Carbon Capture Machine (CCM)

2024 FECM/NETL Carbon Management Research Project Review Meeting

August 5 – 9, 2024

Award DE-FE00032399

Lance A. Scott
Chief Executive Officer

Raj Mosali
Principal Investigator

Revision: August 7, 2024

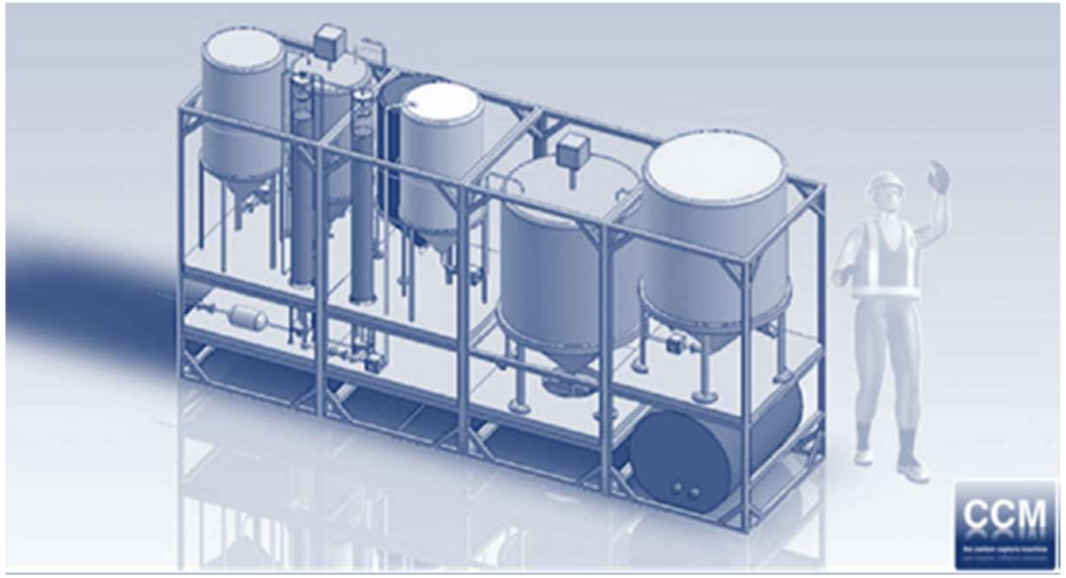
Project Overview

Department of Energy FECM/NETL Award DE-FE00032399

Biomass Ash Valorization by CO_2 Capture for Nano-Sized ACC and Use in Low Carbon Cement

Funding

- DOE – $1,364,279
- Calcify (CCM) – $352,463 (20.53%)



Overall Project Performance Dates

- Project Start Date – 11/01/2023
- 20 kgCO_2/day prototype – 5/10/2025
- Production of Performant Cement with ACC – 7/10/2025
- Project Completion Date – 10/31/2025

Project Overview

Department of Energy FECM/NETL Award DE-FE00032399

Project Participants

- Raj Mosali – Principal Investigator
- Lance A. Scott – Project Director

Overall Project Objectives

- Design and Optimization of Biomass Ash Alkalinity Recovery Unit
- Identification, Characterization, and multi-criteria informed decision on optimal waste sources.
- Design and build 20 kgCO_2/day carbon capture prototype.

  Milestone: Continuous CO_2 capture using biomass ash leachate and continuous synthesis of $CaCO_3$.
- Optimization of precipitation conditions for amorphous calcium carbonate stabilization and production of performant cement. Optimize full CO_2 capture and mineralization process.

  Milestone: Production of performant cement with ACC.

Technical Background

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Preliminary process overview

- Biomass ash leaching using a solvent such as water.
- Alkali extraction from other available waste sources (e.g., Refuse-derived fuel fly ash, Municipal solid waste incineration (MSWI) bottom ash, Mine tailings, Mine gangue, Steel slag, Cement Dust, Coal ash, Industrial waste clinker, Galvanic sewage sludge, etc.).
- Assess alternate sources for alkali production, e.g., Electrolysis, Electro-Chemical Activation (ECA)
- CO2 from flue absorbed using leached water or related dilute alkali source.
- Use concentrated brine to produce ACC.
- Assess a variety of brine sources including aqueous Calcium Chloride ($CaCl_2$), Industrial waste brines, Geologic / Connate brines, Concentrated seawater, Hybrid mixtures.

Technical Background

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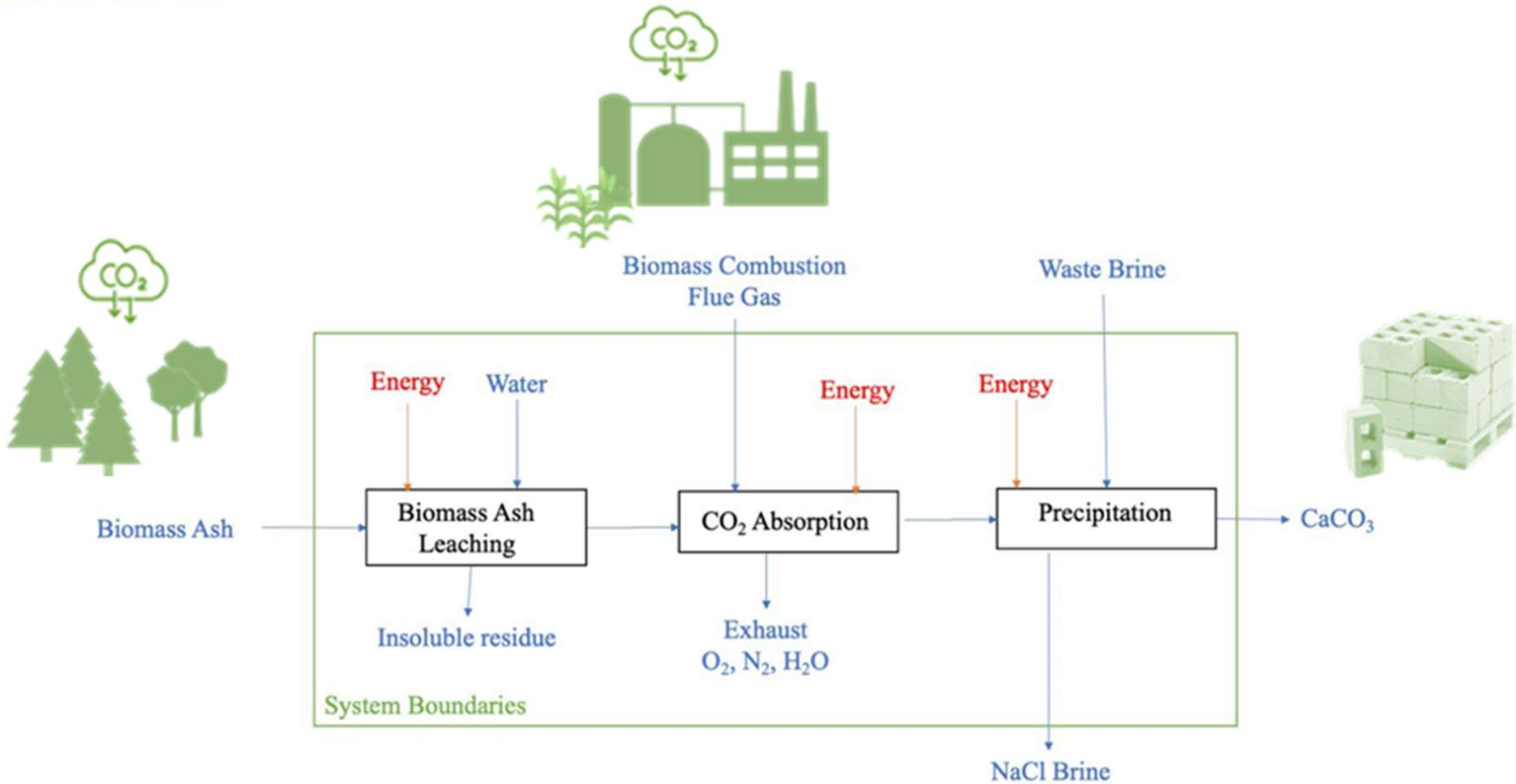
Preliminary process overview



Technical Background

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CCM has developed a prototype carbon capture & utilization (CCU) pilot facility in Ohio that will serve as the basis for the next generation system to process up to 20 kgCO_2/day to produce amorphous calcium carbonate ($CaCO_3$).

