# Microbial Curing of Cement for Energy Applications

## Rutgers U., Lawrence Livermore Nat'l Lab. & U. of Arizona

**Richard Riman**
Distinguished Professor
Rutgers University
Department of Materials Science and Engineering
riman@rutgers.edu

| | |
|---|---|
| Total Project Cost: | $2.9M |
| Length | 36 mo. |

# The Team

- Rutgers University (RU) – Richard Riman & Daniel Kopp
  - Cement & Concrete formulation, curing, and testing
  - Tech2Market Analysis
- Lawrence Livermore National Labs (LLNL) – Yongqin Jiao
  - Microbial Engineering
  - Mechanical & Chemical Modelling
- University of Arizona (UofA) – Hongyue Jin
  - Process optimization for sustainability
  - LCA & TEA

RUTGERS
THE STATE UNIVERSITY
OF NEW JERSEY

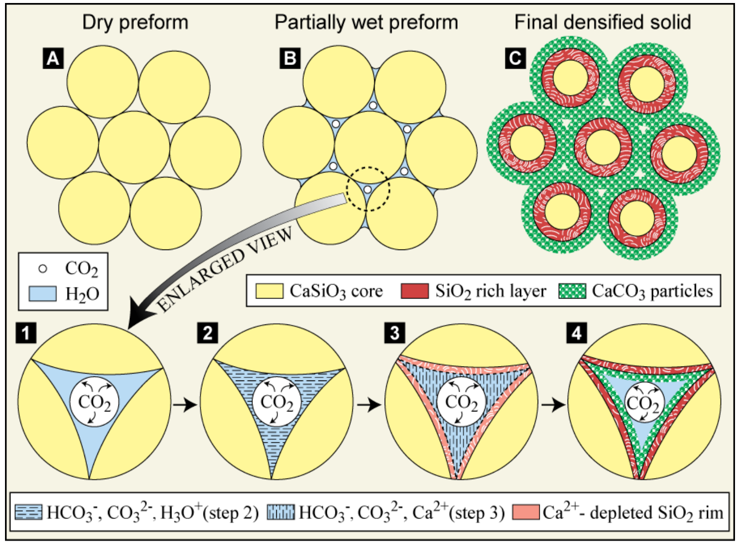
# Project Vision

*Cast-in-place carbonate cement concrete that cures via microbial activity to create monoliths of any length scale.*

# Background: Carbonate Cement

**Carbonate Cement ($CaSiO_3$)** – cement cures via a $CO_2$ gas aqueous solution reaction with $CaSiO_3$ to create a durable carbonate-bonded structure.

- Invented at Rutgers
- Commercialized by Solidia Technologies
- Process has thickness limitations
- Requires $CO_2$ supply chain




A. Pack particles of $CaSiO_3$

B. Infiltrate particle bed with $CO_2$

C. Pore-bound reactive crystal growth fills pores

$$CaSiO_3 + CO_2 \rightleftharpoons CaCO_3 + SiO_2$$

# The Concept

**Objective:** develop a castable/pourable, self-curing carbonate cement concrete using $CO_2$ produced internally via microbes

**Summary**

- *A mix containing bacteria, $CaSiO_3$, & aggregate*
- *Activated by addition of nutrient solution to mix*
- *$CO_2$ released by bacteria hardens concrete*
- *Any thickness can be cast and solidified*

**Impact**

- *$CO_2$ emissions reduced by up to nearly 3 Mt/y*
- *Reduced time and cost to complete construction projects*
- *Eliminates need for a $CO_2$ supply chain*

# Major Objectives

- Select a microbial strain that is:
  - Capable of producing $CO_2$ from *selected-nutrient*
  - Tolerant of cement solution conditions & processing conditions

- Engineer the chemistry and microstructure to facilitate the microbial curing mechanism
  - Process Scale-up:
    - Dilute slurries ➔ Concentrated Slurry ➔ Cement Monolith ➔ Mortar Monolith ➔ 2” x 2” x 2” Concrete Monolith ➔ 4” x 8” Cylindrical Concrete Monolith

- Develop a predictive mechanical model that integrates:
  - Reaction kinetics, thermodynamics, and mechanical performance

- Concurrent LCA & TEA to ensure no environmental or economic RED-FLAGS

# Challenges and Risks

Fundamentally new curing mechanism and microstructure paradigm brings many new challenges and risks:

- **Challenges**:
  - Concrete processing creates basic conditions that are detrimental to microbial viability
  - Microbe and nutrient site occupancy needs to be in “the right place at the right time”
- **Risks:**
  - Poor microbial viability in concrete processing conditions
  - Concrete strength gain is low due to microstructural limitations
  - Microbial production cost is too high

# Results

- 1. Microbial Engineering
  - Strain was down-selected and viability was demonstrated under all relevant concrete processing conditions

- 2. Concrete Engineering
  - >40 mol% carbonation observed via microbial curing
    - ***Advancing the state-of-the-art:***
      - Literature demonstrates carbonation of ONLY pure aqueous species
  - Compressive Strength: Experimental > Control
    - ***Advancing the state-of-the-art:***
      - *Literature never demonstrates high-strength materials*

# TEA & LCA

## Techno-Economic Analysis*

| Cost Category ($/ton) | MBC-A | MBC-B |
|---|---|---|
| Material | 80.2 | 88.1 |
| Utility | 3.4 | 3.3 |
| Other direct | 2.4 | 2.3 |
| Capital | 0.3 | 0.3 |
| Indirect | 4.6 | 4.6 |
| General | 21.5 | 23.4 |
| **Total production cost ($/ton)** | **112.4** | **122.0** |
| Portland cement price ($/ton) | 123.5 | |
| **Net profit margin ratio** | **9%** | **1%** |

## Life Cycle Analysis

| Cement System | Global Warming Impact (kg $CO_2$ eq.) | % Reduction |
|---|---|---|
| Portland cement | 0.9 | - |
| MBC A | 0.21-0.89 | 1% to 77% |
| MBC B | 0.24-0.90 | 0% to 74% |

*MBC = Microbially cured cement

# Potential Collaboration Opportunities

- Microstructure-strength Simulations
- Fractography
- In Situ Environmental SEM
- MR-CT Imaging Of Concrete
- Energy-dispersive X-ray Diffraction Under Mechanical Load
- Standardized Concrete Testing

# Summary

**Objective:** Develop a carbonate cement concrete using internally produced $CO_2$ curing via microbes

## Microbial Curing

- *A mix containing bacteria, $CaSiO_3$, & aggregate*
- *Activated by addition of nutrient solution to mix*
- *$CO_2$ released by bacteria hardens concrete (>25 MPa)*
- *Any thickness can be cast and solidified (cast-in-place)*

## Projected Impact

- *$CO_2$ emissions reduced by up to nearly 3 Mt/y*
- *Reduced time and cost to complete construction projects*
- *Eliminates need for a $CO_2$ supply chain*

RUTGERS
THE STATE UNIVERSITY OF NEW JERSEY

# Acknowledgement

Thank you Joseph King & the ARPAe team

(Madhav Acharya, Sean Vail, Rosemary Cox-Galhotra)

for the helpful suggestions and generous ARPAe support!