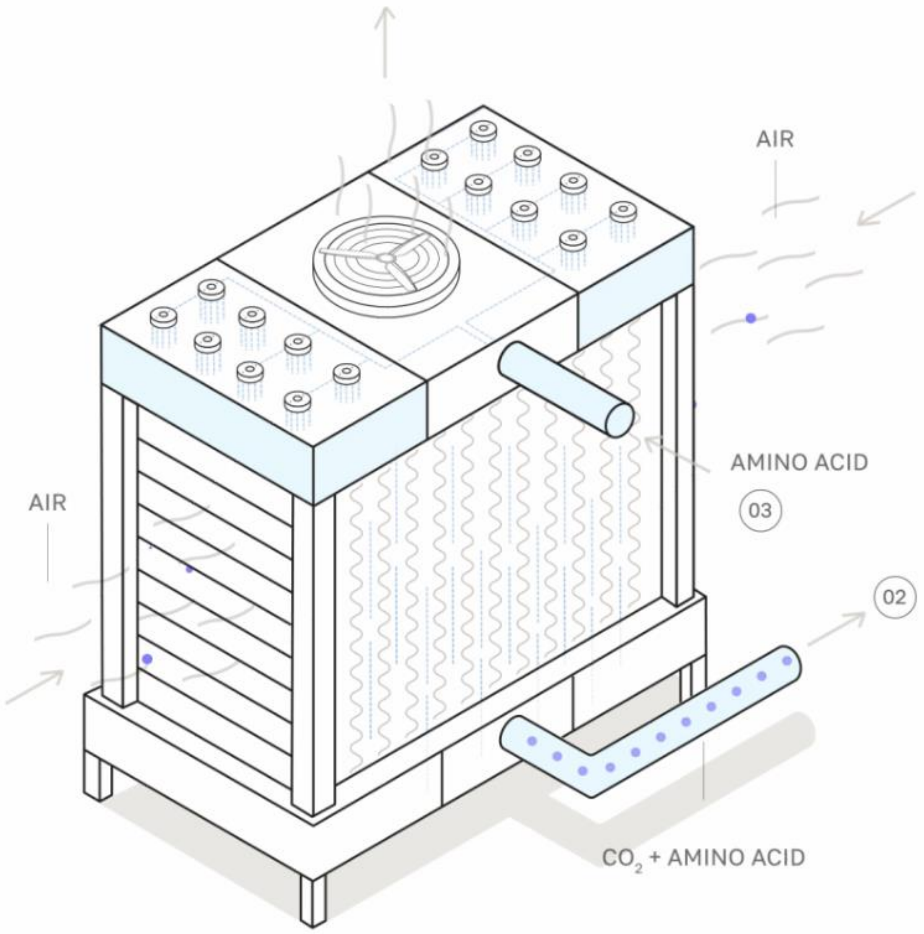
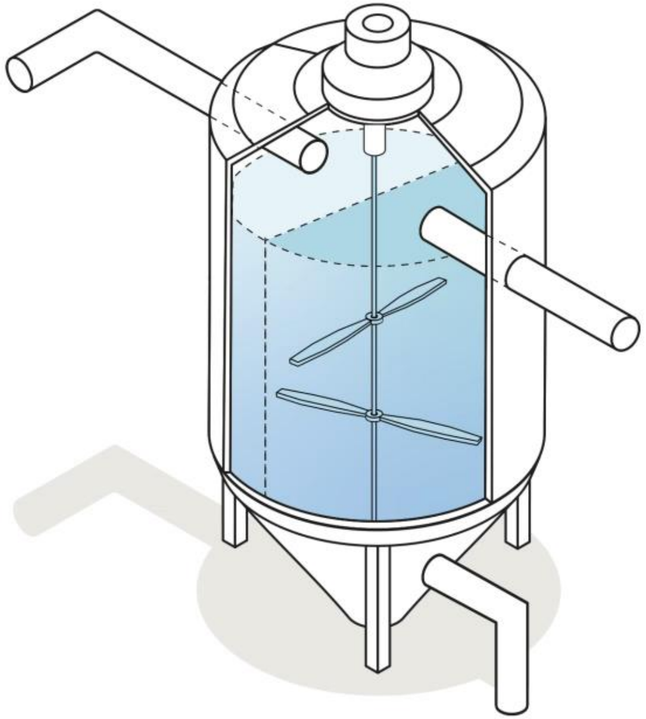


A crystallization reaction is driven by mixing a CO_2-containing amino acid solution with a guanidine.