Technical Background

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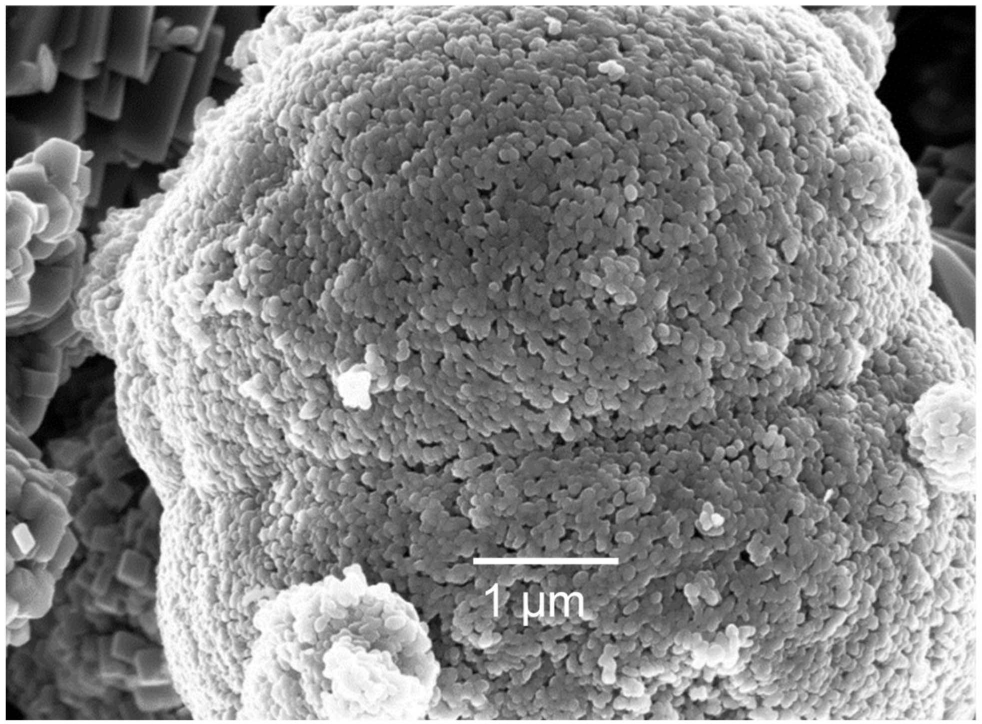
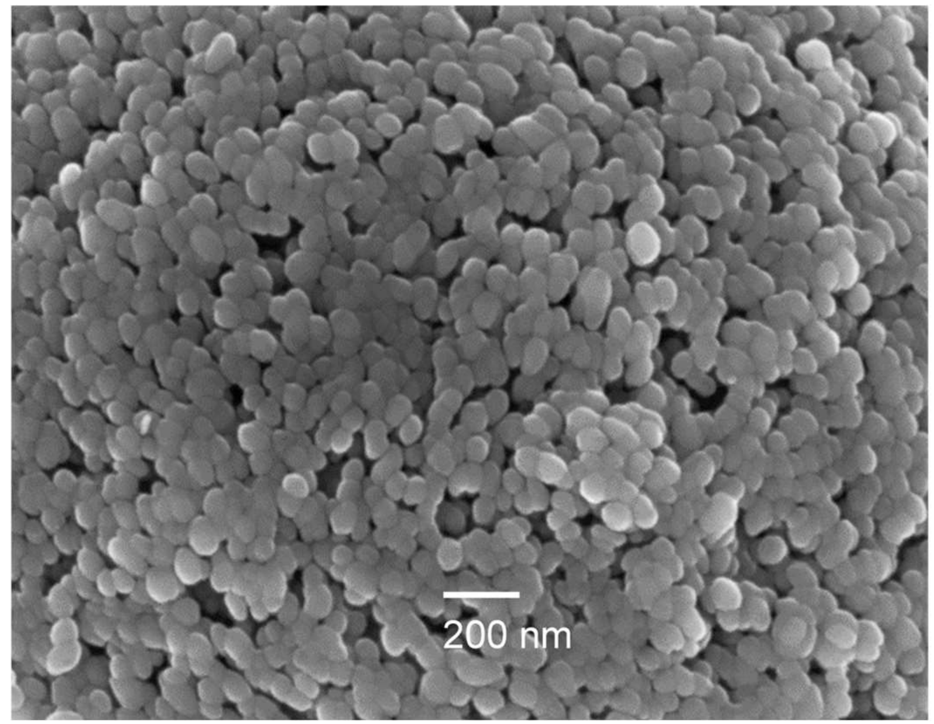
Scanning Electron Microscope (SEM) micrograph of amorphous calcium carbonate formed with CCM proprietary processes





SEM micrograph of amorphous calcium carbonate formed by rapid precipitation and examined shortly after precipitation, ca 5 minutes.

Source: Formation of scawtite, $Ca_7(Si_6O_{18})CO_3 \cdot 2H_2O$, and tilleyite, $Ca_5Si_2O_7(CO_3)_2$, in Portland cements with lowered carbon footprint

L.J. McDonald, W. Afzal* and F.P. Glasser***
** University of Aberdeen, School of Engineering, Aberdeen, Scotland*
***CCM UK, 28 Albyn Place Aberdeen, Scotland, UK*

Technical Background

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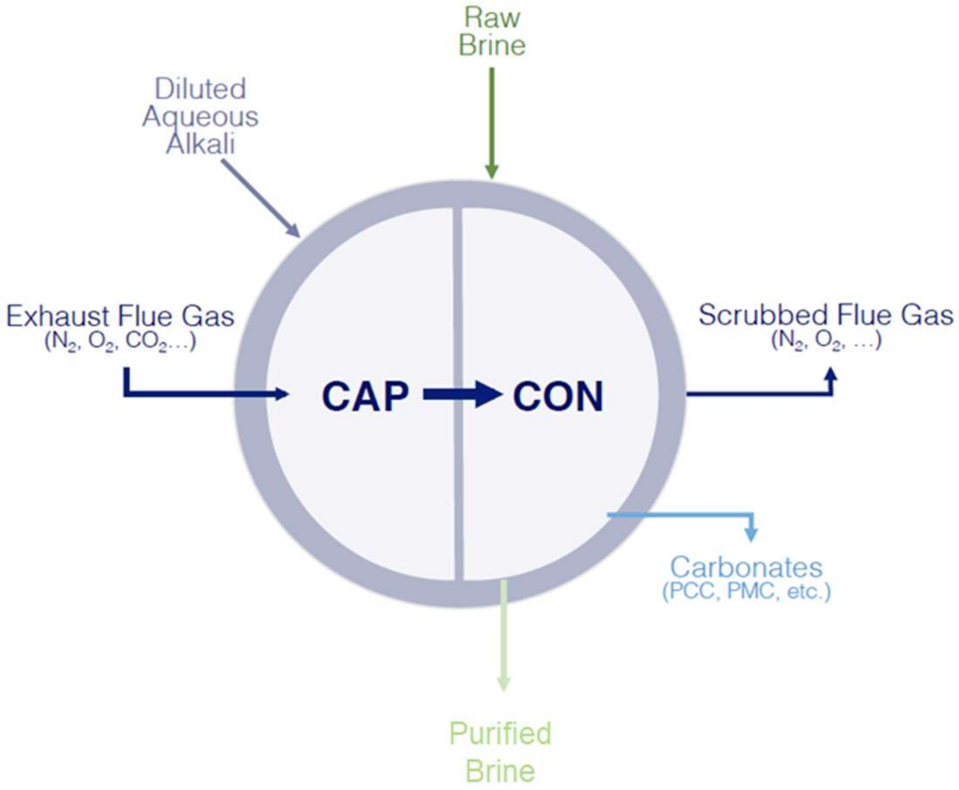
Advantages of CCM technology



The CCM process is termed CAPCON because it CAPtures gaseous CO_2 from process flue gas and CONverts it to stable and insoluble mineral solids.

The process operates at ambient temperature and pressure and does not require solvents other than water.

The proprietary sequential precipitation process operates continuously and efficiently yields valuable and saleable products.

Depleted brine, the third output, can be disposed of, re-injected to the ground, or post-processed for other uses.

The absorption of CO_2 in dilute aqueous alkali and precipitation of carbonates are well-understood processes that present no safety-related concerns

A CCM differentiator is the benign source of Ca_2+ cations from brine, as opposed to CO_2-intensive, hazardous calcination of limestone.

Technical Background

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Advantages of CCM technology

a. The process is highly carbon-negative, generating negative emissions between -825 to -881 kgCO_2 sequestered/ton of CO_2 captured (when sourcing alkali feedstock from waste materials).

b. The goal is to produce a form of ACC that is chemically reactive in concrete, producing a stronger result than traditional $CaCO_3$ commonly added as a supplemental cementitious material (SCM).

c. The proposed CO_2 capture and mineralization strategy has been previously demonstrated to TRL4 using dilute NaOH as the alkalinity source.

d. The CCM methodology produces a wide variety of $CaCO_3$ morphologies with unique characteristics that can be tailored to specific applications.

e. The CCM Techno-economic analysis (TEA) is extremely compelling when input feedstock is sources from waste materials, connate brines, or seawater.

f. The CCM technology is emission-agnostic and can be deployed across a wide range of industries for both retrofit and new installations.

Technical Background

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Challenges of CCM technology

a. Large and replenishing sources of waste ash can be difficult to identify.

b. The uniformity of chemical composition of waste ash may be inconsistent, and evaluation testing is paramount for each feedstock source.

c. Water usage and reclamation can be challenging and energy intensive.

d. Identifying the most desirable morphologies for specific applications to ensure that market pricing provides a compelling TEA.

e. Sources for waste ash and brines differ considerably based on geographic locations, so standardized characterization testing, and a flexible business model are required.

Technical Approach / Project Scope

Department of Energy FECM/NETL Award DE-FE00032399

Task/Subtask	Milestone Title & Description	Planned Completion Date	Verification Method
1.1	Updated Project Management plan	12/06/2023	Updated document provided to DOE
1.2	Technology Maturation Plan	2/10/2024	Document provided to DOE
2	Continuous, selective, and efficient biomass ash alkalinity recovery	11/10/2024	24 hours continuous flow of biomass ash leachate with pH > 12
3.1-3.2	Continuous CO_2 capture using biomass ash leachate and continuous synthesis of $CaCO_3$ with 20 kg/day prototype	05/10/2025	24 hours continuous CO_2 95% capture at 20kg/day flow and precipitation as $CaCO_3$
3.3	Production of performant cement with ACC	7/10/25	ASTM measurements at 28 days exceed Portland Cement control
4.1	Final TEA	10/10/2025	TEA results file and report file provided to DOE
4.2	LCA	10/10/2025	OpenLCA project file, LCA discussion report, LCA summary graphics, NETL CO2U OpenLCA Results tool file and report template file provided to DOE
5.1	Environmental Justice Questionnaire	10/31/2025	Document provided to DOE

Technical Approach / Project Scope

Department of Energy FECM/NETL Award DE-FE00032399

Success Criteria:

a. Identify and classify useable ash content

b. 24-hour continuous flow of biomass ash leachate with pH>12

c. 24-hour continuous CO_2 95% capture at 20 $kgCO_2$/day flow and precipitation as $CaCO_3$

d. ASTM measurements at 28 days exceed Portland Cement control

Technical Approach / Project Scope

Department of Energy FECM/NETL Award DE-FE00032399

Project risks and mitigation strategies

a. Finding suitable sources for waster materials.

b. Finding (or quickly building) adequate testing capabilities.

c. Recruitment of talented workforce on short notice.

