[DE-FE0032259] Resource Assessment for Carbon Dioxide Storage via Accelerated Carbonation Reaction with Recycled Concrete Aggregates (RCA)

2023 FECM/NETL Carbon Management Research Project Review Meeting

Speaker: Seunghee Kim, Ph.D., P.E., University of Nebraska-Lincoln

August 29, 2023

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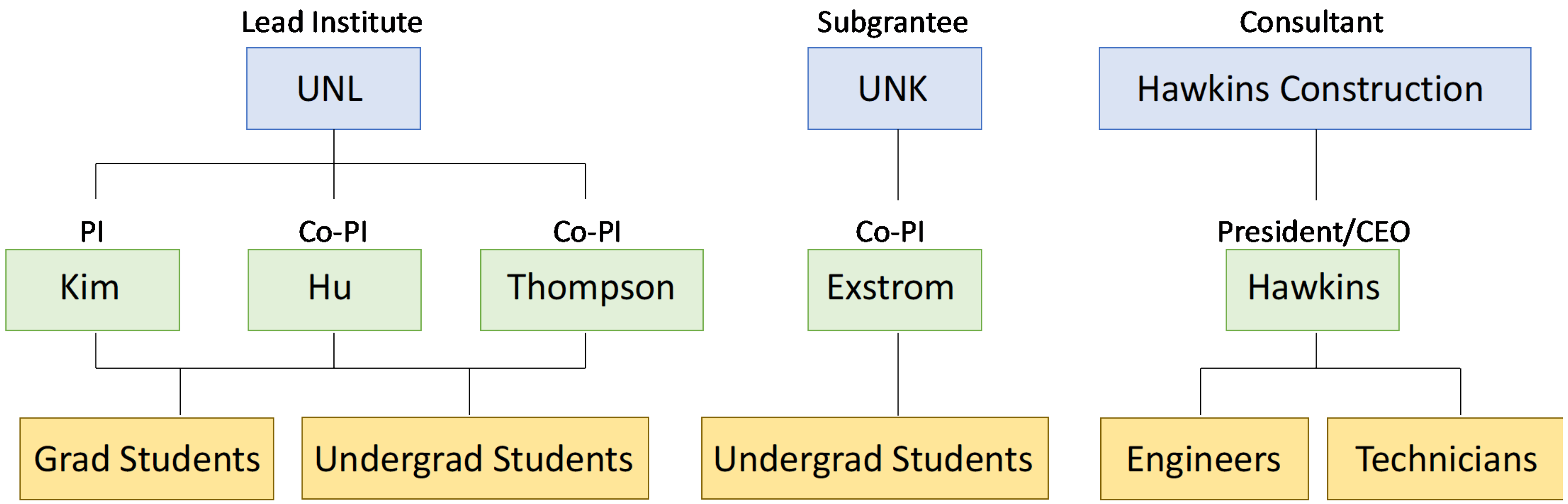
Key Project Participants

- PI: Seunghee Kim, Associate Professor, Department of Civil and Environmental Engineering, University of Nebraska-Lincoln (UNL)
- Co-PI: Jiong Hu, Professor, Department of Civil and Environmental Engineering, UNL
- Co-PI: Eric Thompson, Professor, Economics; Director of the Bureau of Business Research, UNL
- Co-PI: Christopher Exstrom, Professor, Chemistry, University of Nebraska at Kearney (UNK)
- Consultant: Chris Hawkins, President/CEO of Hawkins Construction Company



The organizational chart for project assignments

Project Objectives & Tasks

The Overall Objective

The overall objective is to identify the optimum processes to maximize CO_2 sequestration, enhance the efficiency of carbon mineralization, improve the technology readiness of carbon mineralization, and build and advance the required industrial waste resource base, in particular waste concrete base.

The Scope of Work

Task 1: Project management and planning

Task 2: Field sampling

Task 3: Laboratory analysis of carbonation reactions

Task 4: Resource assessment

Project Performance Dates

Project Performance Dates

July 1, 2023 – June 30, 2025.

Table. Milestones of the proposed project.

Task/ Subtask	Milestone Title & Description	Planned Completion Date	Verification Method
1/1.1	Updated project management plan	9/30/2023	Project management plan file
1/1.1	Kickoff meeting	9/30/2023	Presentation file
2/2.1-2.2	1. List of collected RCA samples and characterization results	3/31/2024	Summary report
3/3.1-3.2	2. Small-scale carbonation reaction tests and the physical and mechanical test results	9/30/2024	Milestone report and presentation file
3/3.3-3.5	3. Large-scale carbonation reaction tests, the prediction of reaction rates and carbon uptake rates, and protocols for optimum CO_2 storage in RCA	3/31/2025	Milestone report and evaluation of derived carbonation and CO_2 uptake rates
4/4.1-4.3	4. RCA resource base, CO_2 storage capacity, and cost and market analysis results	6/30/2025	Final report and presentation file

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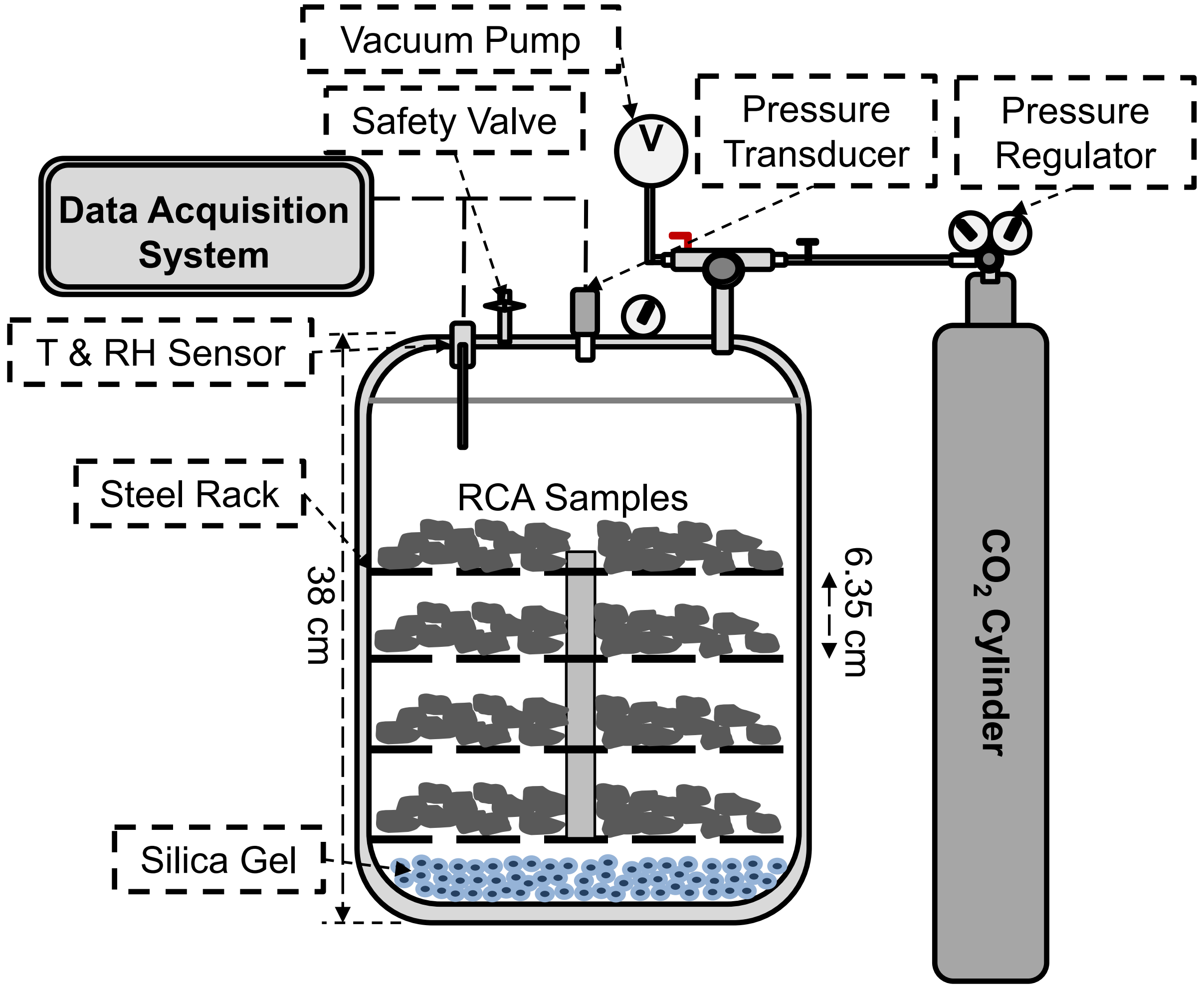
Preliminary research between UNL and Hawkins Construction Company: Small-Scale Reaction Chamber