Transforming CO_2 from liquid to solid

The second step of our process concentrates CO_2 from the amino acid solution into a solid form. This reaction is driven by the mixing of the amino acid + CO_2 solution with a guanidine.

This chemical has a stronger preference for CO_2 than the amino acid, causing a reaction that spontaneously forms a solid. The CO_2 is now trapped within the solid, and the solid-liquid mixture moves on to the third step.

Tasks #2,3

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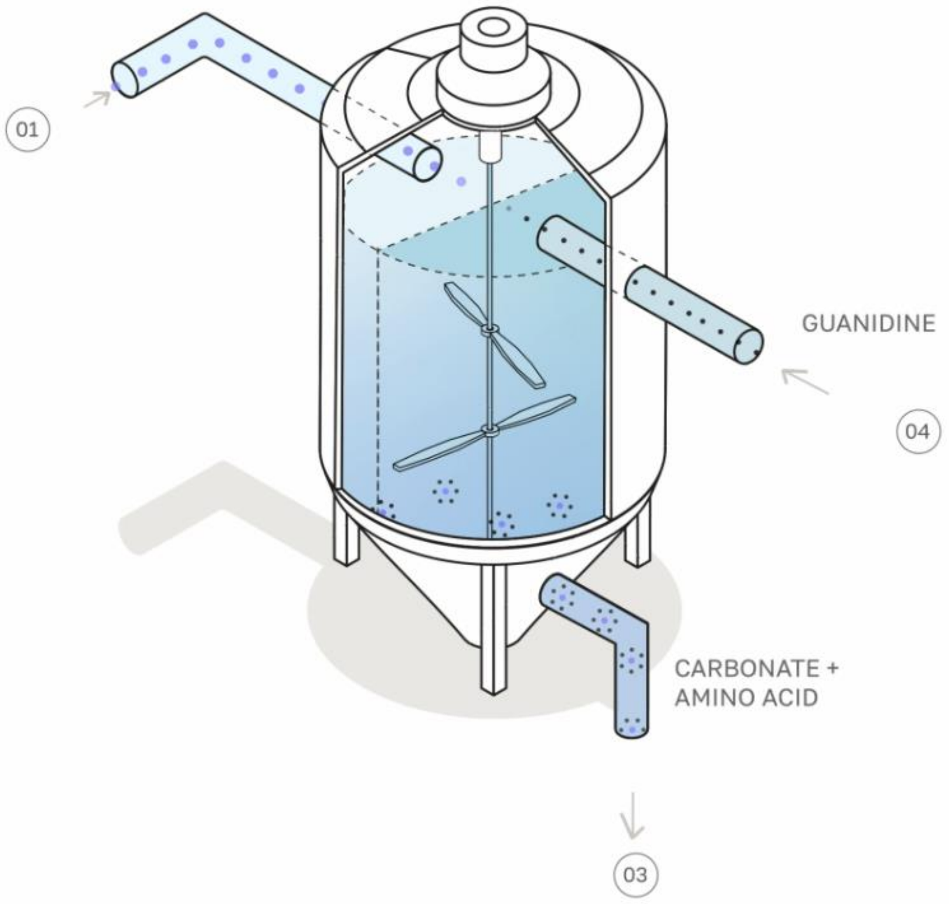