Progress and Current Status of Project

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Accomplishments to date:

a. Leaching process preliminary research results:

   i. Tested the leaching process using distilled water and tap water.

   ii. Tested few samples of Ash from a coal fired power plant

   iii. Average pH tested around 11.8

   iv. Preliminary build of Leaching vessel

   v. Identified the separation techniques for separating leachate from solids

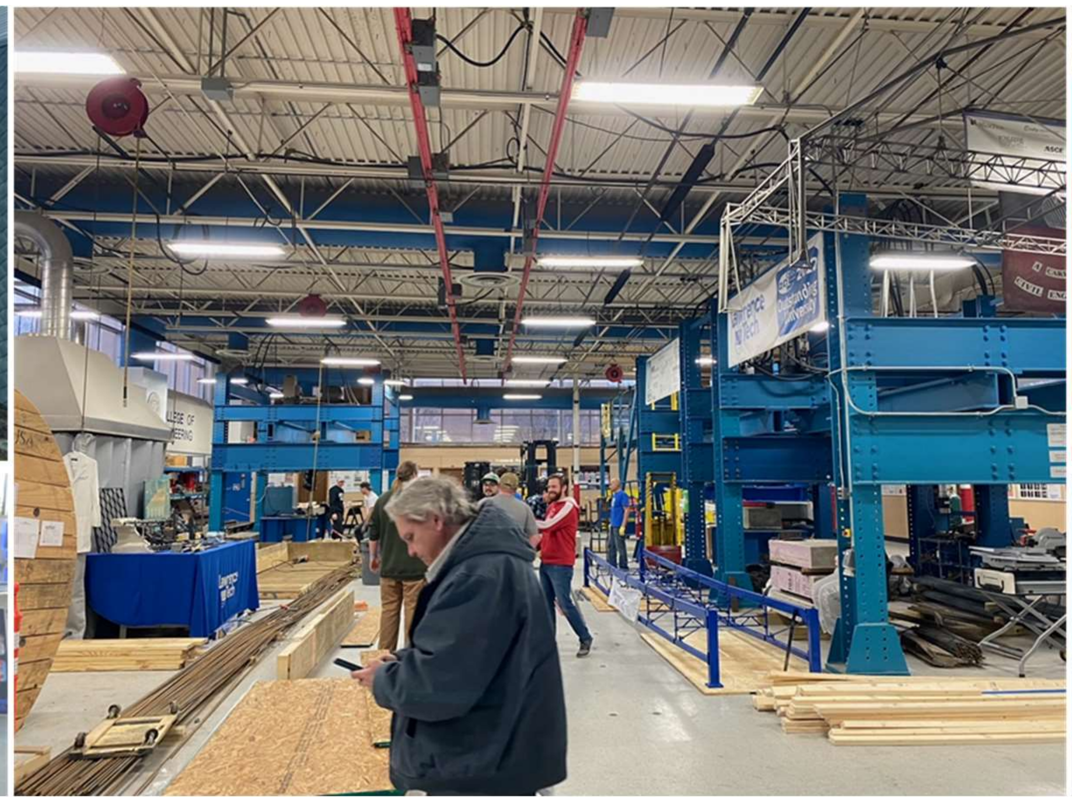
b. Used our existing research pilot system in-kind to perform preliminary methodology validation and refinement for the FECM/NETL 20 kgCO_2/day carbon capture unit to be built later this year.

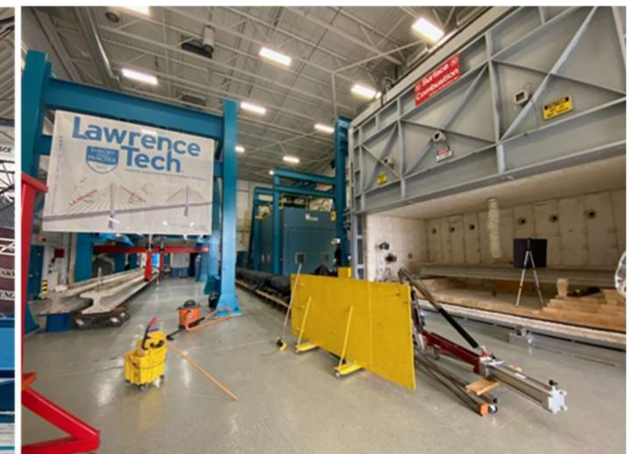
c. Identified all equipment and instruments for the process to accomplish 20 kgCO_2/day size.

Progress and Current Status of Project

Department of Energy FECM/NETL Award DE-FE00032399

d. Secured a contractual relationship with Lawrence Technological University's (LTU) esteemed Nabil Grace Center for Innovative Materials Research (CIMR)





Progress and Current Status of Project

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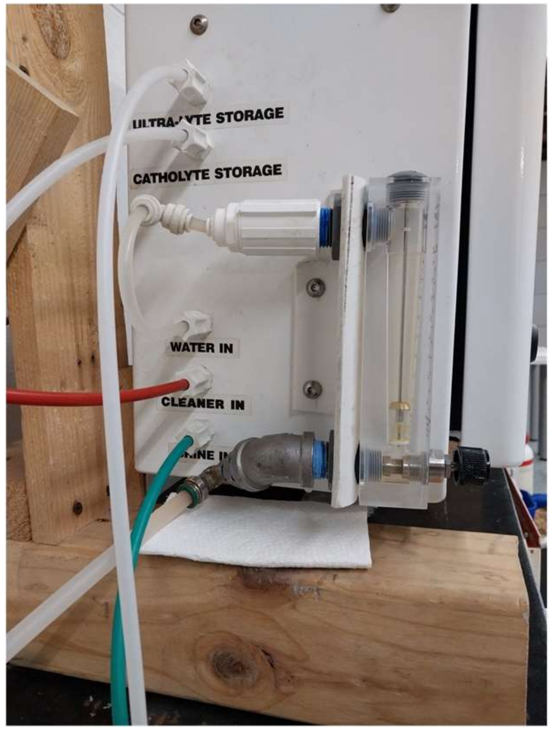
Accomplishments to date (*continued*):

e. Evaluated performance characteristics of various electrolysis and electro-chemical activation technologies.



Progress and Current Status of Project

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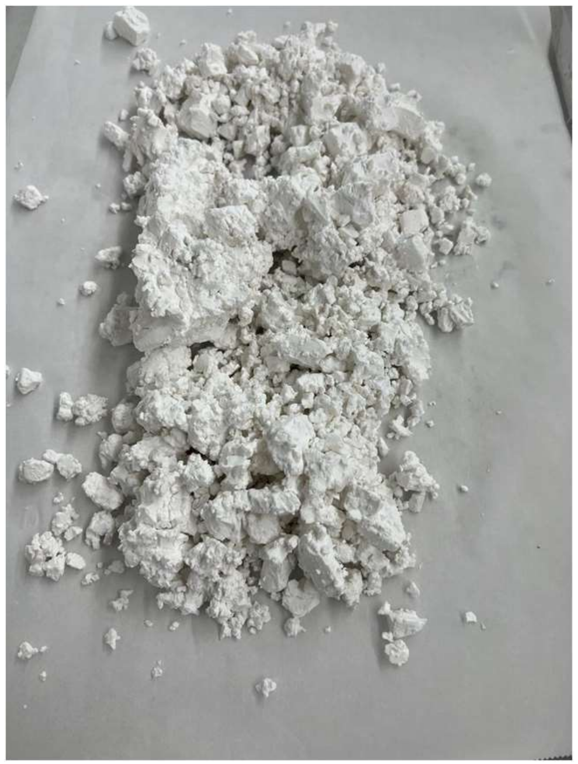
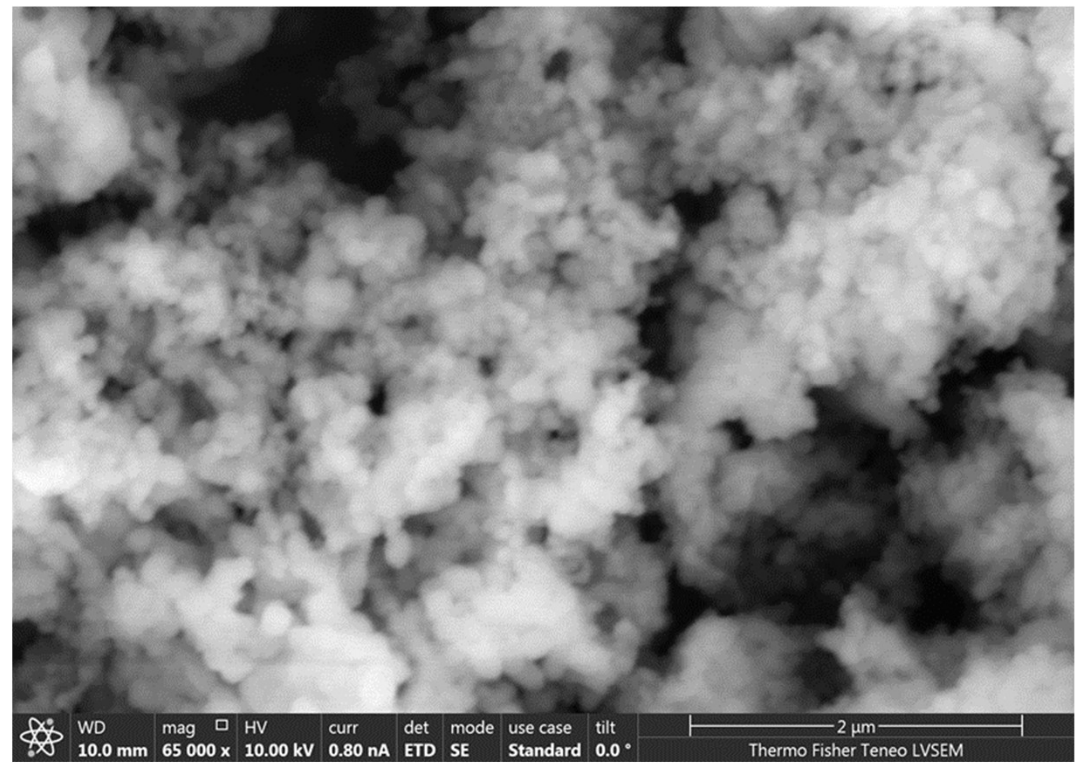
Accomplishments to date (*continued*):

f. First preliminary batches run for functional validation with satisfactory production of nanoscale $CaCO_3$.





