Belite Cement, and Concretes; Novel Low-Energy Approaches to Making Concrete Extremely Durable

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Team Members: Design by Natural Processes, Inc.; Sandia National Laboratories; Titan Cement

Project Goal

The time is right for alternative cementitious materials that use less energy, release less CO_2 and excel in performance and durability. The project team has set out to produce an activated belite and belite-CSA hybrid cements combining the performance elements of both and eliminating the disadvantages of either.

Total project cost:	$2.1M
Current Q / Total Project Qs	Q7 / Q8

TINA-Cement
Annual Meeting
October 13 & 14, 2021

The Concept

- "*Replacing and displacing Portland cement is one of the greatest materials engineering challenges of our time*" *Dr. Thomas Robl*

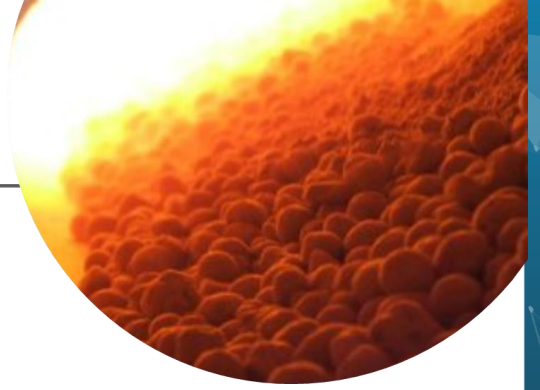
- A concrete that capitalizes on the extreme durability of belite cements by overcoming early-age shortcomings

- Ordinary Portland cement is extremely energy and carbon intensive
  - Approaches
    - Improvements in belite activity
    - Formation of a belite-CSA hybrid
    - Admixtures for improved belite activity

The Team

- University of Kentucky Center for Applied Energy Research
  - Dr. Bob Jewell (bob.jewell@uky.edu);Dr. Tristana Duvallet; Anne Oberlink; Dr. Tom Robl; John Wiseman
- Designs by Natural Processes, Inc.
  - Dr. Carolyn Dry (drycementmixer@aol.com)
- Sandia National Laboratories
  - Dr. Edward Matteo
- Titan Cement (industry partner)
  - Dr. Eric Koehler
  - Dr. Marios Katsiotis

Project Objectives



- ***University of Kentucky Center for Applied Energy Research***
  - Formulation & fabrication of belite clinkers
    - Utilization of a wide variety of alternative raw materials
    - Two clinker varieties: belite-rich clinker; belite-calcium sulfoaluminate clinker
  - Pilot-scale clinker production, hydration studies, mortar strength development, concrete performance and durability

- ***Designs by Natural Processes, Inc. – Dr. Carolyn Dry***
  - Develop and screen activation additives for belite-rich clinkers
- ***Sandia National Laboratories – Dr. Edward Matteo***
  - Provide SOA mechanical testing to verify the durability of novel materials
  - Evaluate the relationship between mechanical failure and permeability evolution
    - A critical parameter in assessing the durability of concrete
- ***Titan Cement – Dr. Eric Koehler; Dr. Marios Katsiotis***
  - Technical guidance throughout the project
- ***Nathan Ball***
  - T2M Development