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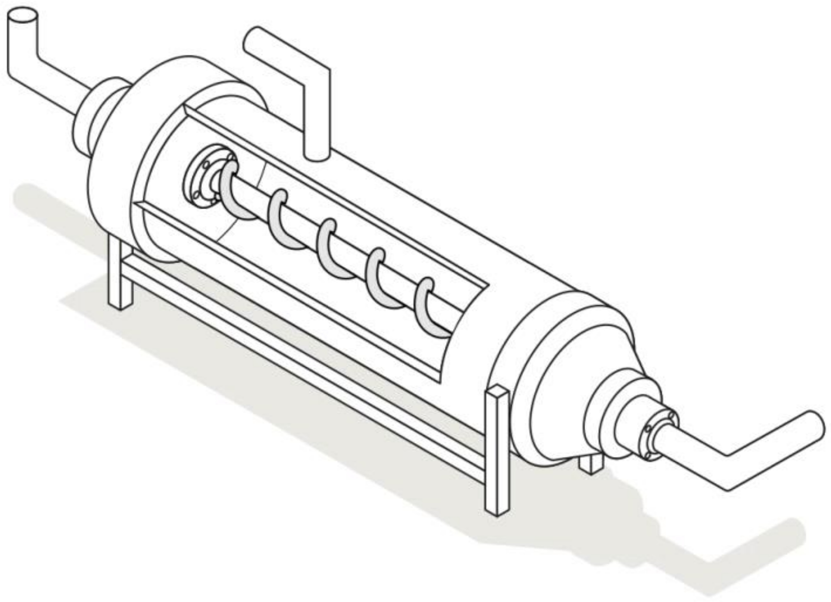
Tasks #2,3

The separation unit operation is performed to isolate the CO_2-containing solid, returning the amino acid solution.

Separating the solid & the liquid

The third stage separates the CO_2-containing solids from the liquid solution. This results in a clean, solid mass that can be effectively managed, along with the original amino acid mixture.

This original mixture is returned as the input to the first stage, where it can capture CO_2 again. Separating the solids is critical to enabling efficient energy delivery in the final step of our process.