Progress and Current Status of Project

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Accomplishments to date (*continued*):

g. Desk research of available geologic salt cavern and brine mapping.

https://www.sciencedirect.com/topics/engineering/salt-cavern

Progress and Current Status of Project

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Accomplishments to date (*continued*):

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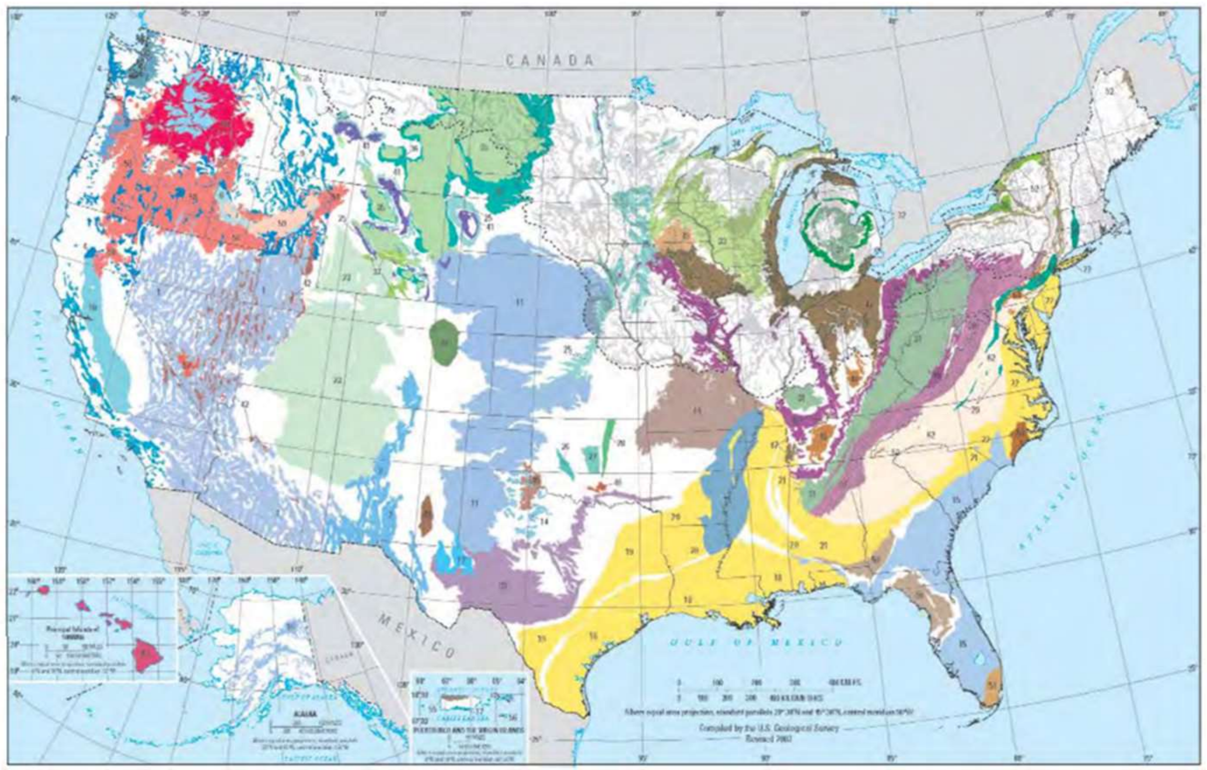

Geophysical Research Letters, Volume: 45, Issue: 10, Pages: 4851-4858, First published: 08 May 2018, DOI: (10.1029/2018GL078409)

http://water.usgs.gov/nawqa/studies/praq/images/USAaquiferMAP11_17.pdf

Progress and Current Status of Project

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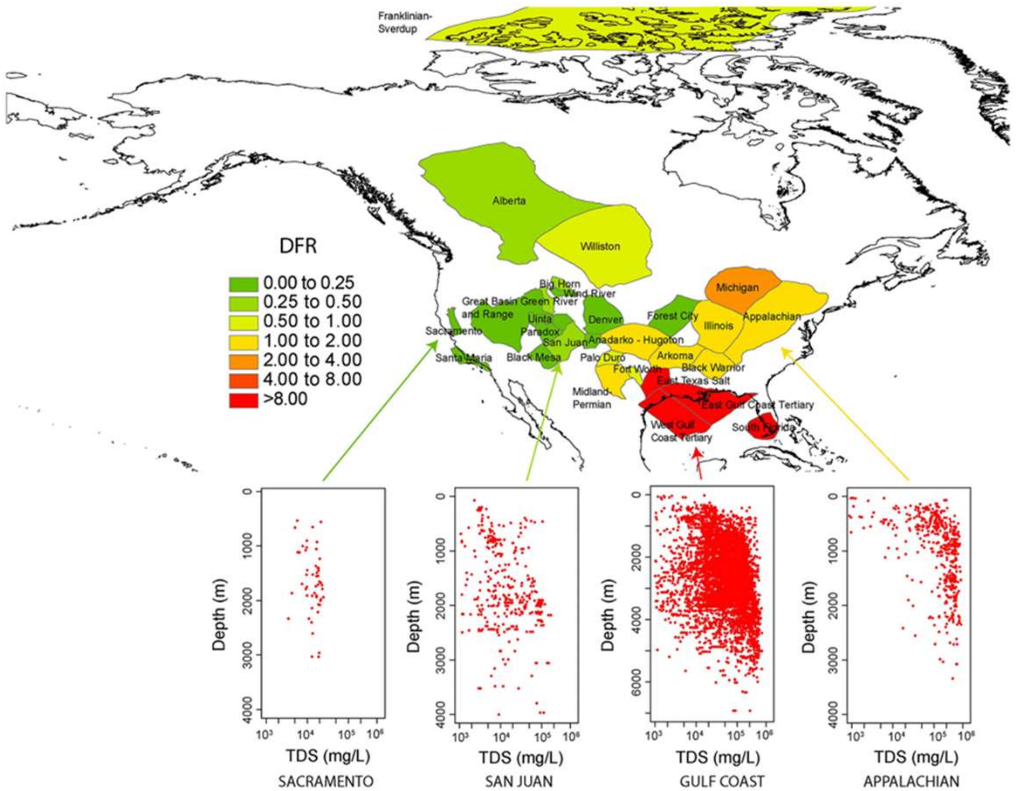

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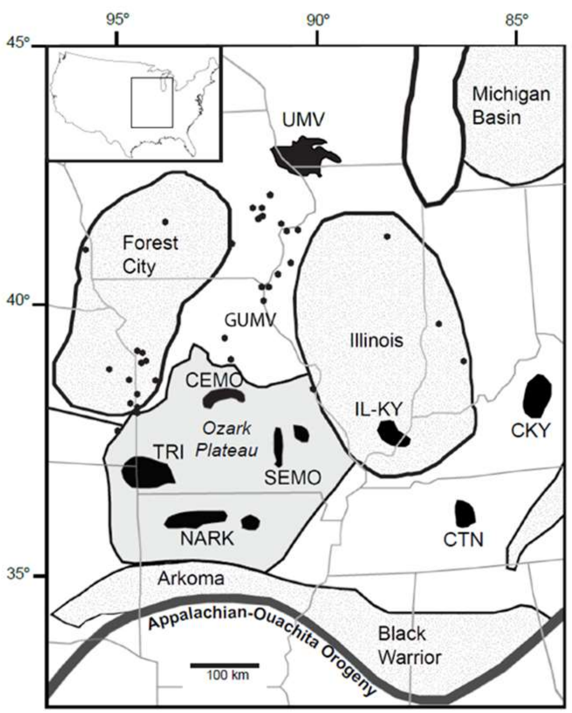

Table 3: Results for the determination of cations by ICP-MS.

SAMPLE ID	sampling method	Li mg/L	B mg/L	Na mg/L	Mg mg/L	K mg/L	Ca mg/L	Fe mg/L	Mn mg/L	Zn mg/L	Cu mg/L	Rb mg/L	Sr mg/L	Ba mg/L	Pb mg/L
12-CIT-100	gas lift	3.1	6	5630	124	9400	2830	28	13	*0.97*	3.5	1.1	125	4	*0.31*
12-CIT-101	gas lift	11	47	45090	2220	645	24600	155	56	49	<0.3**	1.8	932	16	4.4
12-CIT-102	gas lift	11	48	45600	2280	647	24900	136	57	50	<0.3**	1.8	947	*15*	*1.1*
12-CIT-103	gas lift	11	47	45800	2150	650	25000	118	57	50	<0.2*	1.8	952	17	*0.66*
12-CIT-104	gas lift	11	46	47000	2200	672	26300	107	57	50	<0.3**	1.8	982	17	*0.53*
12-CIT-105	gas lift	11	48	45900	2180	648	25500	102	57	51	<0.2*	1.8	974	17	*0.35*
12-CIT-106	ESP	11	45	44500	2060	676	23900	*299*	56	56	<0.2*	1.8	921	16	*0.29*
12-CIT-107	ESP	11	45	44300	1970	667	23500	*309*	51	51	<0.2*	1.8	907	16	*0.19*
12-CIT-108	ESP	11	47	46900	2090	646	24900	243	56	54	<0.3**	1.9	957	17	*0.61*
12-CIT-109	VS	12	48	46800	2200	661	25000	73	57	53	*1.8*	1.8	959	17	*0.54*
12-CIT-110	VS	11	47	46300	2100	649	25300	101	57	53	*0.79*	1.8	962	17	*0.52*
12-CIT-220	gas lift	11	45	48000	2070	679	25500	116	57	52	<0.2*	1.8	986	17	*1.8*
12-CIT-221	gas lift	11	48	48400	2150	679	25700	99	58	54	<0.3**	1.9	992	17	*0.51*
12-CIT-222	U-tube	11	48	47200	2210	713	25200	140	59	55	8.0	1.8	984	17	7.3
12-CIT-223	VS	11	47	48800	2140	690	23500	129	56	53	4.4	1.8	905	17	9.6
12-CIT-224	U-tube	10	40	41800	1730	985	23000	101	44	38	*0.26*	1.7	882	15	*0.77*
12-CIT-225	VS	11	47	48000	2110	685	25300	115	56	53	*1.7*	1.8	990	17	9.0
13-CIT-103	U-tube	9.7	47	47200	2240	882	23800	311	59	54	1.0	1.9	970	10	0.9
13-CIT-105	U-tube	9.5	48	45700	2200	814	23800	271	59	53	0.8	1.9	959	15	1.3

*less than limit of detection (MDL)
**less than limit of quantitation (LOQ)
Values in italics are not within the range of lowest to highest calibration standards

Mississippi Valley-type Mineralization in the US Mid-Continent

Summary of Community Benefits / Societal Considerations (CB/SCI) and Impacts (if applicable*)

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- For the proposed project, our public engagement strategy will include not only the economically active, but also members of underserved and disadvantaged communities (DAC) including individuals living in geographic proximity to the proposed project activity, geographically dispersed sets of individuals (such as migrant workers or Native Americans) where either type of group experiences common conditions, young adults, and the elderly. This engagement strategy will be guided by the principles of accountability, transparency, and collaboration, and we will endeavor to utilize the recently released Climate and Economic Justice Screening Tool (CEJST) BETA resource provided by the White House Council on Environmental Quality (CEQ) that aims to help identify DACs as part of the Justice40 Initiative.