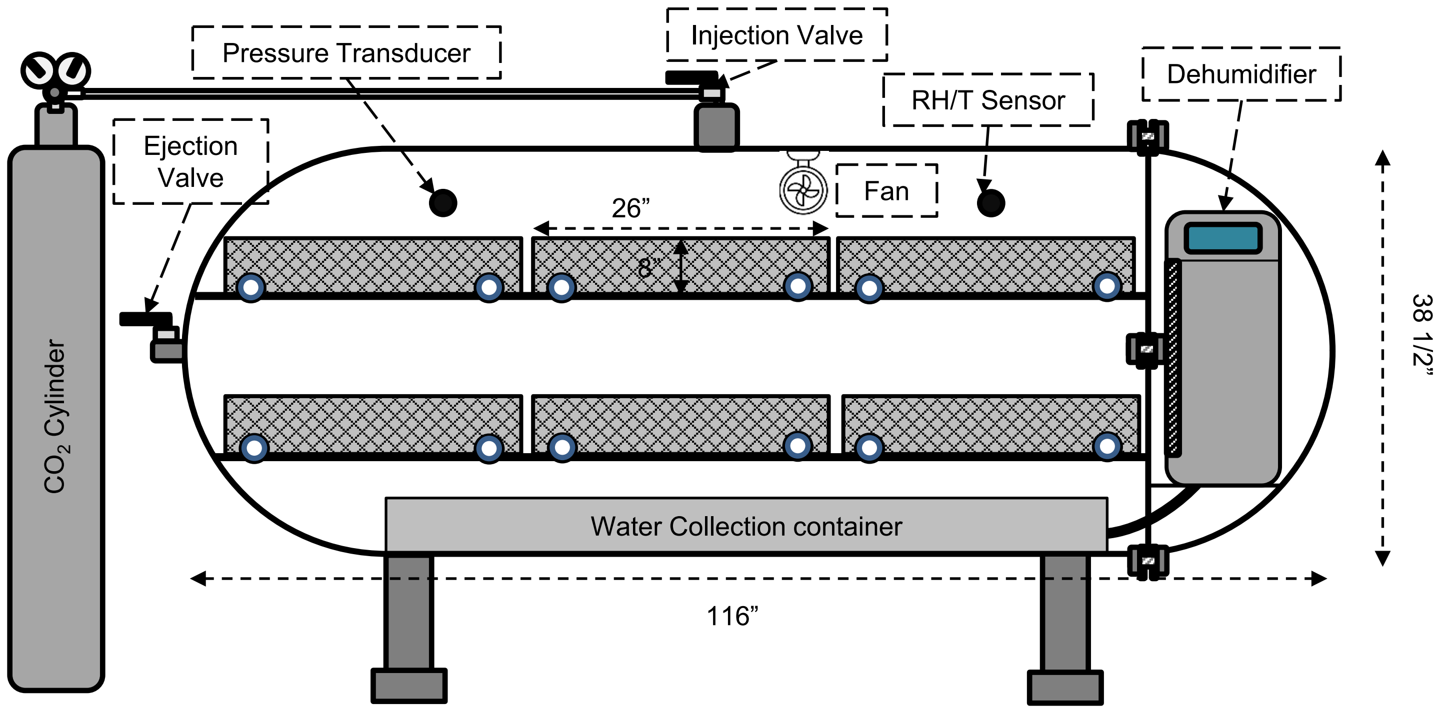
$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

$C\text{-}S\text{-}H + CO_2 \rightarrow CaCO_3 + SiO_2 + nH_2O$

Carbonation variables:

(1) Pressure, (2) Temperature, (3) Reaction time, (4) Relative humidity

Preliminary research between UNL and Hawkins Construction Company: Large-Scale Reaction Chamber



Carbonation variables:

(1) Pressure: 1 – 60 psi (7 – 414 kPa)

(2) Temperature: ambient temperature, cold temperature, and hot temperature

(3) Reaction time: 1 – 24 hours

(4) Relative humidity: 5 – 80%

Project Locations

- UNL – Peter Kiewit Institute & Hawkins Construction Company in Omaha & City Campus
- UNK – Bruner Hall of Science

Importance of Project towards advancing DOE Program Goals

Scientific and Technological Merit

- AOI-4 Carbon Storage Technology. Emphasis on classifying RCA with key indices, lab measurements of carbonation reaction, CO_2 uptake rates at different scales, and mechanical & chemical characterization of carbonated RCA.
- The research will provide valuable results for RCA resource base and CO_2 storage potential.
- Potential to achieve a minimum of 20 million tons of permanent CO_2 storage per year.

Novelty of the Project

- In-house, fabricated, small- (30-Liter) and large-scale reaction chambers (one-ton capacity).
- Specially designed physical, mechanical, and chemical test sets: deliver higher-value products for the construction industry and green market.
- Collaboration between academia and industry.

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Project Execution Plan

Task 1.0 Project Management and Planning

Subtask 1.1 – Project management plan

Subtask 1.2 – Diversity, Equity, and Inclusion

Task 2.0 Field Sampling

Subtask 2.1 – Acquisition of RCA

- From different locations with temp-humidity
- Source code for concrete mixture
- Origin of infrastructure, size and gradation

Subtask 2.2 – Characterization of RCA

- Physical/mechanical properties of RCA
- Residual mortar content (RMC)
- Chemical composition
- → several groups of RCA

Task 3.0 Lab Analysis of the Carbonation Reactions

Subtask 3.1 – Measurement of reaction kinetics at small-scale reaction chamber

- Different RCA groups, CO_2 pressure, temperature

Subtask 3.2 – Measurement of physical and mechanical properties of CO_2-treated RCA

- Physical/mechanical/chemical tests

Subtask 3.3 – Measurement of reaction kinetics at large-scale reaction chamber

Subtask 3.4 – Prediction of reaction rates and carbon uptake rates at anticipated field conditions