Task #3

STEP 03 – SOLID-LIQUID SEPARATION

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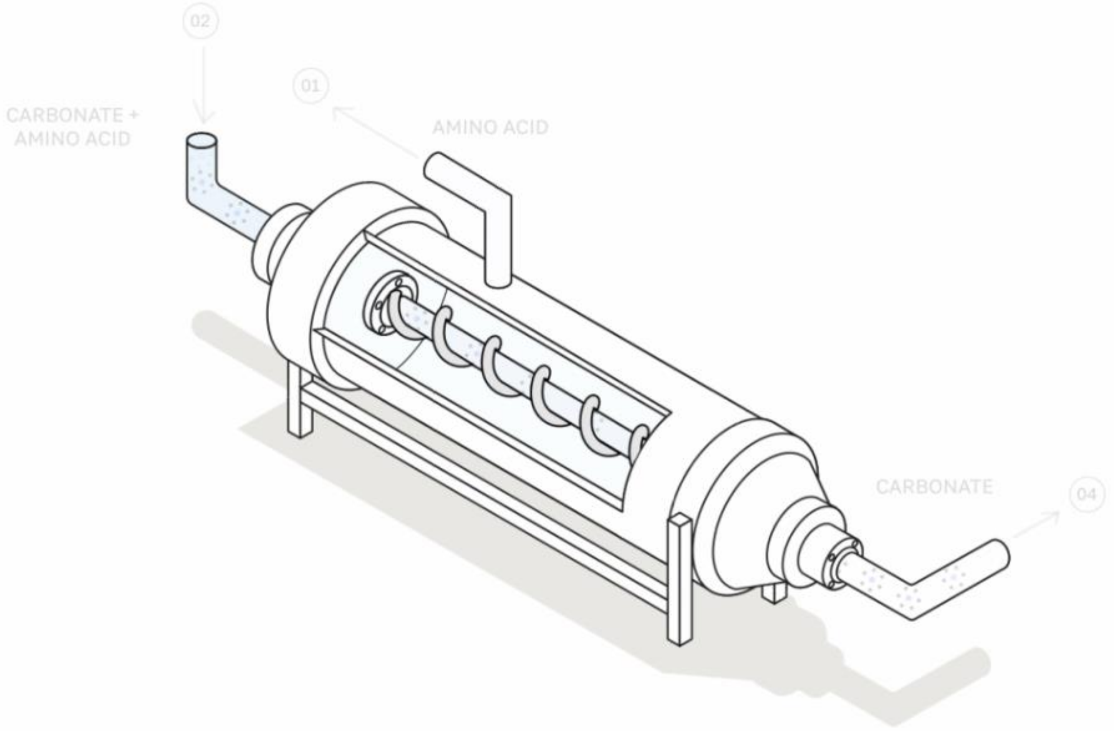
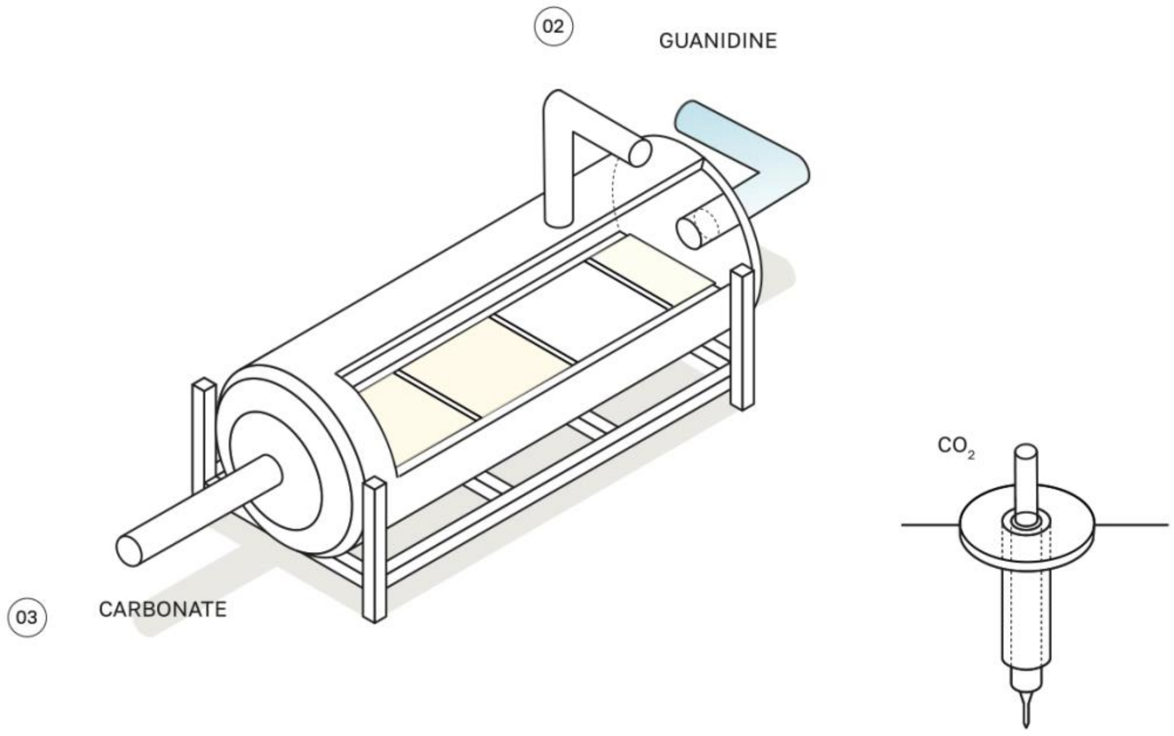


Task #3

Via low-temperature (~100°C) heat, the CO_2 is liberated from the solid, and the guanidine is regenerated again.



