Concrete Innovations:
Pathways to Reducing Carbon Footprint

Donn Thompson, AIA, LEED AP BD+C

NRMCA

BUILD WITH STRENGTH

BUILD WITH STRENGTH MINNESOTA

About the Course – LCI-101

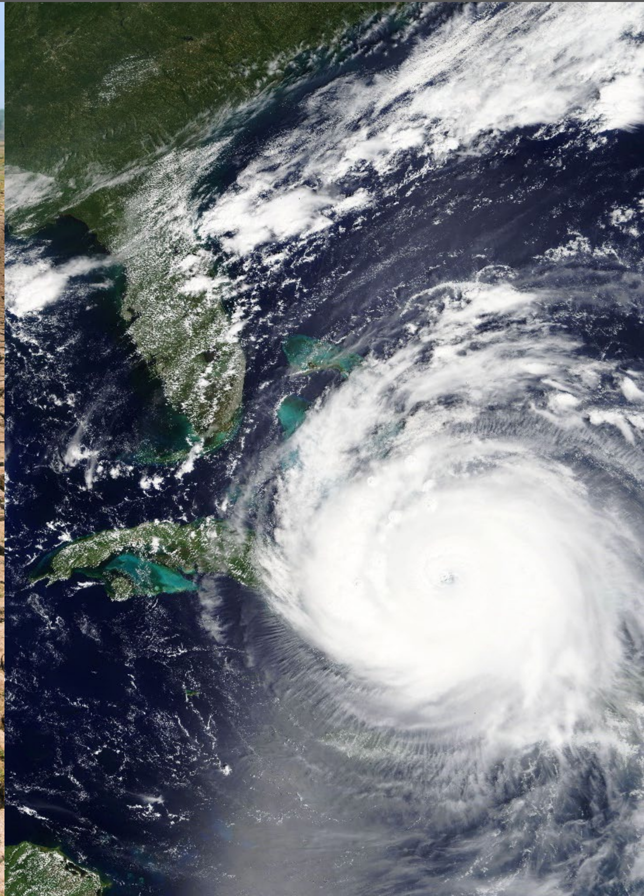
Learning Objectives:

- Define the term – embodied carbon
- Understand how to establish up front carbon objectives and engage stakeholders early in design to reach more sustainable results
- Understand how specifications affect the GWP of a concrete mix.
- Understand how to quantify embodied carbon of concrete on a project and reduction strategies available in the local market