- Solid-gas kinetic models, CO_2 mass consumption

Subtask 3.5 – Development of Protocols for Optimum CO_2 sequestration of RCA

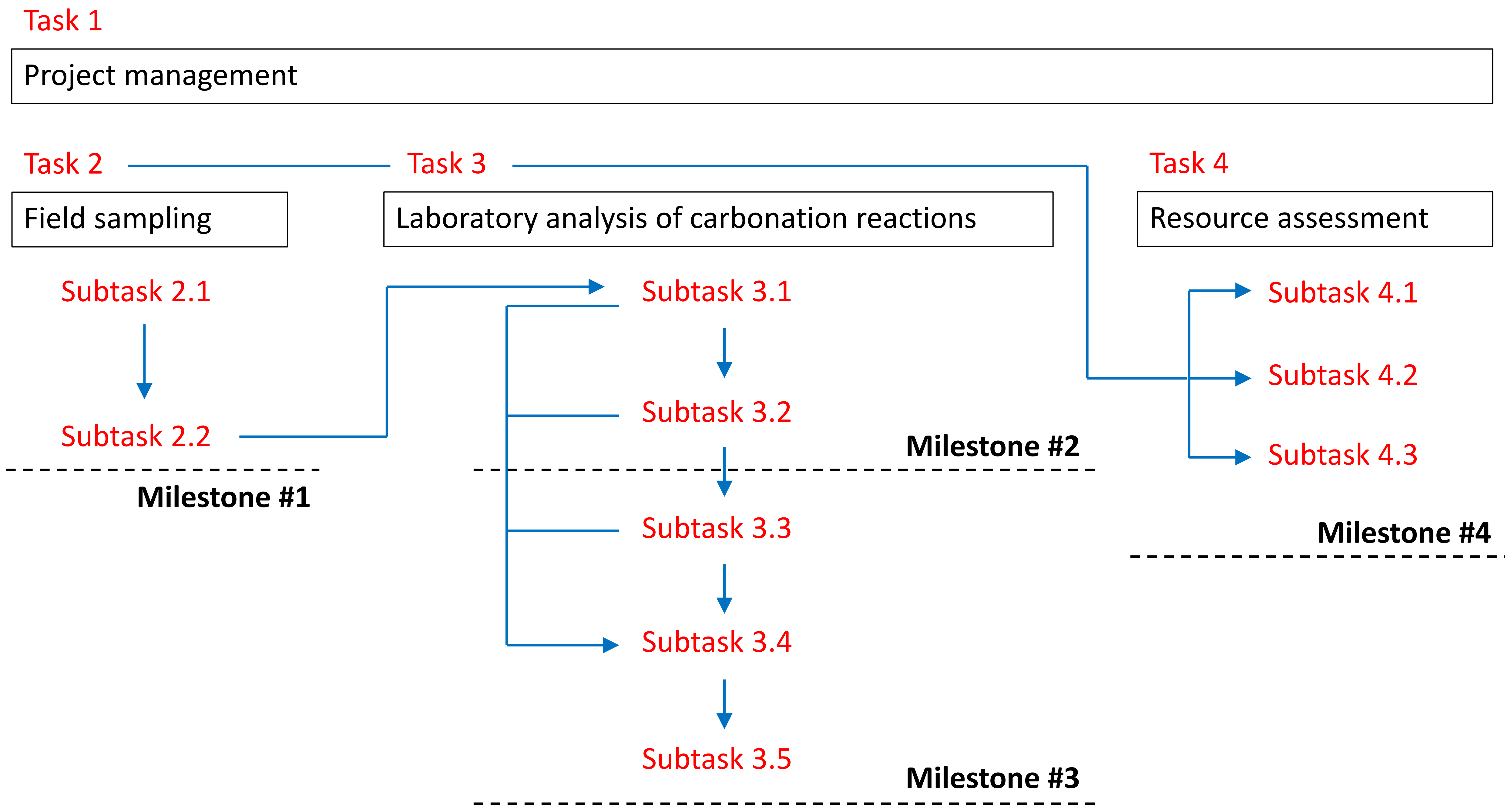
Task 4.0 Resource Assessment

Subtask 4.1 – Resource assessment of RCA: expected resources of each RCA groups

Subtask 4.2 – CO_2 storage potential

Subtask 4.3 – Cost and market analysis: Industrial wastes and mineralization process

Project Schedule & Key Milestones



Expected Outcomes and Impacts

Expected Outcomes and Impacts

- Improve the quality of the RCA resource base and carbon sequestration capacity via the carbonation of RCA in the *ex-situ* mineralization setting.
- First set of quantitative test data on carbonation reaction rates and carbon uptake rates with different RCA groups.
- Potential to disrupt the $19 billion stone aggregate industry in an environmentally positive manner.
- Reduced burden on the construction and demolition waste management.
- Target cost: $15-18 per ton for Carbonated RCA *vs*. $22-28 per ton for natural limestone aggregates.

Project Success Criteria

Task/ Subtask	Decision Point Description	Date	Success Criteria
1	Decision regarding revision of Project Management Plan	9/30/2023	New Project Management Plan submitted if necessary.
2.1-2.2	Field sampling – acquisition and characterization of RCA	6/30/2024	Source materials are classified with residual mortar content, chemical composition, and other relevant physical/ mechanical indices.
3.1-3.3	Determination of carbonated RCA properties	3/31/2025	Improvements in the physical, mechanical, and environmental characteristics of source materials after the carbonation reaction are demonstrated.
3.4-3.5	Derivation of carbonation reaction rate and CO_2 uptake rate	3/31/2025	Carbonation reaction rates at anticipated in-situ conditions are derived. Potential carbon uptake rates at the presumed mass-scale operation are estimated.
4.1	Resource assessment of RCA	6/30/2025	The location, quantity, availability, and accessibility of RCA resources by each classified quality group are identified.
4.2	CO_2 storage potential	6/30/2025	CO_2 storage potential ($MtCO_2$ stored or sequestered) of identified RCA resource groups is assessed.
4.3	Cost and market analysis	6/30/2025	The cost analysis of carbonation operation, as well as supply, demand, and market analysis are completed.

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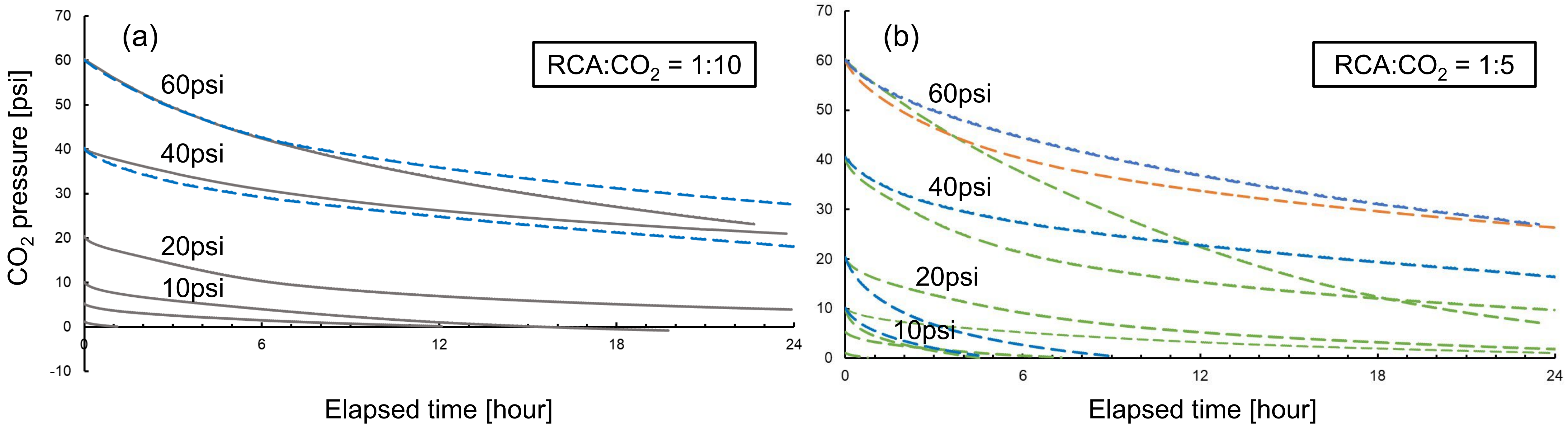
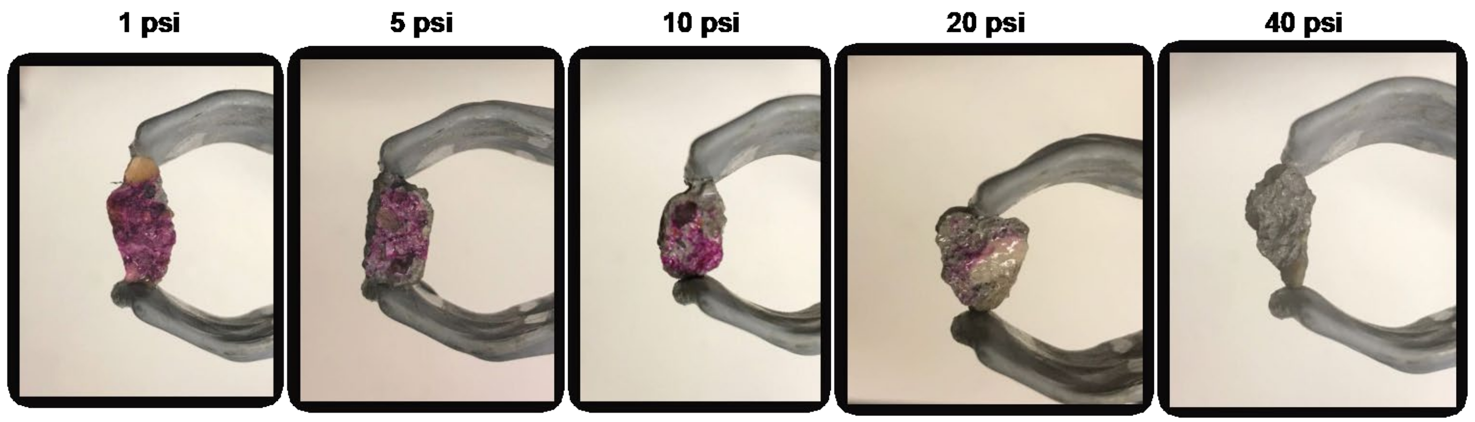
Summary of Significant Accomplishments/Key Findings (1)