Liberating CO_2 for long-term storage

Finally, the solid mass is heated to low temperatures with renewable energy.

This heat releases the CO_2 into pure, gaseous form where it is collected and sequestered permanently underground.

The remaining solid is the original guanidine which is returned to the second stage of the process to work, again.

Tasks #2,5

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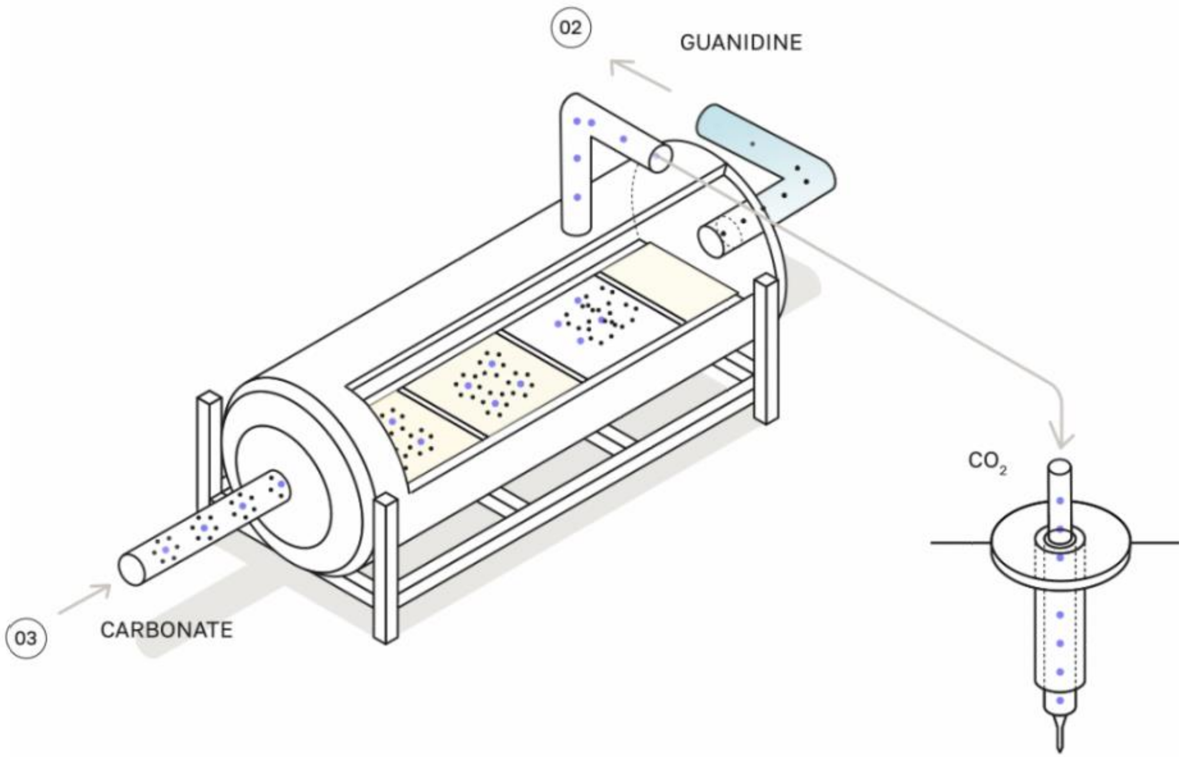

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Project Status

	Description of Objectives	Q4 ’23 – Q1 ‘24	Q2 ‘24– Q3 ‘24	Q4 ‘24 – Q1’25	Q2 ’25- Q3’25
Task 1	Preliminary TEA & LCA TMP CBP work – first review Final TEA & LCA	✓	✓		
Task 2	Possible degradation mechanisms identified + analytical capability set-up Sorbent costs @ scale investigated 100+-eq. cycles investigated with test		✓		
Task 3	Crystallization parameters identified Crystallization process developed & optimized for liquid-solid separation Basic equipment designed	✓			
Task 4	Absorption model build & validation Contactor built & commissioned Contactor performance validation	✓			
Task 5	Investigation of vacuum-assisted regen Investigation of steam-assisted regen		✓		