1 Learning Unit/HSW

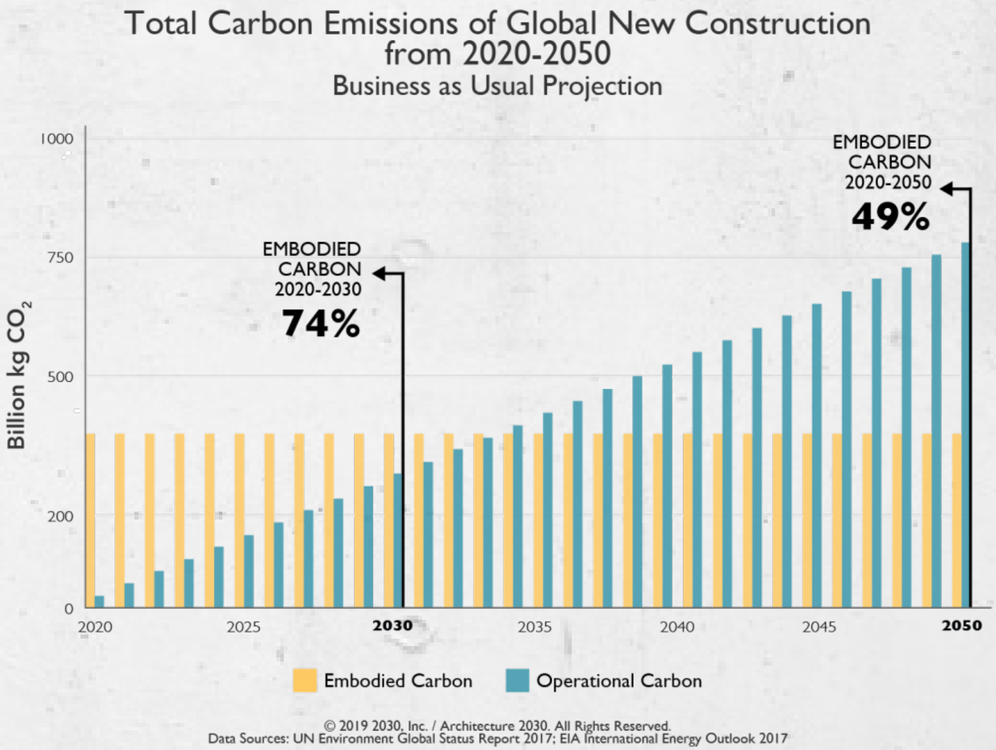
The Problem





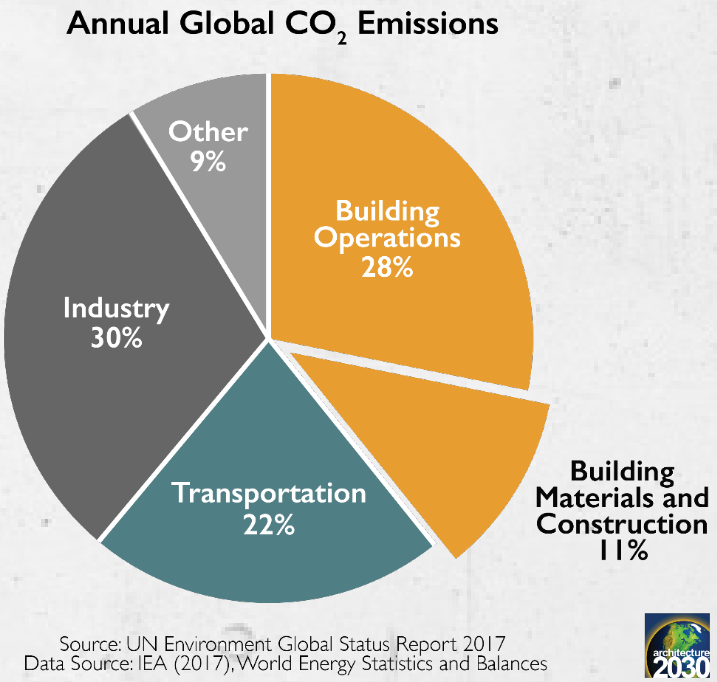
The Reality

- Every year
  - 6.13 billion square meters of buildings are constructed.
  - 3729 million metric tons CO_2 per year.
- By 2050
  - embodied carbon emissions and operational carbon emissions will be roughly equivalent.