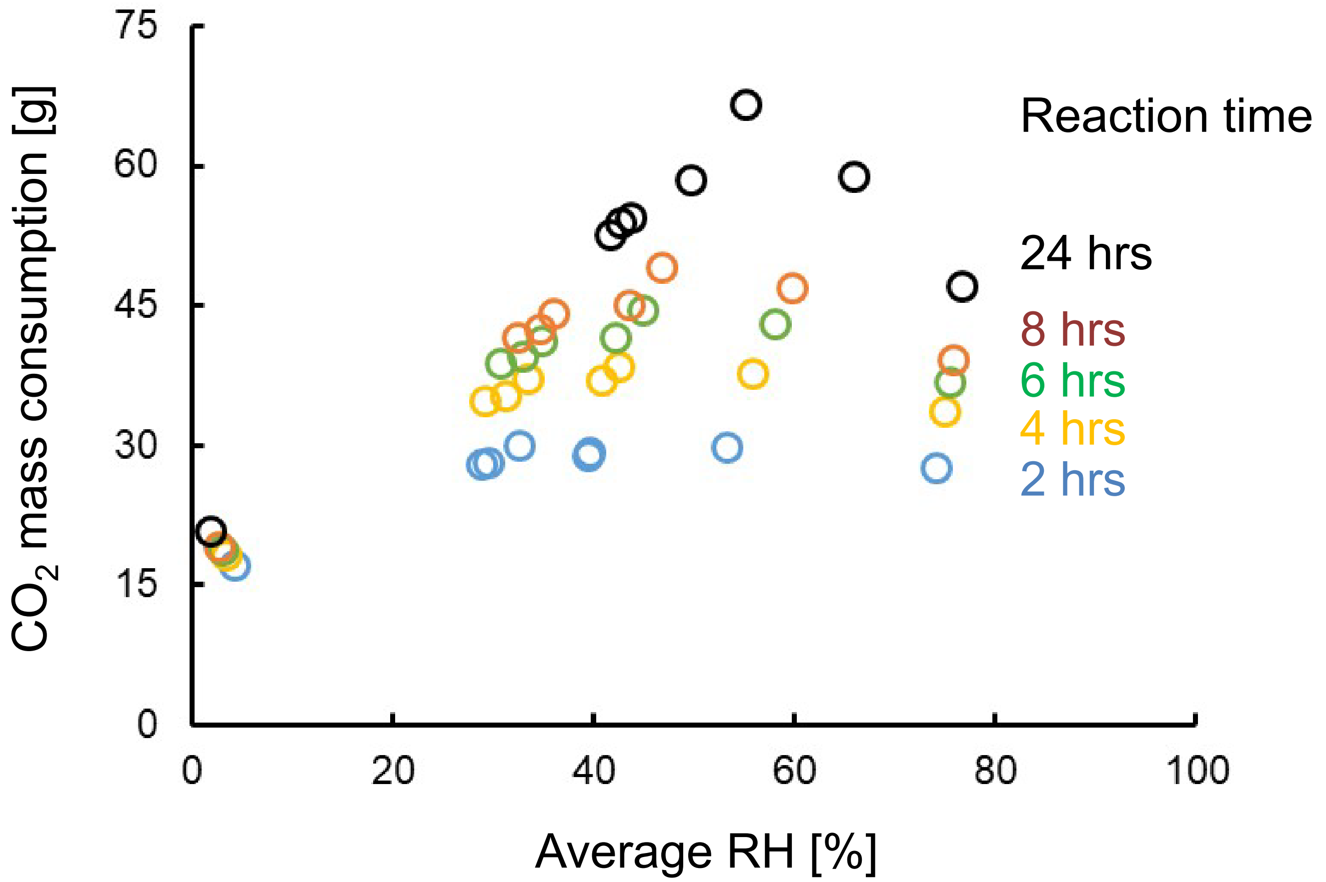
CO_2 Pressure and Reaction Time

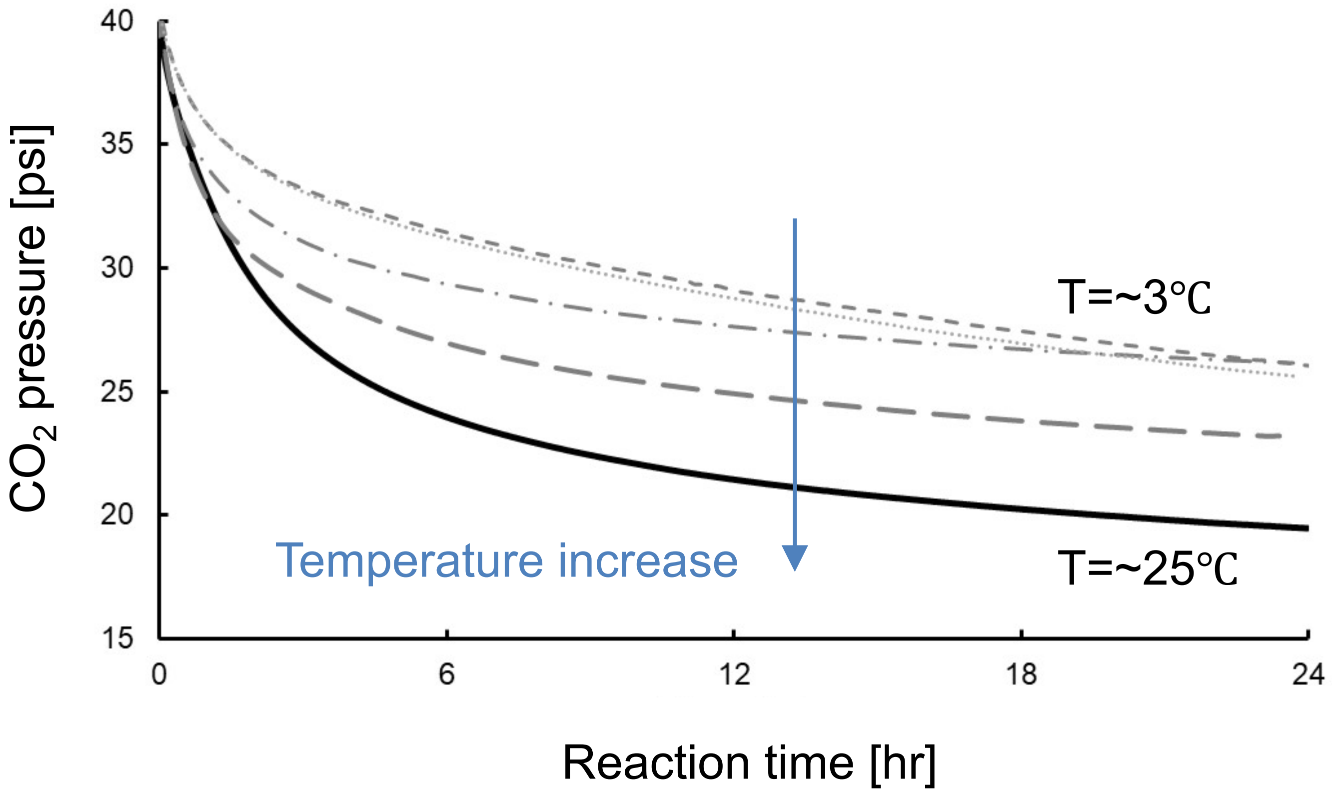




Summary of Significant Accomplishments/Key Findings (2)