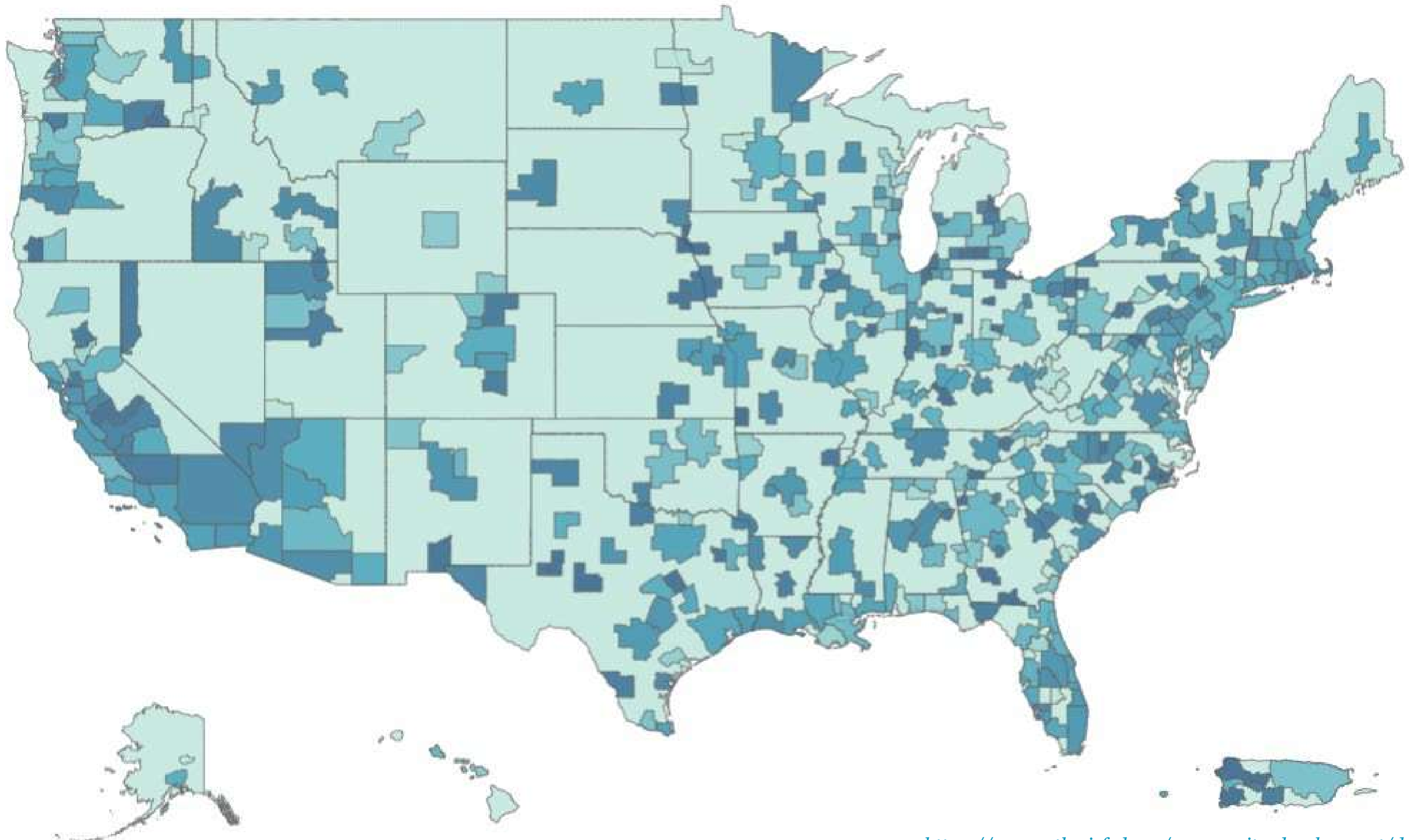
- Milestones in the project will be agreed with public engagement experts representing each of the project partners and local community representatives. Examples of engagement activities will include working with schools and community colleges, faith groups, and economic development agencies aiming to support indigenous populations and minority groups.

- Underserved communities have been unfairly impacted by climate change and the environmental consequences of industry. For example, petrochemical industries, power plants, landfills, or otherwise environmentally destructive industries are often located in areas of underserved, low-income communities, making residents more susceptible to poor air quality and negative health disparities. Furthermore, sociodemographic factors contribute to worsening health disparities from air pollution in low-income communities.

- CCM's project proposes to dramatically reduce air and landfill pollution from biomass or waste combustion sources or from cement kilns. Specifically, the use of a scrubber will prevent the release of carbon dioxide, as well as SOx, NOx, and particulate emissions from combustion and incineration sources. Furthermore, the prevention of a fraction of biomass ash from reaching landfills will mitigate the possibility of ash components from entering soil and water sources. Poor families and people of color are also more likely to be impacted by the global impacts of climate change, such as more frequent extreme weather events, increased food and water prices due to droughts, or rising sea levels. By mitigating carbon emissions, the proposed project works to indirectly mitigate impacts most severely felt by disadvantaged communities.

Community Investment Explorer 2.0: Data Tool

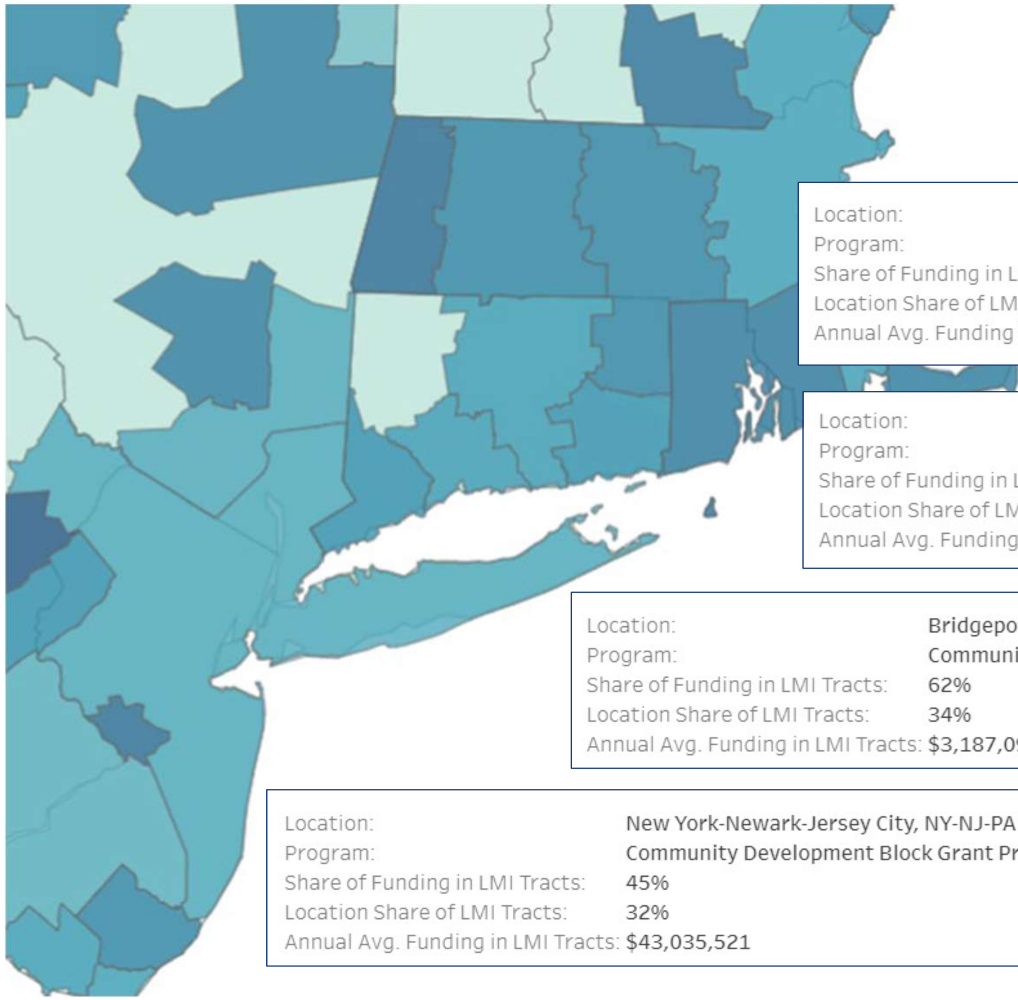
Funding in Low to Moderate Income (LMI) Communities



https://www.stlouisfed.org/community-development/data-tools/community-investment-explorer/data-tool

Community Investment Explorer 2.0: Data Tool

Funding in Low to Moderate Income (LMI) Communities



Location:	Providence-Warwick, RI-MA
Program:	Community Development Block Grant Program
Share of Funding in LMI Tracts:	78%
Location Share of LMI Tracts:	33%
Annual Avg. Funding in LMI Tracts:	$8,712,871

Location:	Hartford-East Hartford-Middletown, CT
Program:	Community Development Block Grant Program
Share of Funding in LMI Tracts:	54%
Location Share of LMI Tracts:	31%
Annual Avg. Funding in LMI Tracts:	$4,479,114