Planned work timeline ✓ Completed work **Work in progress**

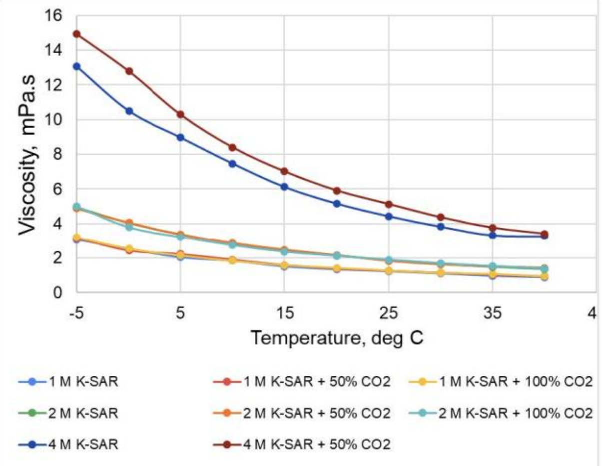
Selected Results – Task 4: Contactor Development

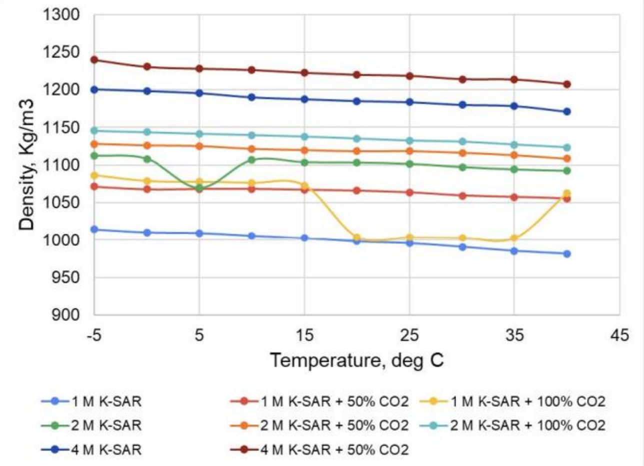
Develop a model for CO_2 absorption and validate it with data collected in relevant conditions

Objectives & Progress: Developing a model for the CO_2 absorption process in an air-liquid contactor that takes into account Holocene's chemistry, physical properties of the aminoacid solution, etc that helps determine the optimal design of the contactor as well as operating conditions (concentrations, air flowrates, etc).

Commissioning completed. Air-liquid contactor performed within specifications (pressure drop, CO_2 absorption rate, liquid distribution, residence time).

Learnings. Viscosity and density of the amino acid solution impact liquid-side mass transfer rates significantly.





Design Parameter	Min. Requirement	Holocene's Pilot Plant Contactor
Packing length / air travel distance (m)	> 1.5	1.75
Packing height (m)	> 0.5	1.19
Packing width (m)	> 0.5	0.65
Packing specific surface area (m2/m3)	> 150	150…500
Volumetric air flow (m3/h)	> 2,000…4,000	3,622

Selected Results – Task 5: Regeneration (ORNL Team)

Investigate the possible regeneration temperature reductions through vacuum-assisted processes