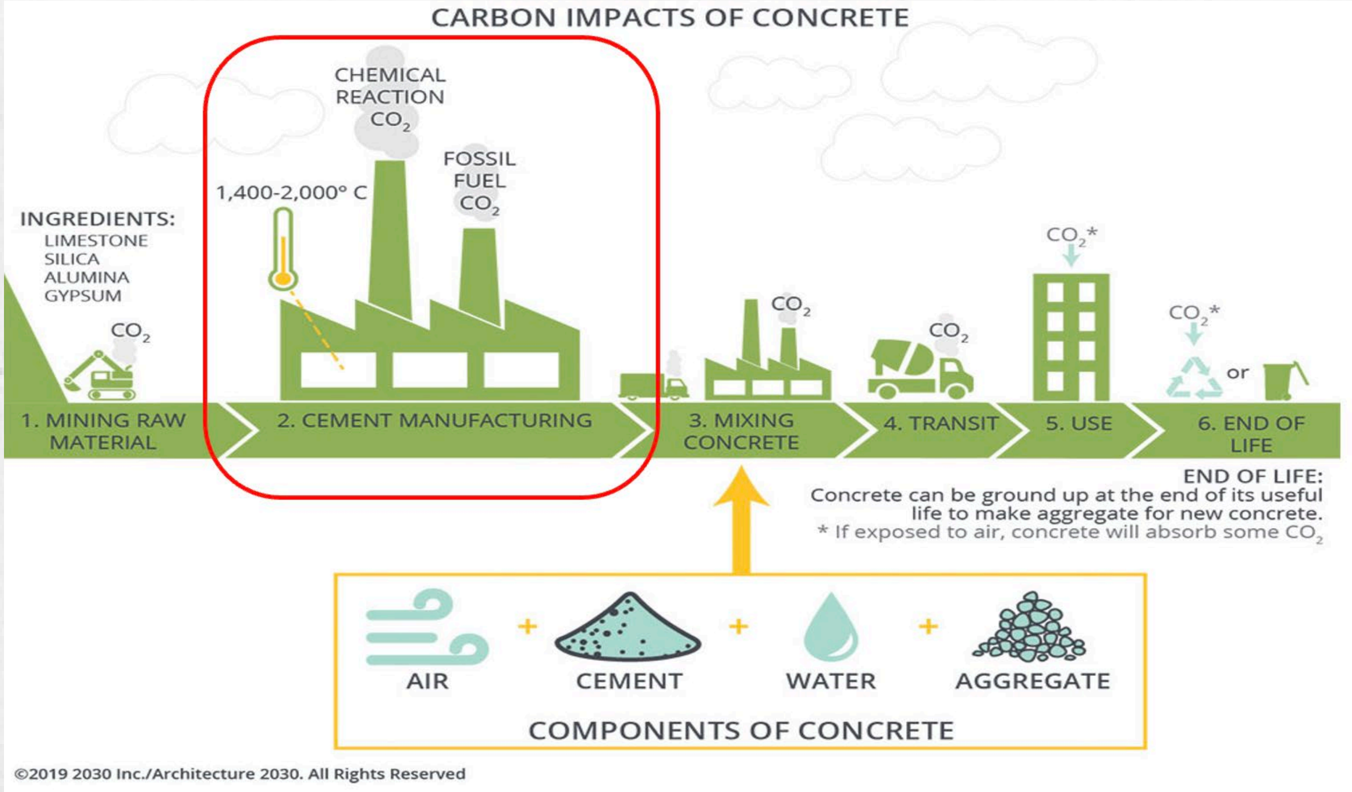


The Challenge

- Embodied carbon from the building materials produce 11% of annual global GHG emissions.
- Concrete, iron, and steel alone produce ~9% of annual global GHG emissions.
- Likely will need to build with more robust materials like concrete.
- How do we minimize environmental impacts?