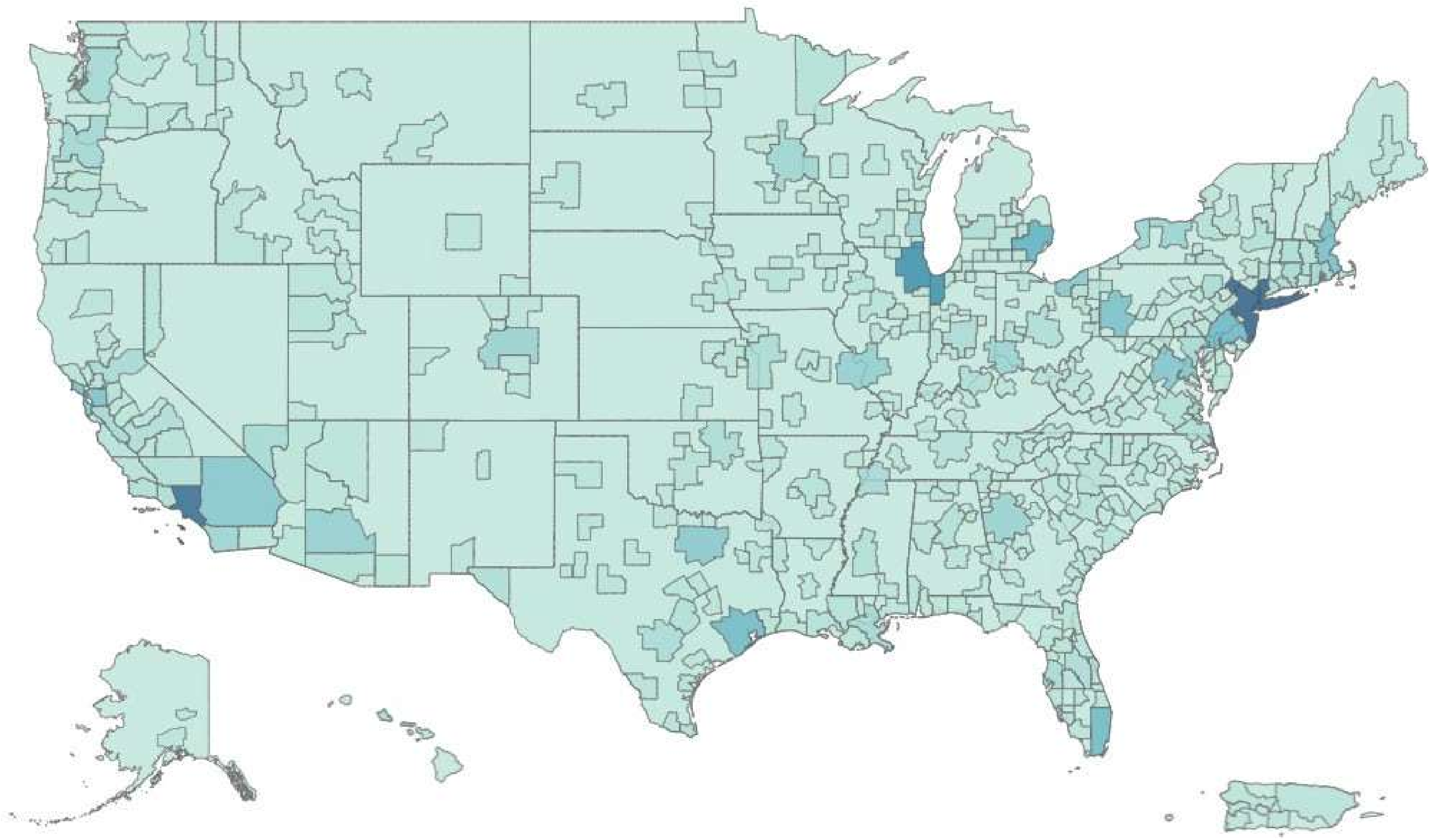
Location:	Bridgeport-Stamford-Norwalk, CT
Program:	Community Development Block Grant Program
Share of Funding in LMI Tracts:	62%
Location Share of LMI Tracts:	34%
Annual Avg. Funding in LMI Tracts:	$3,187,095

Location:	New York-Newark-Jersey City, NY-NJ-PA
Program:	Community Development Block Grant Program
Share of Funding in LMI Tracts:	45%
Location Share of LMI Tracts:	32%
Annual Avg. Funding in LMI Tracts:	$43,035,521

https://www.stlouisfed.org/community-development/data-tools/community-investment-explorer/data-tool

Community Investment Explorer 2.0: Data Tool

Funding in Communities of Color



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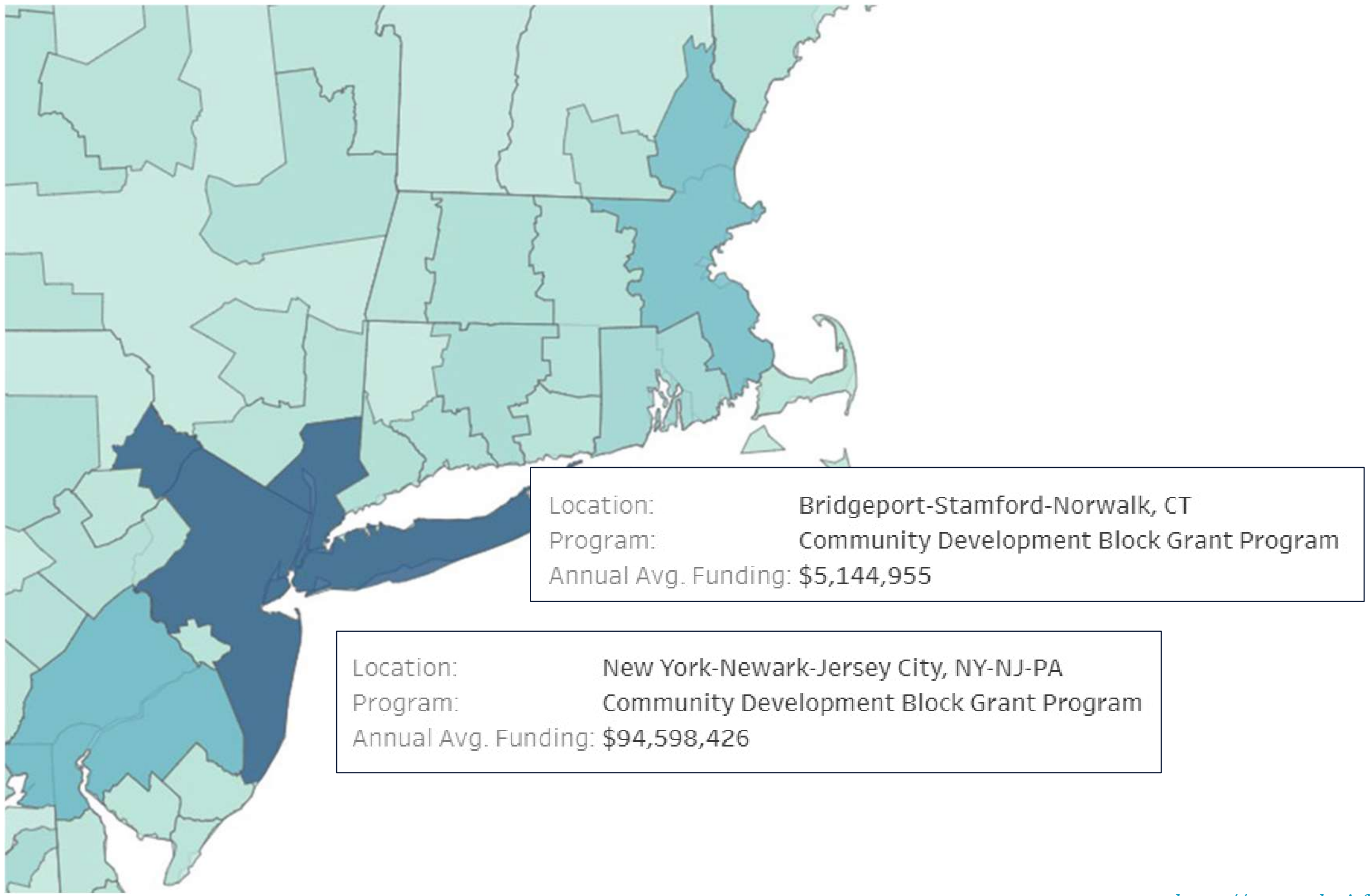

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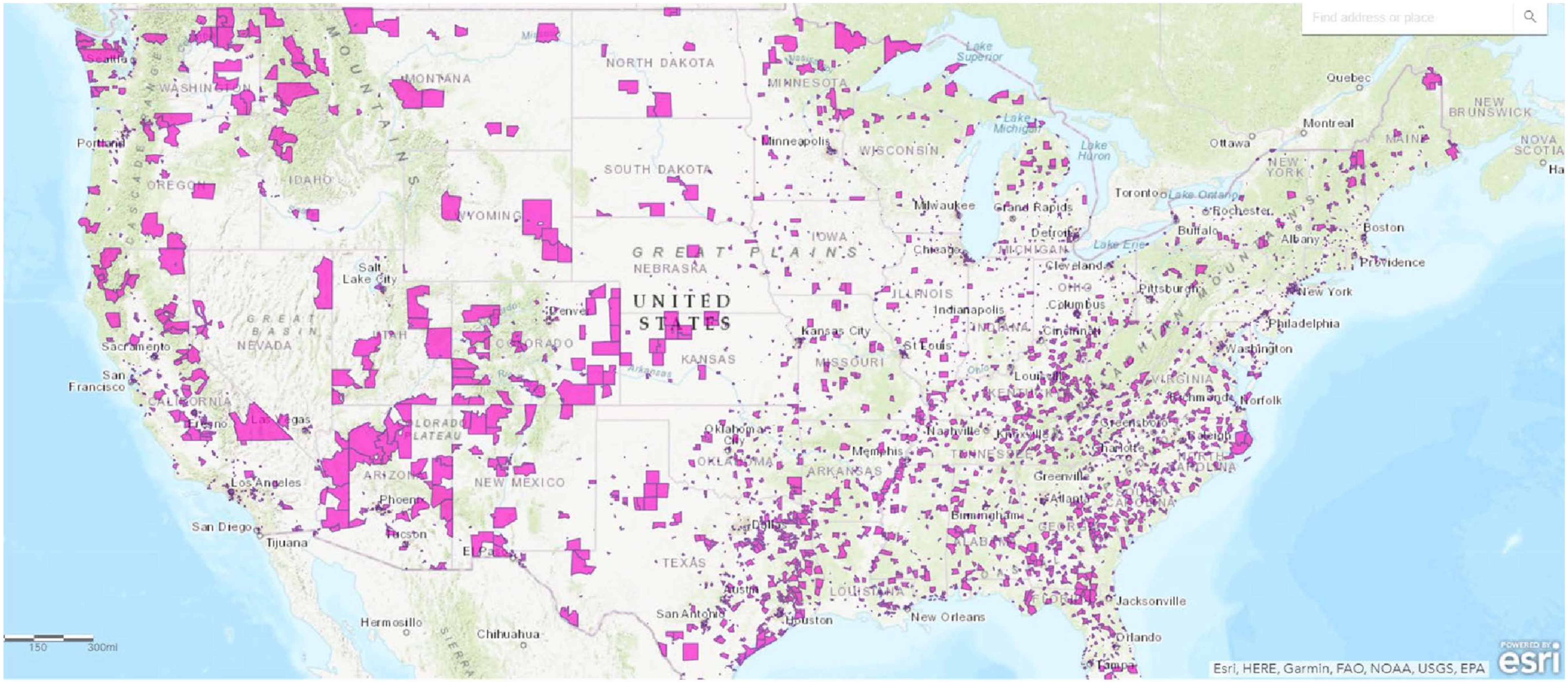
Diversity, Equity, and Inclusion Plan – U.S. Opportunity Zones