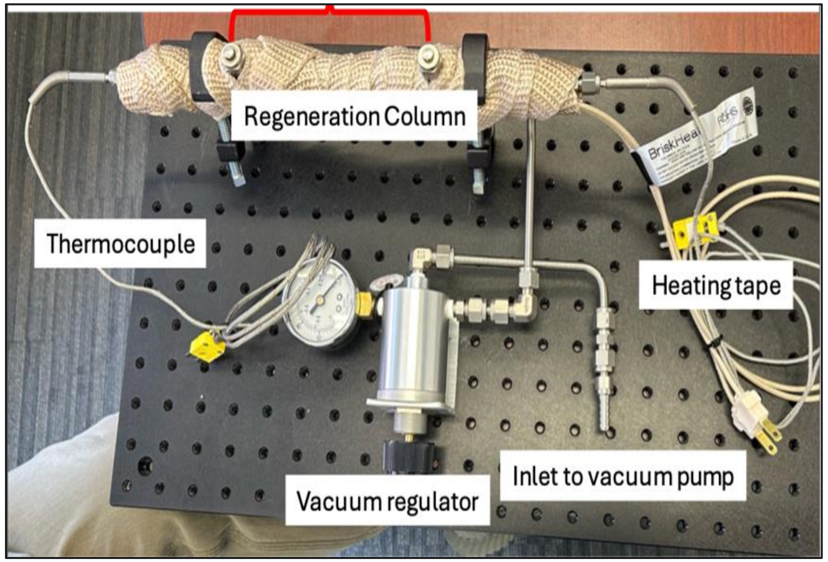
Objectives & Progress: Demonstrating the impact of pressure during the regeneration process, and confirming the removal of water and CO_2 from guanidine carbonates using indirect heating and vacuum.

Test Rig & Analytical Methods (TGA) in Place. ORNL designed and built a simple setup to study the regeneration of guanidine carbonates.

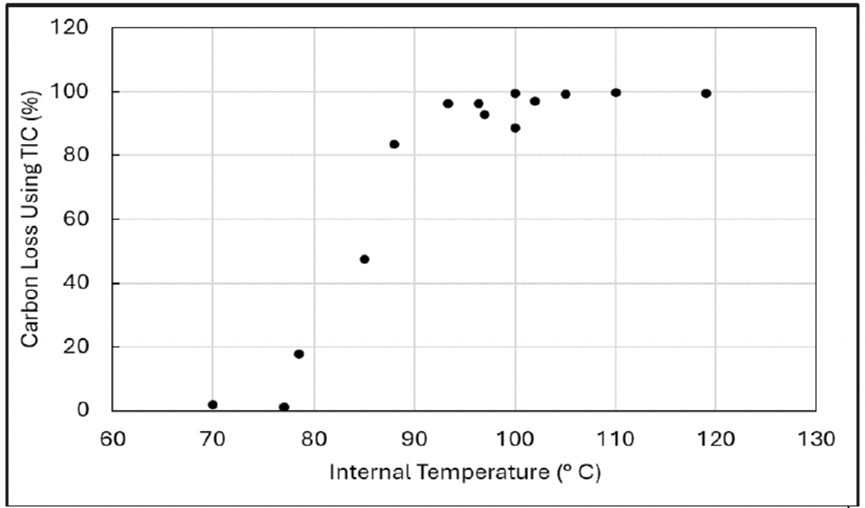
Campaign Parameters: Tested pressures of 0.2 atm (a) to 1 atm (a) and temperatures of 70-110C.
For TGA campaigns, sample weight, atmospheric gas (N_2/air/CO_2), particle size, heating rates were varied.

Learnings. For certain carbonates of guanidine derivates, tests at 0.2 atm(a) show almost the complete removal of CO_2 at temperatures ~85C. Vacuum could be a useful process condition to enable better regenerations. Regeneration starts earlier than anticipated, at 80C.

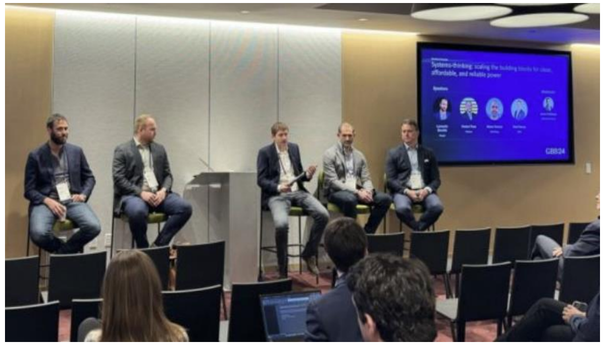
From the TGA campaigns, method was validated to allow for regeneration kinetics investigation (Q3 '24).