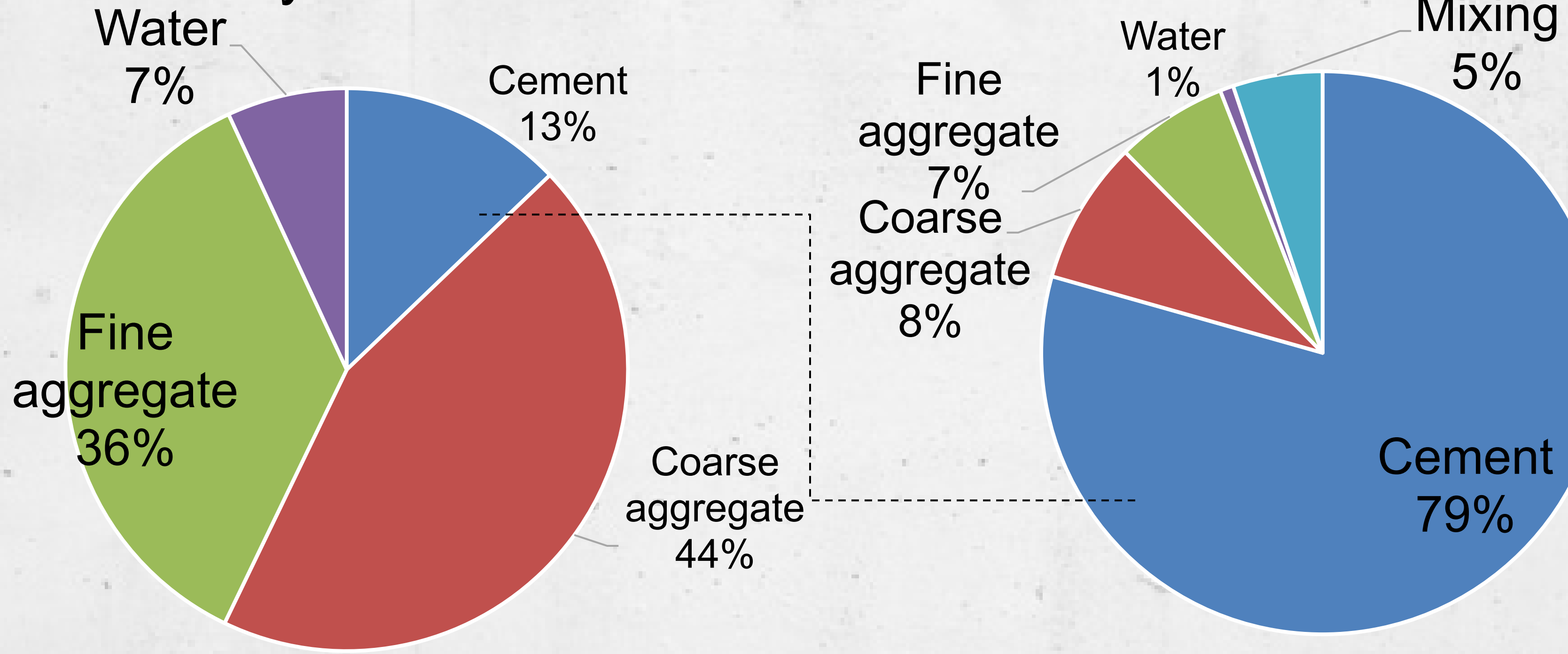


The Challenge



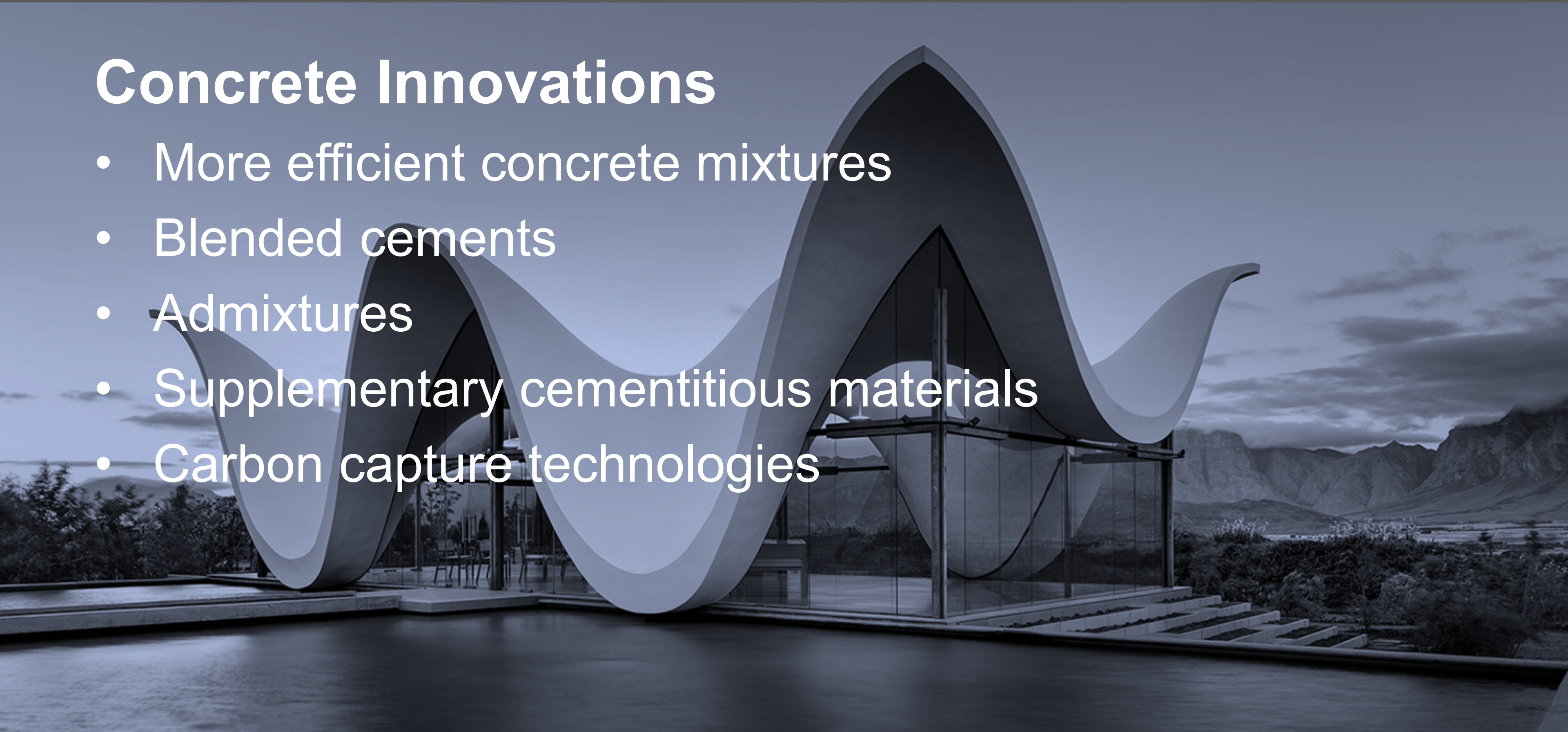
Cement drives concrete's environmental impact

By **mass** | By **GHG emissions**



3000 psi mixture with no SCMs