https://opportunityzones.hud.gov/resources/map



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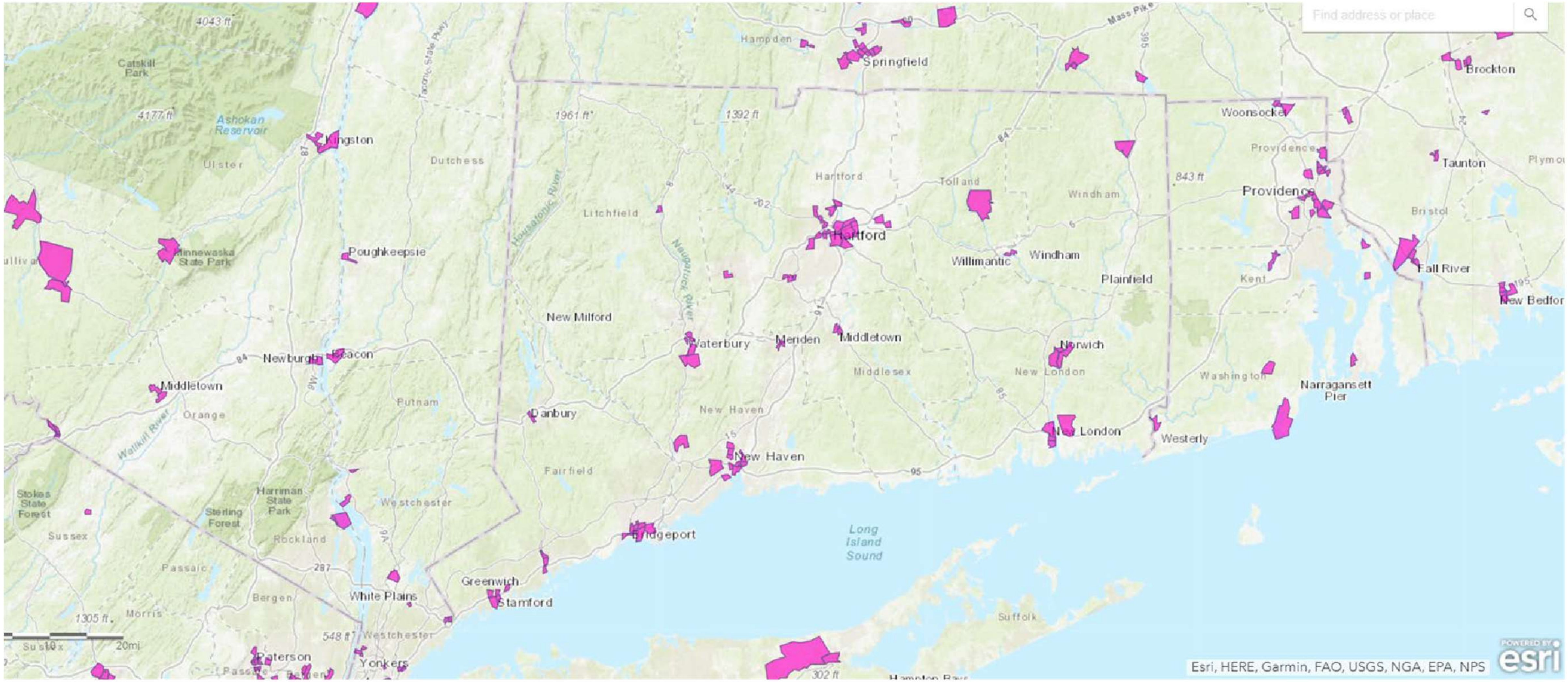
Diversity, Equity, and Inclusion Plan – Connecticut Opportunity Zones

https://opportunityzones.hud.gov/resources/map



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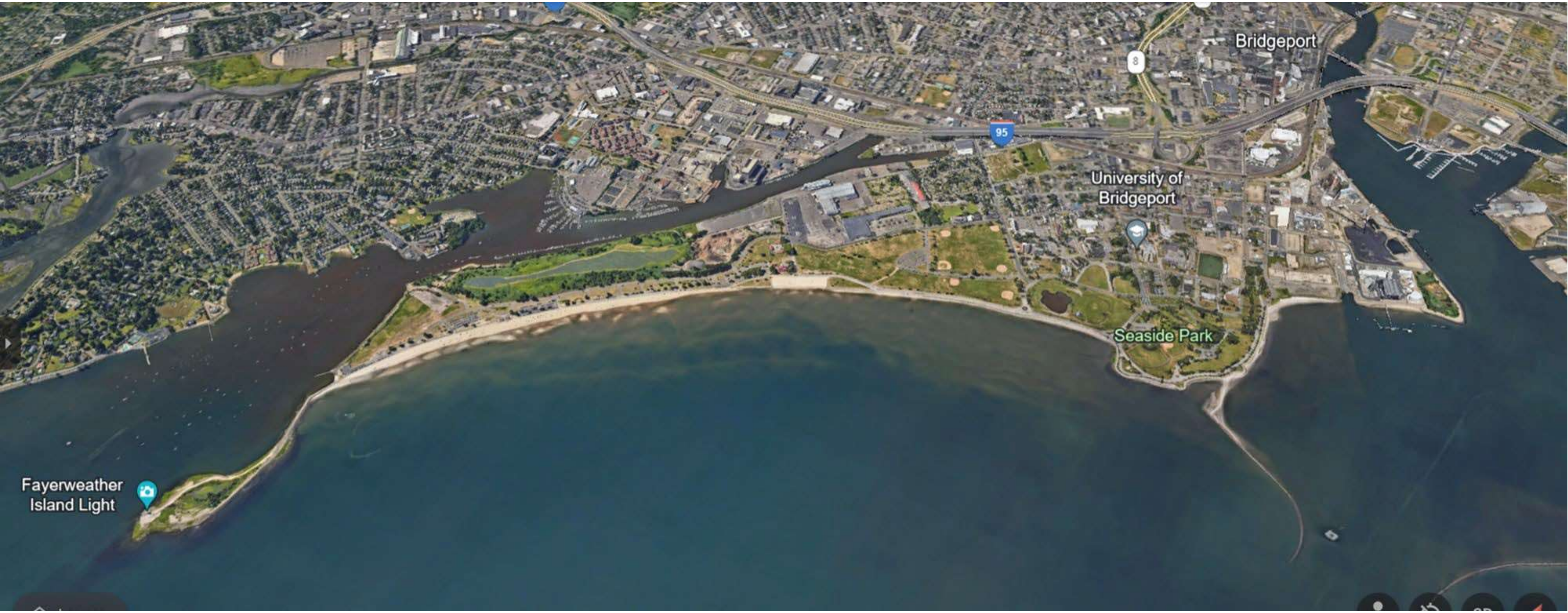
Diversity, Equity, and Inclusion Plan



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Diversity, Equity, and Inclusion Plan

DOE NETL Award DE-FE0032399

Diversity, Equity, and Inclusion Plan

1 **Water Pollution Control Authority (WPCA)** operates two wastewater treatment facilities and maintains the sewer system in the City of Bridgeport

2 **Bridgeport Regional Aquaculture Science and Technology Education Center** serves a community of diverse students with a broad range of social, economic, cultural and ethnic backgrounds.

3 **O&G Industries, Inc.** is a leading provider of construction services and products in the Northeast, with cement manufacturing and asphalt production at this Bridgeport site.

4 The **Wheelabrator** waste-to-energy plant in Bridgeport is one of several incinerators that sends waste ash to a landfill in Putnam

5 **Bridgeport Harbor Station 3 –**PSEG. Decommissioned coal plant.

6 **Bridgeport Harbor Station 5 –** 500 MW highly efficient combined cycle generating station that Generation Bridge II acquired from PSEG in February 2022.
.

7 **Goodwin University** Celebrated the opening of a "Manufacturing Epicenter" on University of Bridgeport Campus in October 2023.

8 **UB**'s 56-acre campus is home to 14 schools, colleges and institutes.The College of Engineering, Business, and Education provides comprehensive professional, education, and research opportunities to a diverse community in engineering, sciences, technology, computing, business, management, entrepreneurship, finance, analytics, accounting, education, teacher preparation, and educational administration..

9 **Bassick High School and Bridgeport Military Academy** – New 205,000 sqft facility with 48 classrooms, labs, trade programs, Advanced Manufacturing, Aeronautical Tech.

10 **Housatonic Community College** is a Connecticut State Community College with an Advanced Manufacturing Technology Center for training future leaders of CT's manufacturing workforce and placing students into jobs after graduation.

11 **The Mary & Eliza Freeman Center** – Mission to restore, preserve, and ensure the viability of the Freeman Houses and Little Liberia; teach the history of Connecticut Blacks.

12 **Metro-North Railroad** connects Bridgeport to surrounding Northeast locations, including New York City's Grand Central Station. Six new express trains were recently were added with travel time of 1 hour 22 minutes.

13 With over 132 years of service, **The Bridgeport & Port Jefferson Steamboat Company** is an institution within both the Long Island and Southern Connecticut communities.

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Diversity, Equity, and Inclusion Plan

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Diversity, Equity, and Inclusion Plan

Lessons Learned

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Discuss lessons learned and mitigation strategies employed during technology development and project execution

a. Leave adequate time for staffing.

b. Leave adequate time for equipment purchase and lead time.

c. Work with DOE Contract team to set a target launch date.

Plans for future testing/development/commercialization

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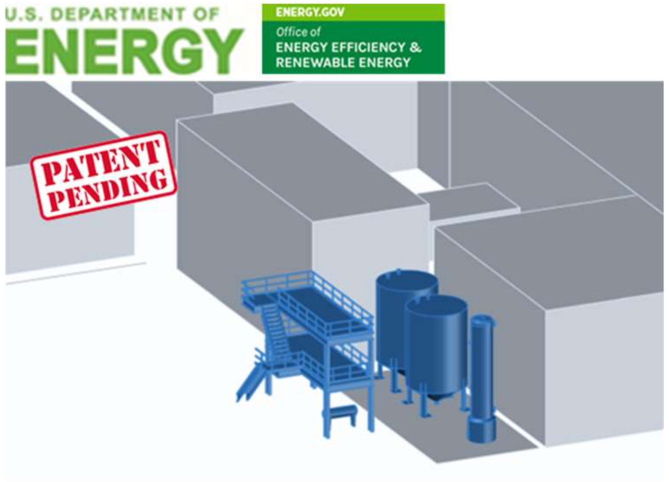
Plans for future testing/development/commercialization:

a. U.S. Department of Energy DE-FOA-00002804 Award DE-EE00010852.

b. U.S. Department of Energy Office of Clean Energy Deployment (OCED) opportunities.