Project Objectives

Year 1

1 Material Acquisition

2 Belite-CSA Clinker Development

3 Rich-Belite Clinker Formulations

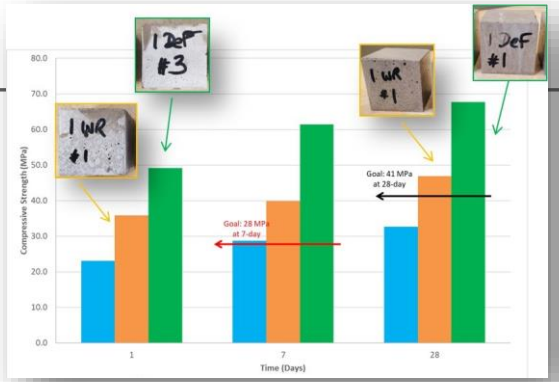
4 Initial T2M Plan

5 Compressive Strength Assessment

6 Go/No-Go Pilot-Scale Production of Clinkers

Project Objectives

Year 2



8 Mortar Performance: Activators/Aggregates

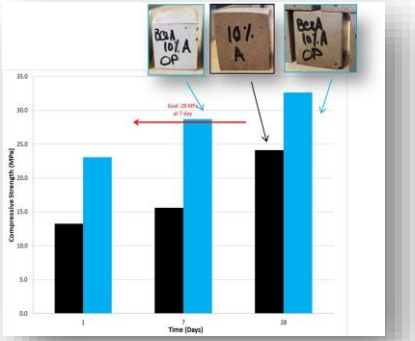
10 Revised T2M Plan

11 Go/No-Go Belite-Concrete Durability

7 Novel Activators & Aggregate Package

9 Concrete Performance: Activators/Aggregates

12 Final T2M Plan



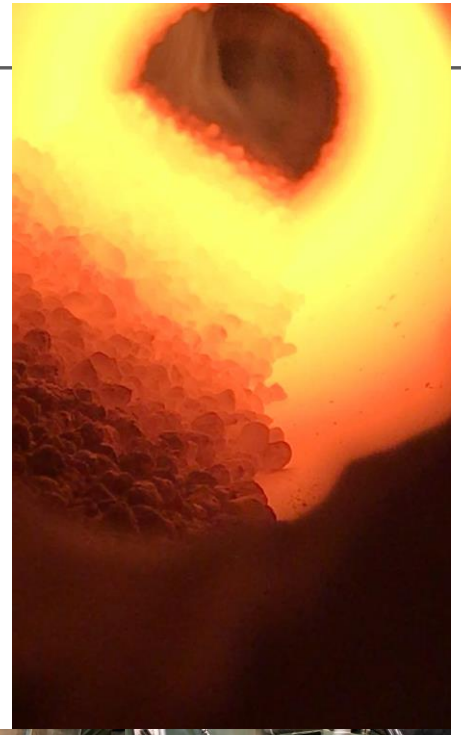
BCSA Concrete

Belite-Rich Concrete

Cement Products

BCSA Cement

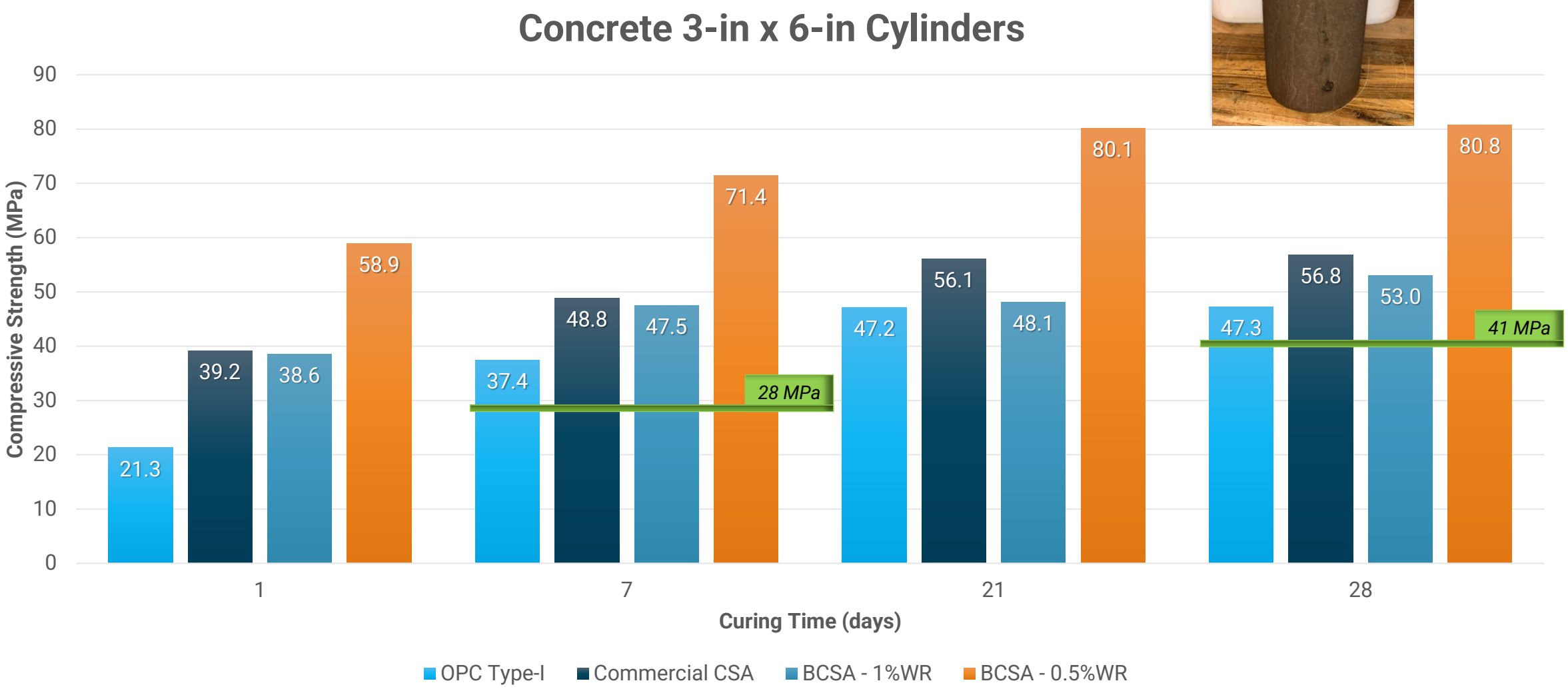
Belite-rich Cement



	OPC Type I (Plant #1)	OPC Type I (Plant #2)	CSA Cement (Plant #3)
Alite (C_3S)	48.7	54.4	4.2
Belite (C_2S)	25.3	25.7	22.3
Ye`elimite ($C_4A_3\$$)	3.3	1.5	46.6

Results – BCSA Cement

ARPA-E BCSA



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CHANGING WHAT'S POSSIBLE

Results – Belite-Rich Cement

DESIGNS BY NATURAL PROCESSES, INC

Energy and GHG Comparison

Nature of Material	Generic Product Composition	Embodied Energy (MJ/ton)	GHGs (ton/ton)
DNP Cement	Mixture of belite clinker, oxides, mineral phases	1435	0.52
OPC	Mixture of oxides, small amount of sulfates, calcium silicate hydrates	8800	0.85

CO_2 Uptake Results

- Developed technology has embodied energy nearly 8x lower than OPC and almost half the GHG emission
- Goal of 6,000 psi (28 days) achieved with both mortar and aggregate compositions