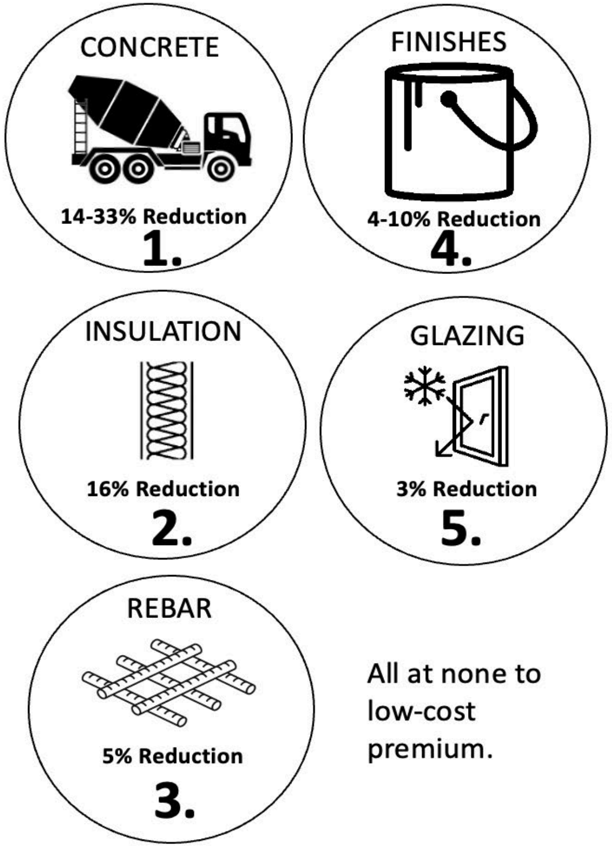
The Solutions



Concrete Innovations

- More efficient concrete mixtures
- Blended cements
- Admixtures
- Supplementary cementitious materials
- Carbon capture technologies