Relative Humidity (RH) and Temperature



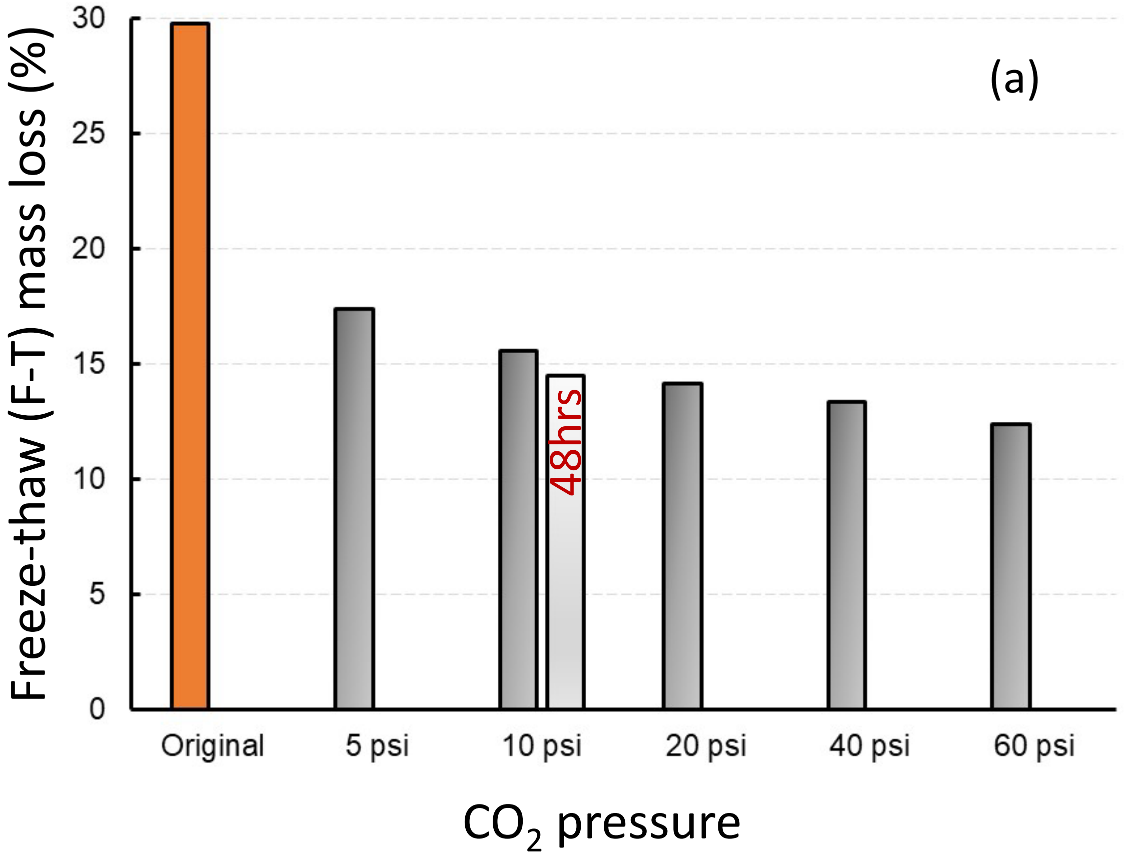


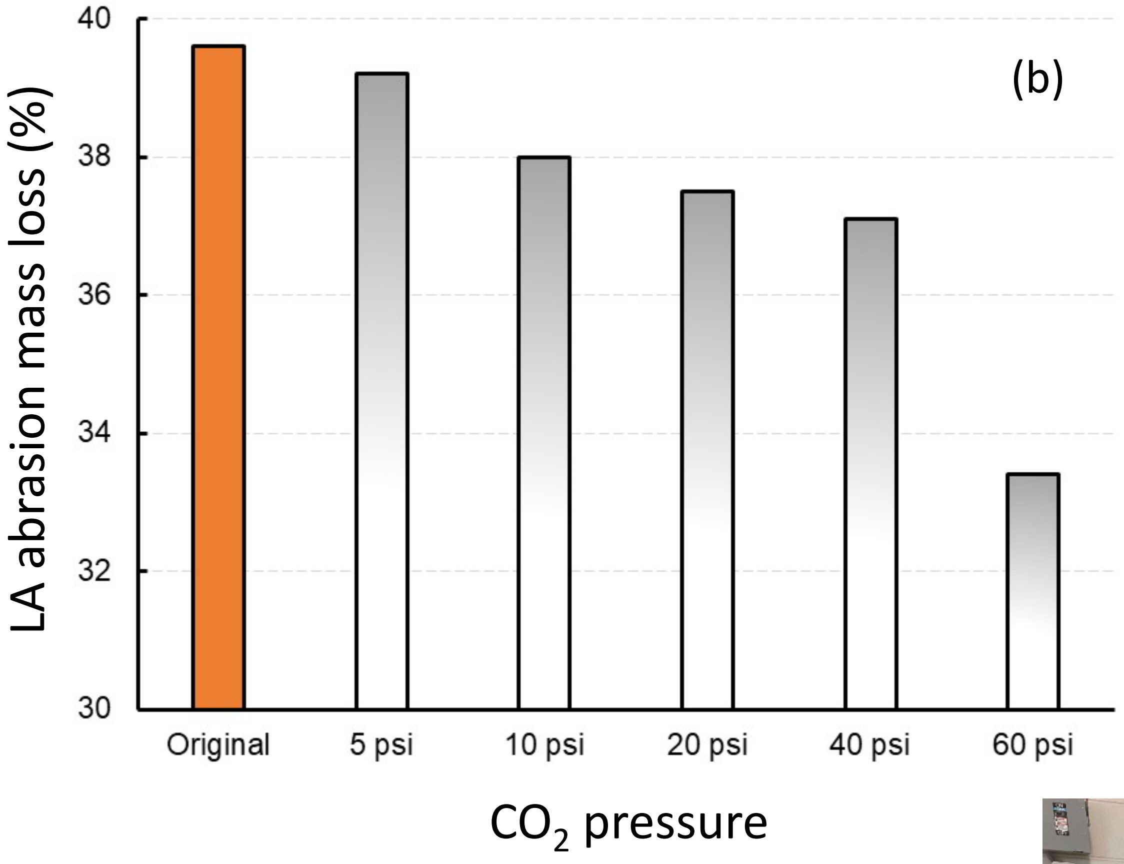
Optimum CO_2 consumption, thus maximum CO_2 storage, can be achieved when the RH is maintained between 45%-55% during the carbonation reaction.

Temperature could play an important role in accelerating the carbonation reactions.

Summary of Significant Accomplishments/Key Findings (3)