Test rig



CBP Progress – Local Engagement



WHAT: Holocene host tours, webinars, and lectures for local community members. These have included groups of teachers, high school students, college students and student groups, politicians, global communities, and many TN-based institutions.

WHEN: ongoing

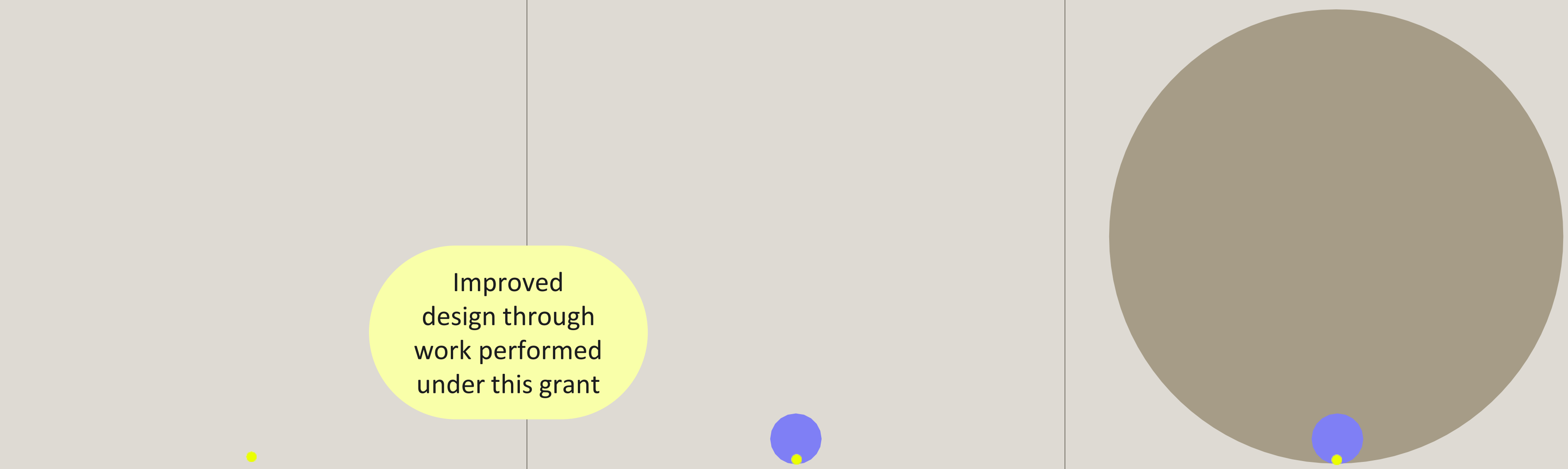
WHERE: virtual & community centers & local conferences

WHY: In person, community engagement via tours, lectures, and webinars are a core part of our broader engagement efforts.

HOW: targeted relationship building with key community leaders in Knoxville & beyond.

TECHNOLOGY DEVELOPMENT PATHWAY

We design our scaling pathway to balance market & technology parameters.



Facility Name	Pilot (aka “Test”)		Demonstration		Commercial+
Design Capacity (tonnes-CO_2/yr)	10	500X →	5000	100X →	500,000+
Online Date (QQ YYYY)	Q2 2024	2.5YR →	Q4 2026	3.5YR →	Q2 2030
Tech Readiness (TRL Level)	TRL 5/6/7*		TRL 7/8/9*		TRL 9+
Facility Objective (qualitative)	Fully integrated, industrial pilot running in relevant conditions		Directly scalable unit operations, all key TEA parameters proven out		Commercially operating facility delivering CDR reliably to customers

Source: Holocene | *Range of TRL’s provided to acknowledge (1) advancing facility performance during lifetime, AND (2) ranging TRL evaluations from independent experts.

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