More Efficient Concrete Mixtures



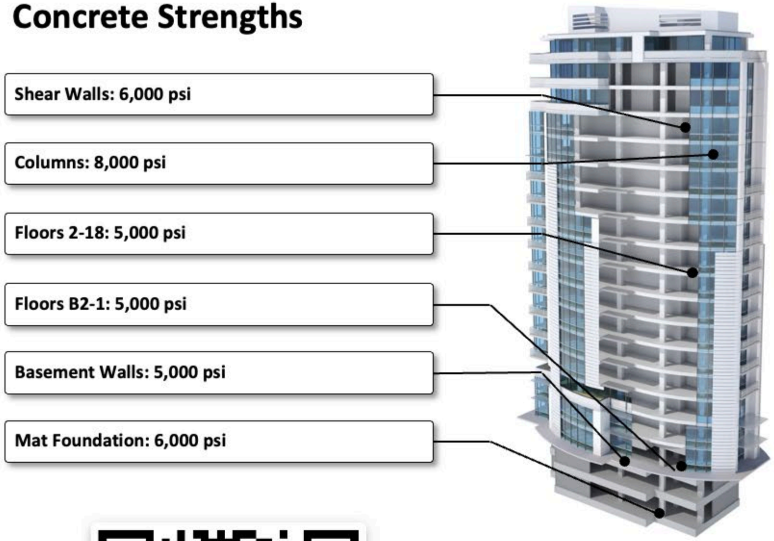
All at none to low-cost premium.

Communicate Carbon Reduction Goals

RMI Report, Reducing Embodied Carbon in Buildings Low-Cost, High-Value Opportunities July 2021

More Efficient Concrete Mixtures

Concrete Strengths



NEW
NRMCA
CARBON
BUDGET
CALCULATOR

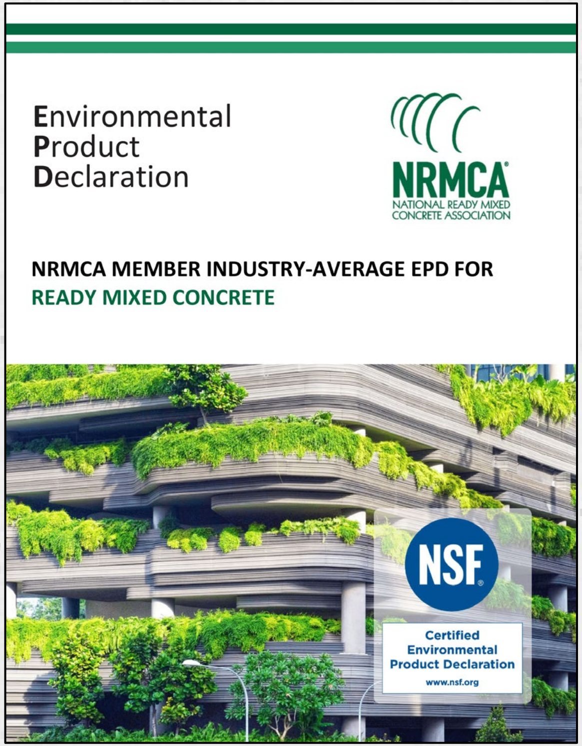
Set a Carbon Budget

Resist the temptation to set carbon footprint limits for individual classes of concrete.