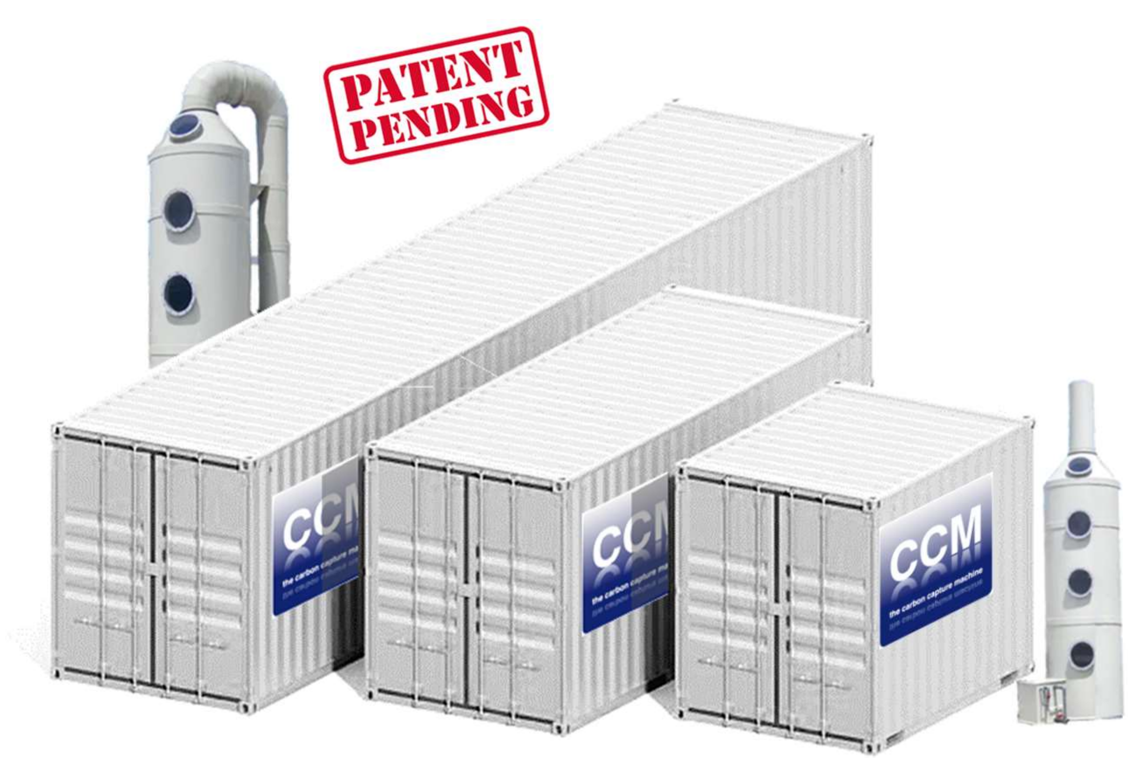
c. Commercial scale modularized and containerized solution.



Plans for future testing/development/commercialization

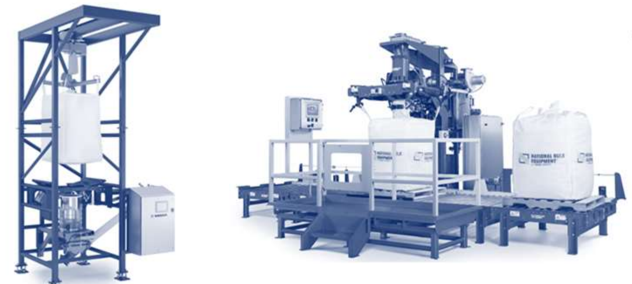
Department of Energy FECM/NETL Award DE-FE00032399

Chemical storage

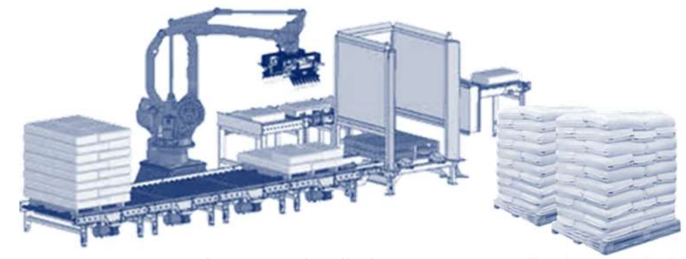


Carbon Capture Machine (CCM)

- Scalable containerized design for a wide range of engine/furnace sizes
- Emission “agnostic” – natural gas, biogas, diesel, coal, etc.
- Produces a wide range of $CaCO_3$ or $MgCO_3$ carbonates for a variety of applications
- Purified NaCl brine output is desirable for numerous industrial applications



Bulk bag fillers



Automated palletizer

Drying equipment

Appendix

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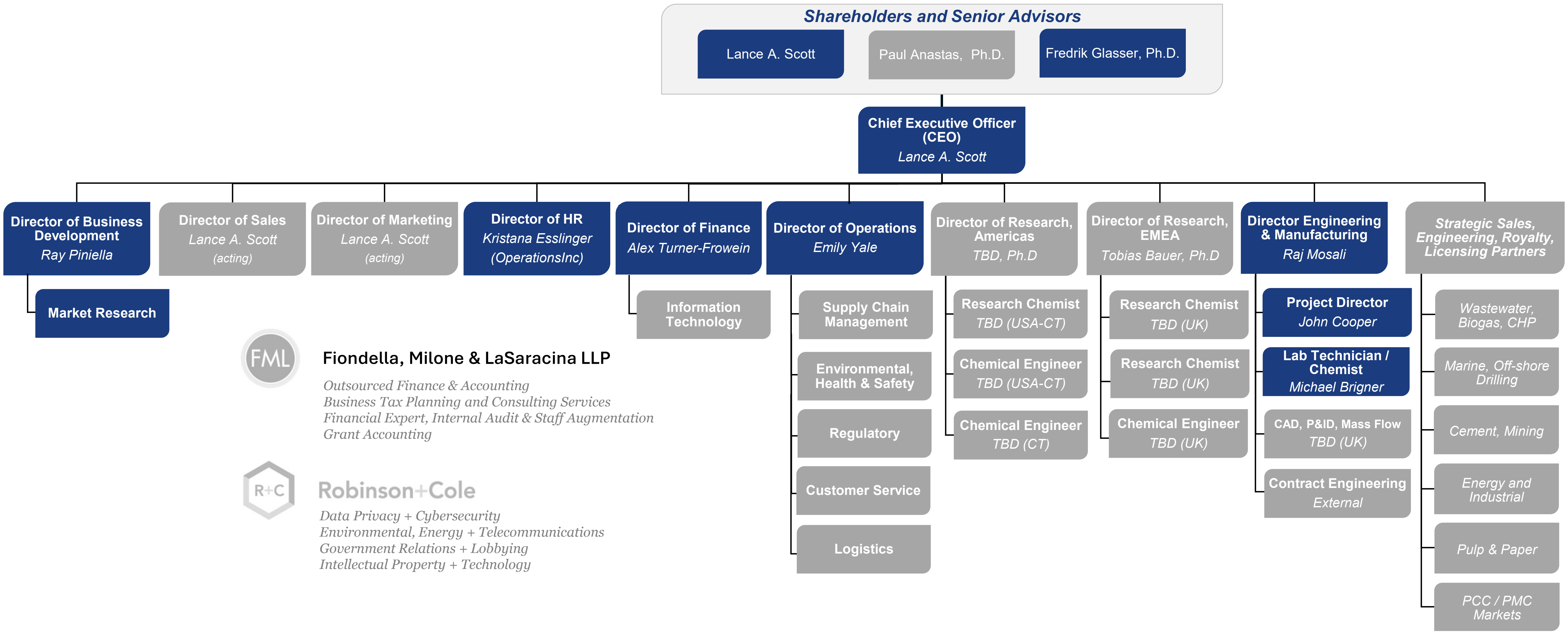
CCM Organizational Structure

Cross-functional International Matrix Organization with 'hands on' Board of Advisors



Gantt Chart

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Task #	Subtask #	Task Name	2023 Q4	2024 Q1	2024 Q2	2024 Q3	2024 Q4	2025 Q1	2025 Q2	2025 Q3	2025 Q4
1.0		**Project Management and Planning**									
	1.1	Project Management Plan **Milestone**									
	1.2	Technology Maturation Plan **Milestone**									
2.0		**Design and Optimization of Biomass Ash Alkalinity Recovery Unit** Identification,									
	2.1	Characterization, and multi-criteria informed decision on optimal waste sources									
	2.2	Design, build, and proof of concept of flow extraction unit									
	2.3	Optimization of flow extraction of Na_2O and K_2O									
		Milestone: Continuous, selective. and efficient biomass ash alkalinity recovery									
3.0		**Design and build integrated 20kg CO2/day prototype for amorphous calcium carbonate production from flue gas using biomass ash and desalination brines**									
	1.	Model and size separate and integrated units of alkalinity									
	2.	Source and build 20 kg CO2/day prototype									
		Milestone: Continuous CO2 capture using biomass ash leachate and continuous synthesis of CaCO3 with 20 kg/day prototype									
	3.	Optimization of precipitation conditions for amorphous calcium carbonate stabilization and production of performant cement									
	4.	Optimize full CO2 capture and mineralization process									
		Milestone: Production of performant cement with ACC									
1.		**Perform a detailed assessment of economic and environmental impacts of amorphous calcium carbonate production from flue gas using biomass ash and desalination brines**									
	2.	Techno-economic analysis (TEA) - **Final Milestone**									
	3.	Life Cycle Assessment (LCA) **Milestone**									
5.0		**Community Engagement, Inclusion and Diversity**									
	1.	Environmental Justice Questionnaire **Milestone**									
	2.	Community and Stakeholder Survey									

Thank you for your consideration…