Mechanical Properties and Durability Improvement of Carbonated RCA

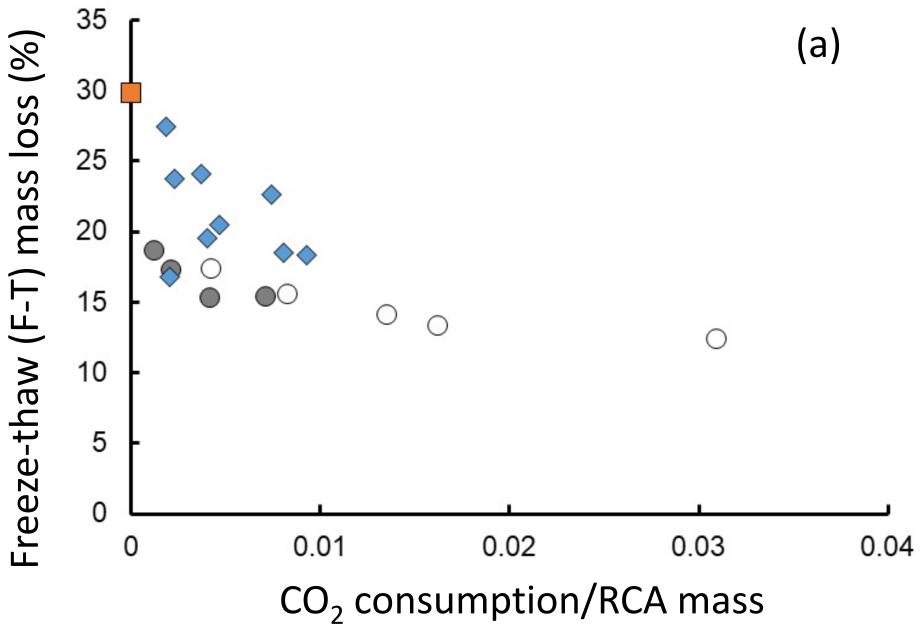


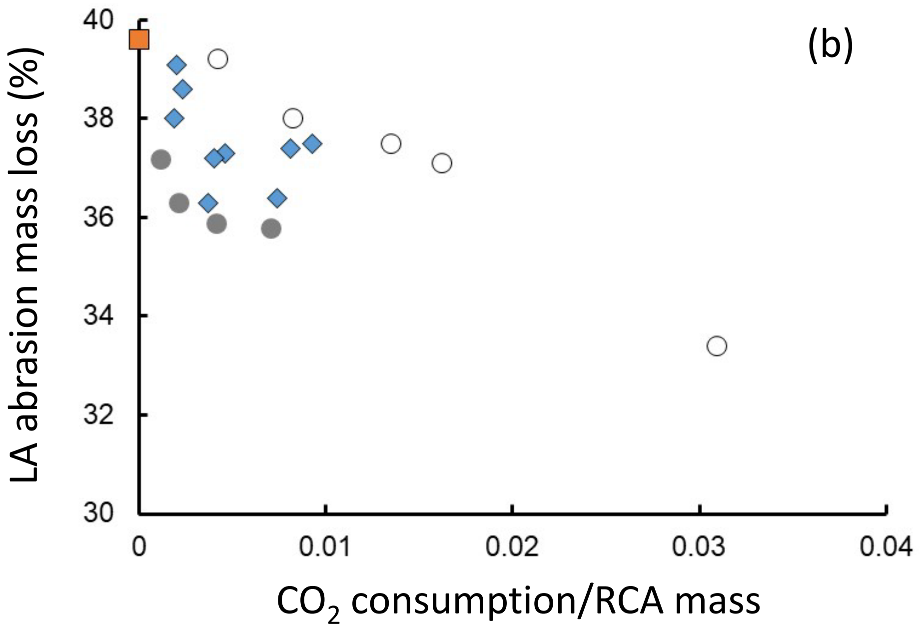


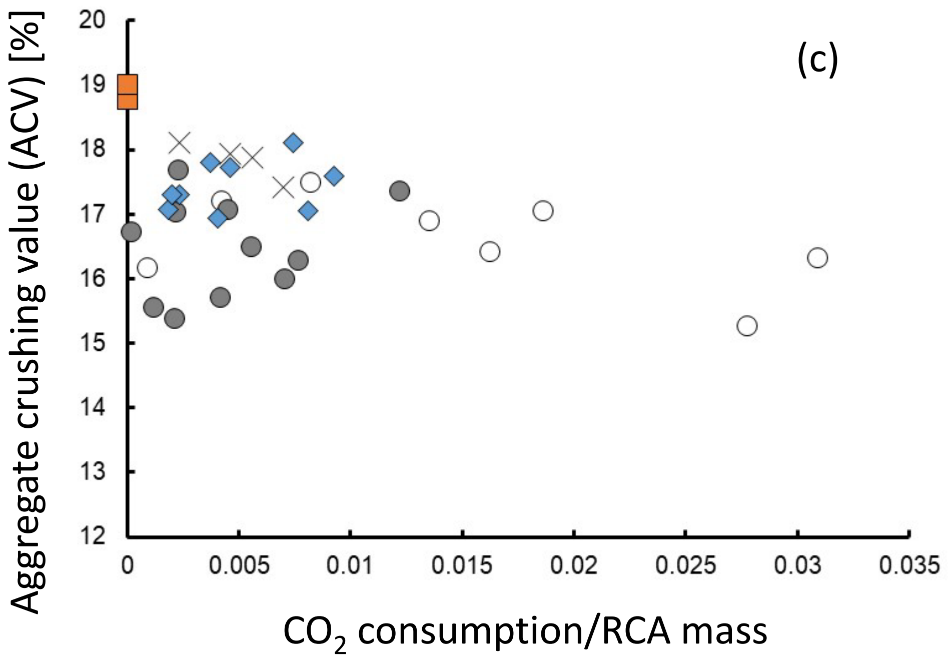
Preliminary results: The mass loss of RCA after (a) the F-T resistance and (b) LA abrasion tests for the different CO_2 pressures during the carbonation treatment.

Summary of Significant Accomplishments/Key Findings (4)