- Non-hydraulic cement
- Cures via chemical reaction to the belite-rich clinker

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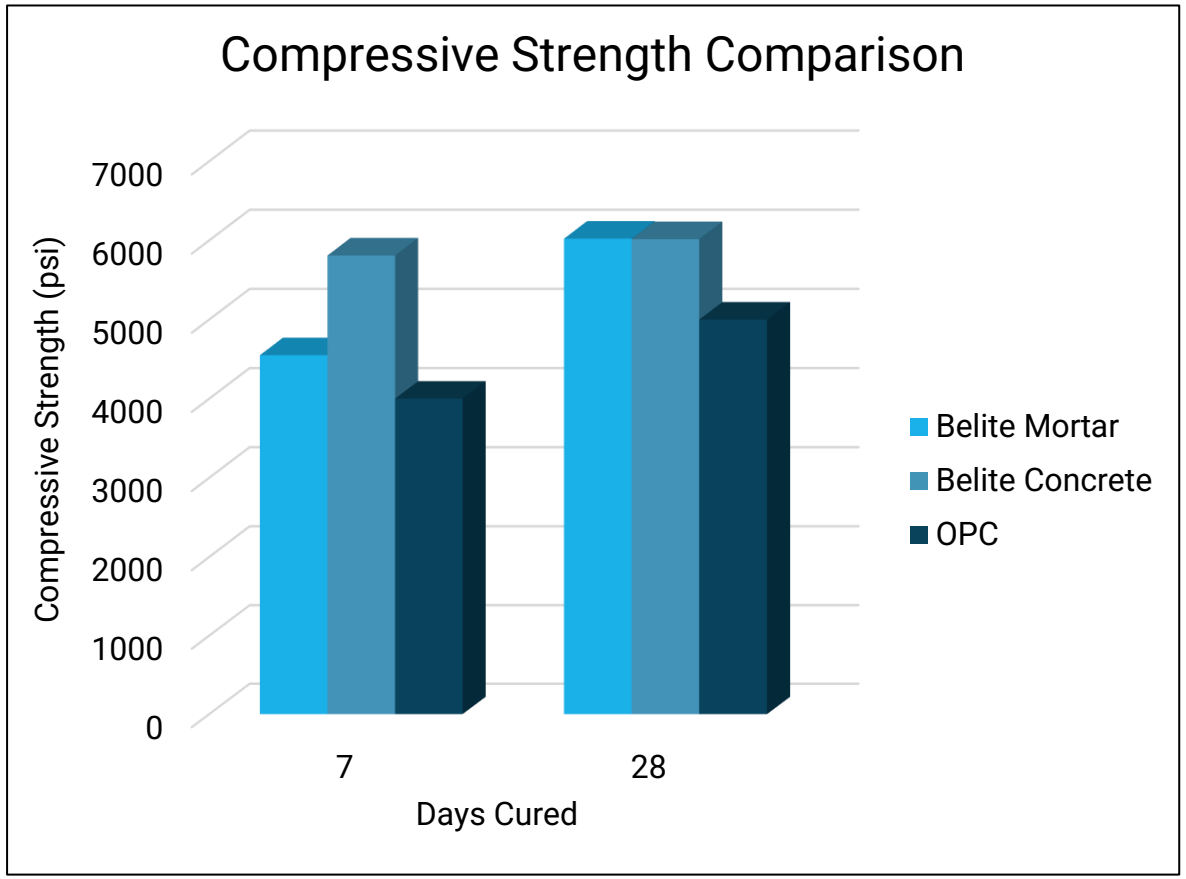
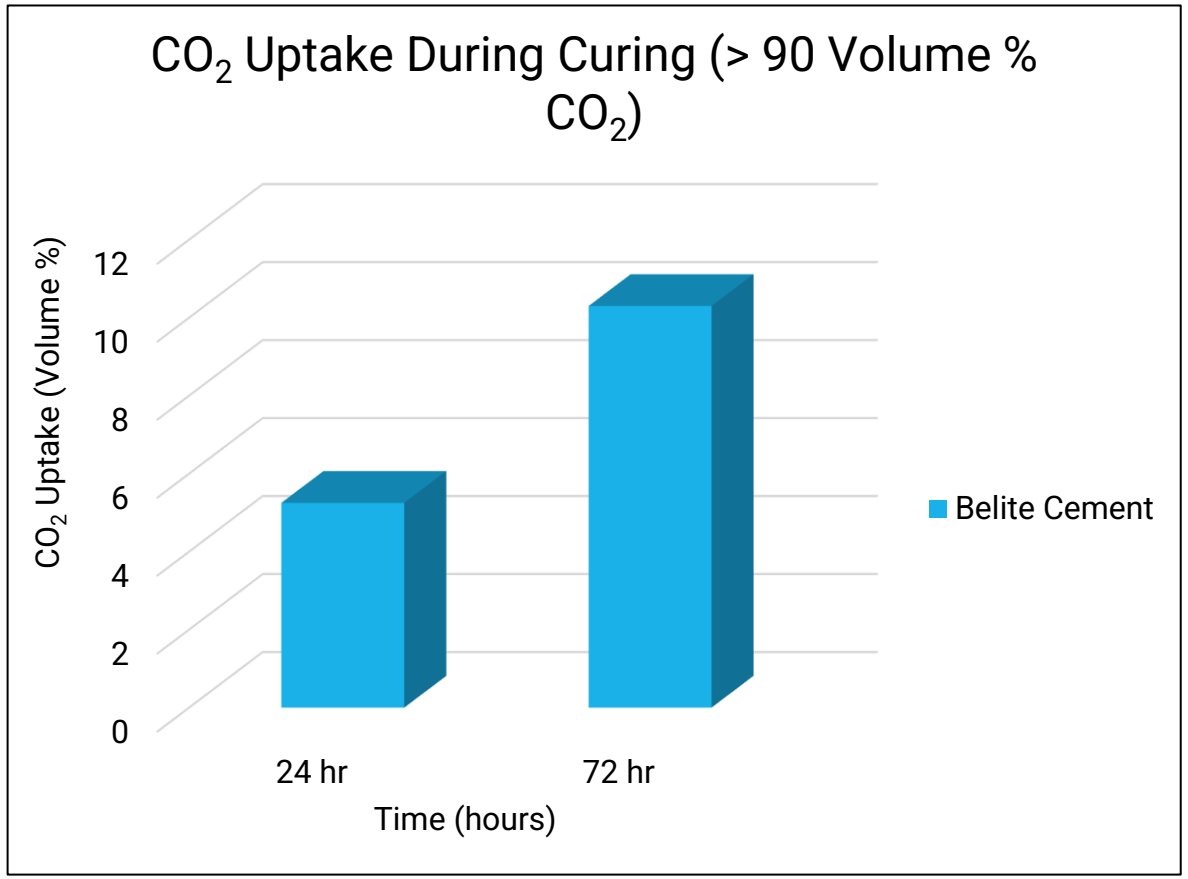
Results – Belite-Rich Cement