Mechanical Properties and Durability Improvement of Carbonated RCA

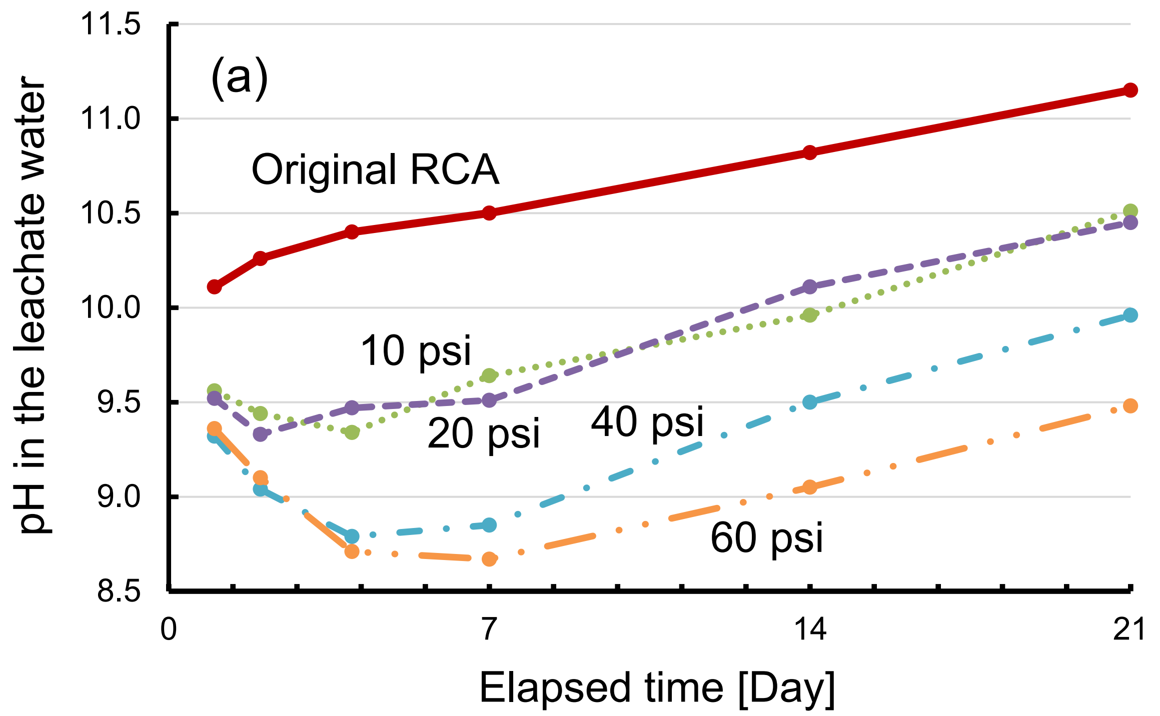


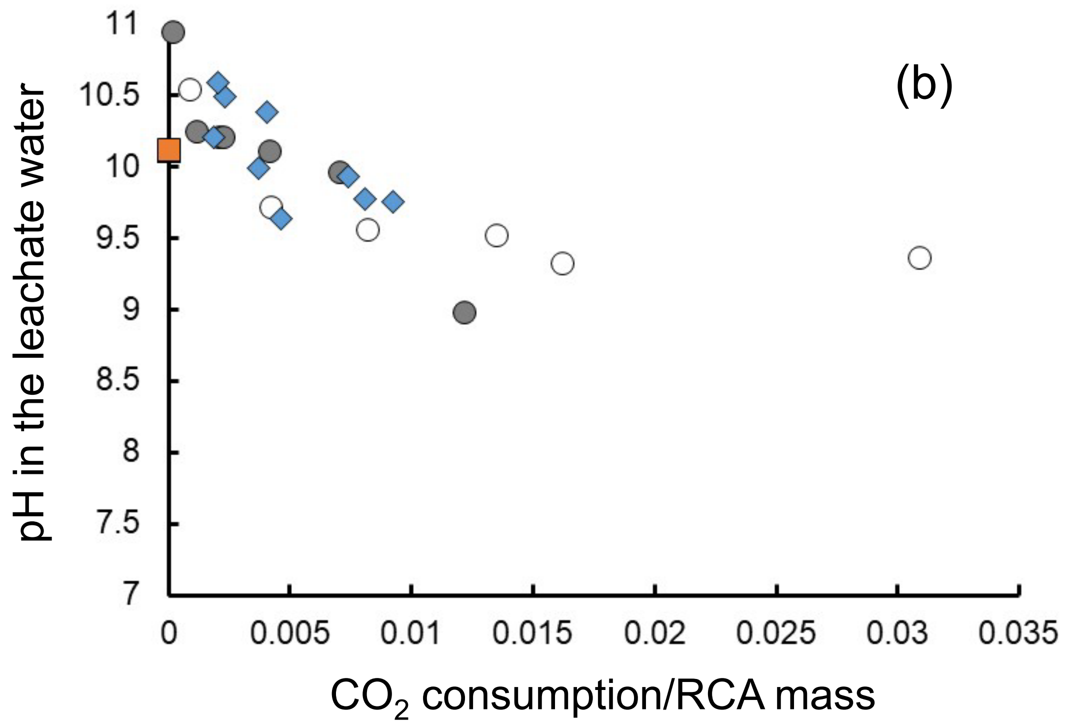


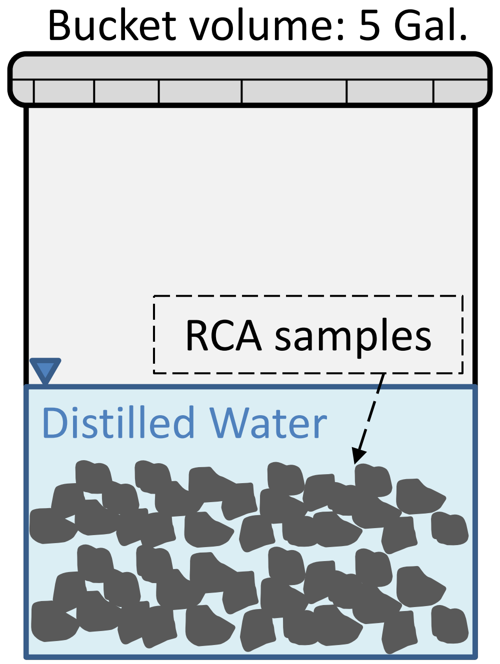


Summary of Significant Accomplishments/Key Findings (5)

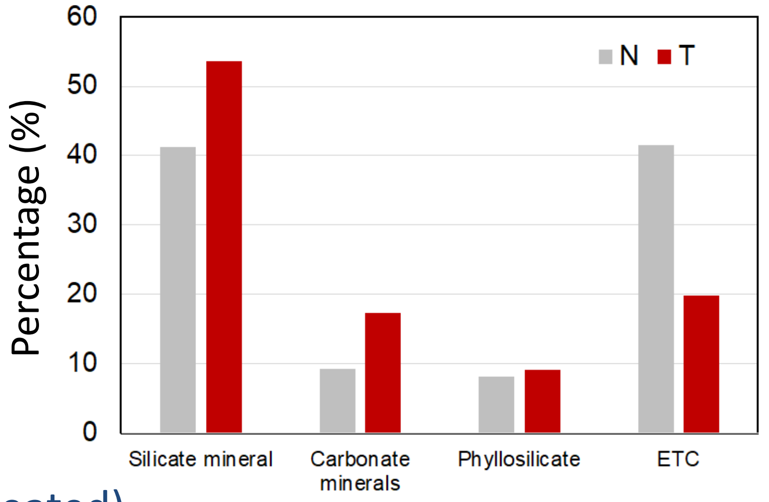
Chemical Change of Carbonated RCA







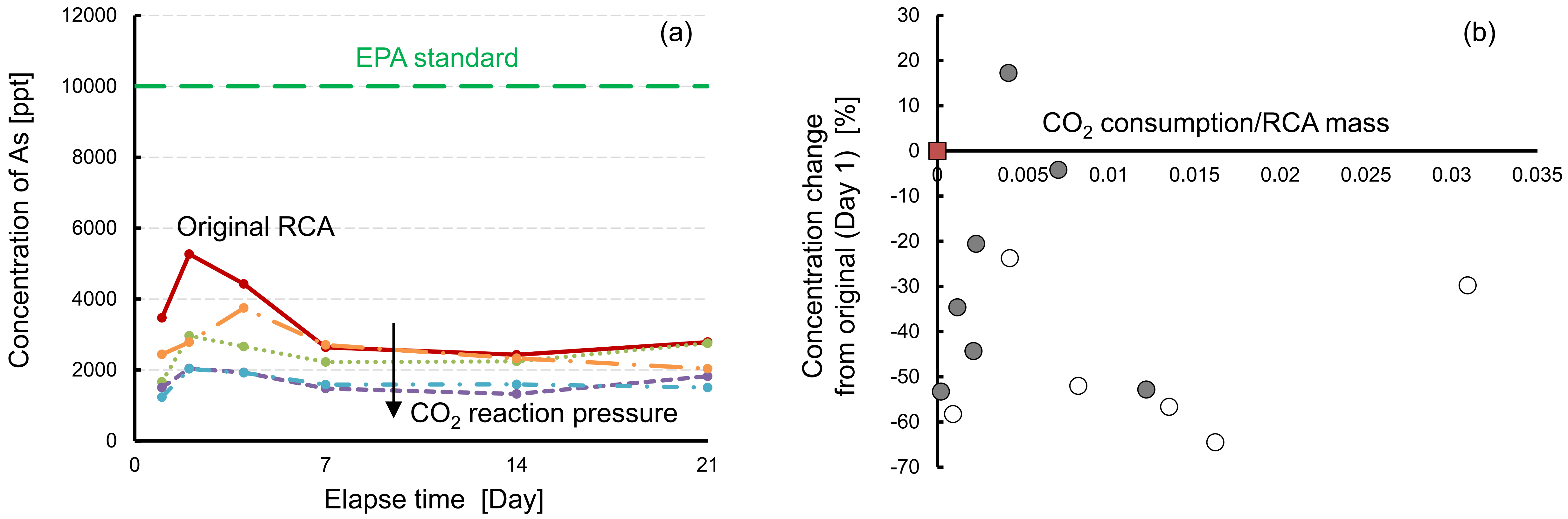
Preliminary results: The batch leaching test: (a) pH in the leachate water with time elapses for different CO_2 reaction pressures and (b) pH in the leachate water after 24 hours of time elapse with respect to the CO_2 consumption (normalized by RCA mass).



Example – XRD analysis RCA (non-treated (N) *vs.* treated)

Summary of Significant Accomplishments/Key Findings (6)

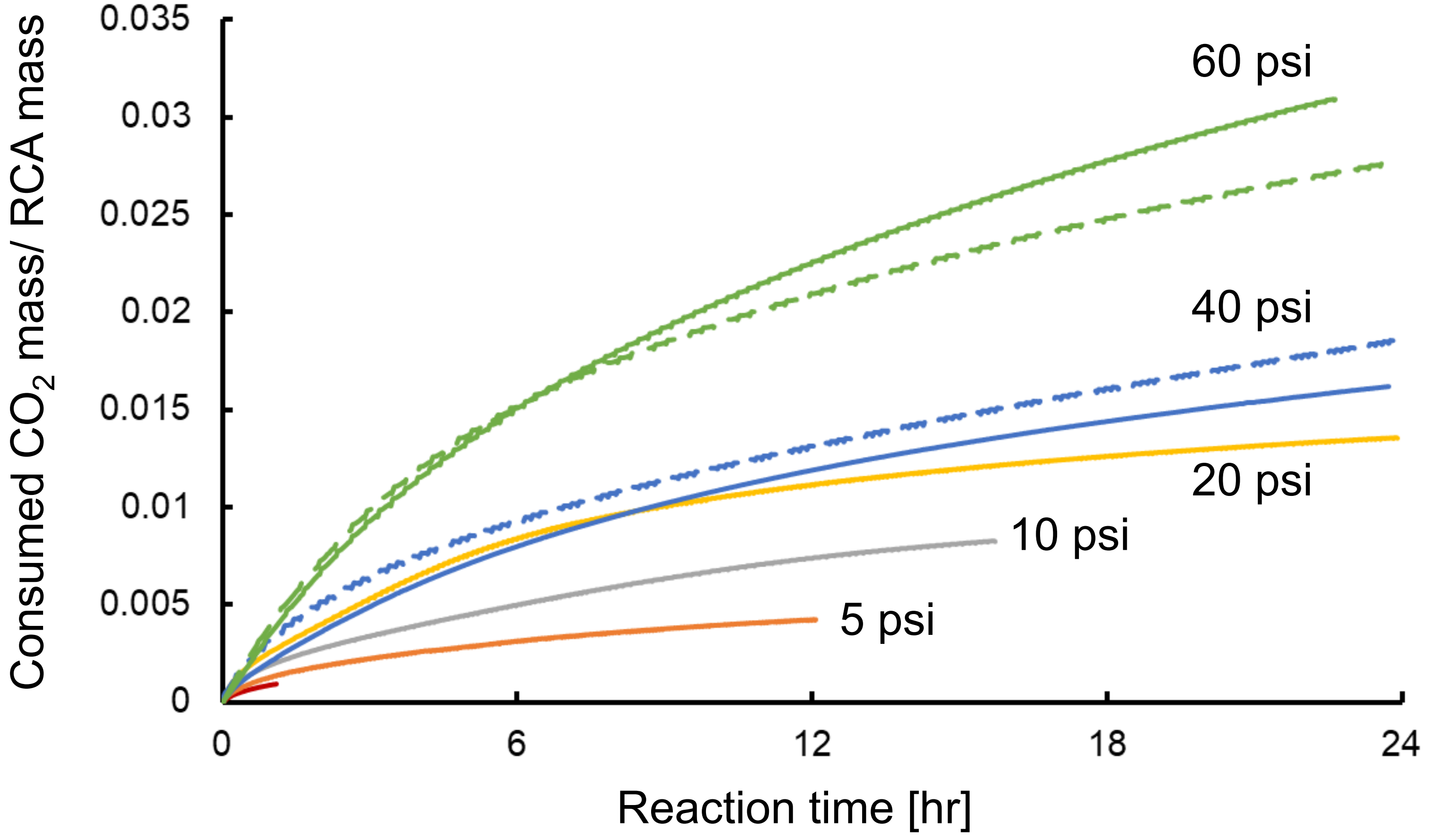
Chemical Change of Carbonated RCA



Preliminary results: The batch leaching test: (a) concentration of Arsenic (As) in the leachate water with time elapses for different CO_2 reaction pressures and (b) the concentration reduction (%) after 24 hours of time elapse with respect to the CO_2 consumption (normalized by RCA mass).

Summary of Significant Accomplishments/Key Findings (7)

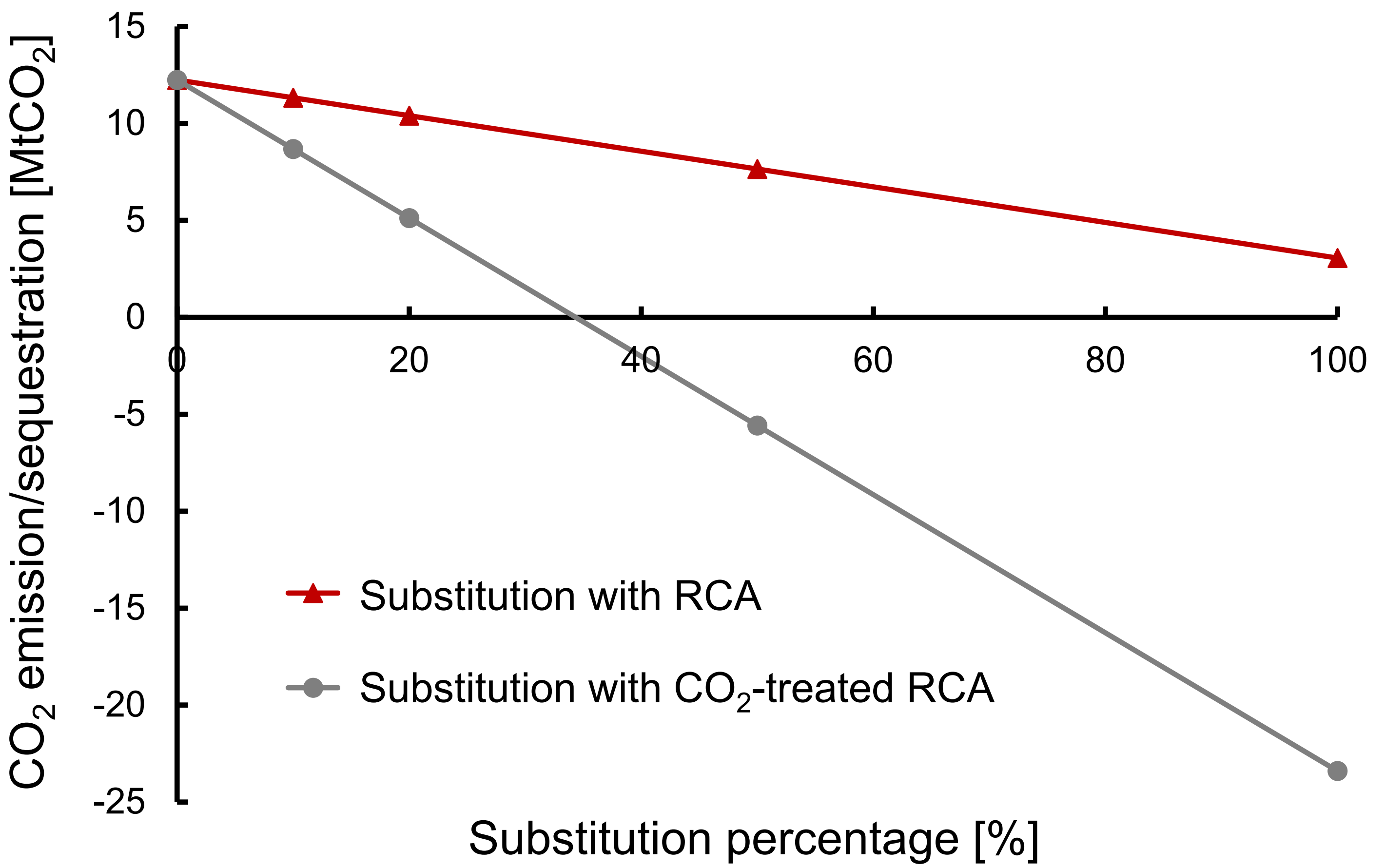
CO_2 Storage Potential



The CO_2 mass consumption (normalized by RCA mass) during the carbonation reaction of RCA for various CO_2 pressure conditions.

Summary of Significant Accomplishments/Key Findings (8)

CO_2 Storage Potential



Annual CO_2 emission (+) or sequestration (-) potential in the United States. The red line represents the scenario in which natural aggregates (NA) are replaced with the original RCA; the gray line represents the scenario in which NA is replaced with CO_2-treated RCA.*

Global warming potential (GWP)

Constituent [kg]	GWP [kg CO_2-eq][1]	Annual CO_2 emission/ sequestration [$MtCO_2$-eq][2]
Natural coarse aggregates	0.0068	12.24
Original RCA	0.0017	3.06
CO_2-treated RCA	-0.013	-23.4

[1] Global warming potential;
[2] Based on the presumed 1,800 million tons of annual U.S. demand.

* Additional benefits of freight reduction is not included here.

Status of Project Objectives and Tasks

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Subtask 4.2 – CO_2 storage potential

Subtask 4.3 – Cost and market analysis: Industrial wastes and mineralization process

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Community Benefits Plan

- **Objective 1**: Recruit, develop, and graduate a talented and diverse pool of student.
- **Objective 2**: Perform outreach to students in minority or underrepresented groups outside of UNL/UNK.
    - UNL's Summer Research Program (SRP) to host students from teaching-oriented collages.
    - High School Research Program to provide research opportunities.
- **Objective 3**: Provide meaningful training and learning experiences to all team members to improve their understanding of diversity, equity, and inclusion concepts and enable them to apply these ideas to model behaviors.
    - Engineering and Computing Education Core (ECEC) Spring Excellence in Teaching Series focusing on teaching inclusivity.
    - Workshops specifically geared towards the project team's needs related to the Complete Engineer initiative.
- **Objective 4**: Use a robust set of assessment metrics to collect and monitor data relevant to reporting and evaluating diversity, equity, and inclusion-related issues within our project team.
    - Annual evaluations to monitor plan actions described for DEI Objectives 1-3.
    - SMART milestones at the end of each project year to measure the success of the DEI plan actions.

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Next Steps

Task 2.0 Field Sampling

Subtask 2.1 – Acquisition of RCA

From different locations with temp-humidity

Source code for concrete mixture

Origin of infrastructure, size and gradation

Tentative locations:

- Midwest region: NE (Omaha metro), IA (Des Moines/Ames)
- Southwest region: TX (Austin metro)
- Southeast region: NC (Charlotte metro)
- Northeast region: NJ (Vineland/Glassboro)

Subtask 2.2 – Characterization of RCA

Physical/mechanical properties of RCA

Residual mortar content (RMC)

Original concrete mix design

→ several groups of RCA

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Acknowledgment - Funding Supports

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

NEBRASKA
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Thank you!
Questions?