DESIGNS BY NATURAL PROCESSES, INC

Compressive Strength Results



CO_2 Uptake Results



Challenges, Risks and Potential Partnerships

- Scale-Up, Scale-Up, Scale-Up : *Reproducing industrial kiln conditions in the laboratory*

Dimensions:
0.2m x 2.4m

Production Rate:
36 kg/day

Laboratory Rotary Kiln

Industrial Rotary Kiln

Dimensions:
6m x 100m

Production Rate:
8,000 tons/day

- Dependent on the formulation of interest
  - Sources of raw materials at a price acceptable to industry
    - Mitigate with alternative sources
- Looking for partnerships or collaboration opportunities
  - Extensive analytical and physical testing equipment
  - Unique teaming opportunities with creative capabilities

Photo by "My Life Through A Lens" on Unsplash

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CHANGING WHAT'S POSSIBLE

Challenges, Risks and Potential Partnerships

- Keep potential costs low
  - Evaluate industrial waste streams (byproducts)
- Eliminate formulations that require extensive retention times
  - Activators
- Market acceptance
  - Target known specifications
  - Cement industry knows their customers' needs
  - **CO_2 reduction!!!**
    - Low Energy/Low Carbon Cement
      - Road to Commercialization

BIG SAT CEMENT

Summary Slide

- Development of a belite-CSA cement and an activated-belite cement
  - Utilize commonly available materials, including industrial byproducts
  - Exhibit predictable performance
    - Equivalent to or better than OPC
    - Be compatible with installed infrastructure in the construction industries
    - Price/cost competitive

- Extreme durability coupled with reduced CO_2 emissions

- High-volume belite cement with early strength development, enhanced durability, and created with lower energy and CO_2 emissions
  - Belite-CSA Cement
  - Belite-Rich Cement

- Final goals and deliverables
  - Durability testing
  - Scale-up for an industrial run

https://arpa-e.energy.gov