More Efficient Concrete Mixtures

Communicate Carbon Reduction Goals

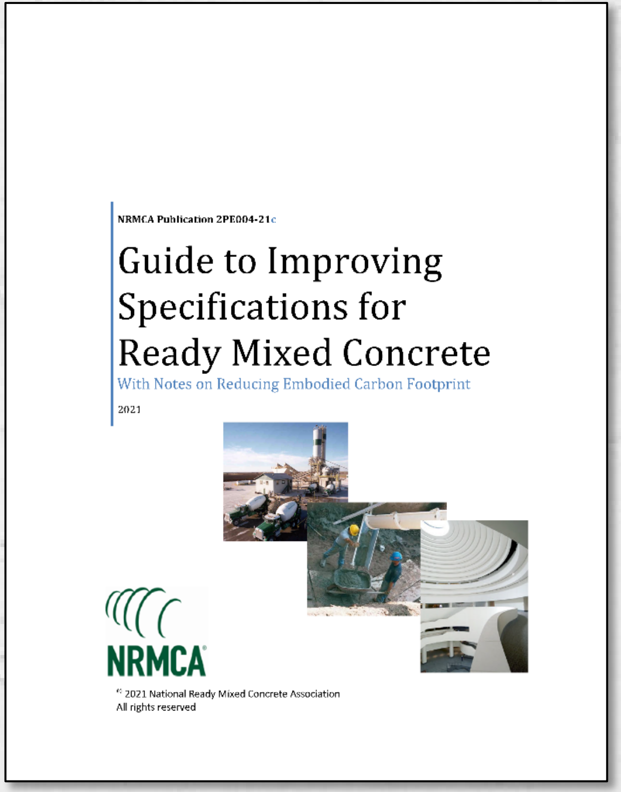
Baselines/Benchmarks



More Efficient Concrete Mixtures

- **Performance-based Specifications**
  - No limitations on materials and quantities

TIP: Guide specification at www.nrmca.org/sustainability


NRMCA Publication 2PE004-21c

Guide to Improving Specifications for Ready Mixed Concrete

With Notes on Reducing Embodied Carbon Footprint

2021

Prescriptive specifications limit opportunities to reduce concrete environmental impact

Common prescriptive requirements	Occurrence in Specifications
Restriction on SCM quantity	85%
Maximum water-cement ratio	73%
Minimum cementitious content for floors	46%
Restriction on SCM type, characteristics	27%
Restriction on aggregate grading	25%

Source: Obla & Lobo, NRMCA, 2015

More Efficient Concrete Mixtures

Manufacturer Qualifications:

- NRMCA Certified Concrete Production Facility
- NRMCA Concrete Technologist Level 2

Installer Qualifications:

- ACI Flatwork Finisher

Testing Agency Qualifications:

- Meets ASTM C1077
- ACI Concrete Field Testing Technician Grade I
- ACI Concrete Laboratory Testing Technician Level I
- Results certified by a registered design professional

QUALITY CONTROL

Blended Cements

ASTM C 595

Cement Type	Description	Notes
Type IL (X)	Portland-Limestone Cement	Between 5% and 15% interground limestone
Type IS (X)	Portland-Slag Cement	up to 70% slag cement
Type IP (X)	Portland-Pozzolan Cement	up to 40% pozzolan. Fly ash is the most common.
Type IT (X)(X)	Ternary Blended Cement	

- (X) identifies the percentage of portland cement replacement

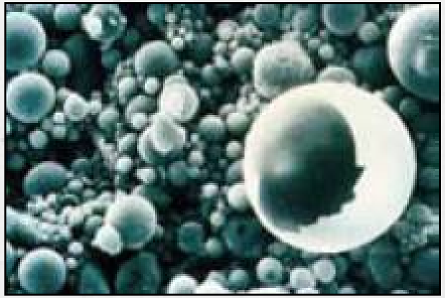
- TIP: Permit ASTM C 595 hydraulic cements
- TIP: Permit ASTM C 1157 hydraulic cements

Admixtures

- Water reducing
  - Decreases water demand
  - Decreases cement demand
- Strength enhancing admixtures
  - Decreases cement demand
- Viscosity modifying
  - Improves workability
- Set accelerating
  - Can compensate for high SCMs
- TIP: Permit all admixture types (details in guide spec)

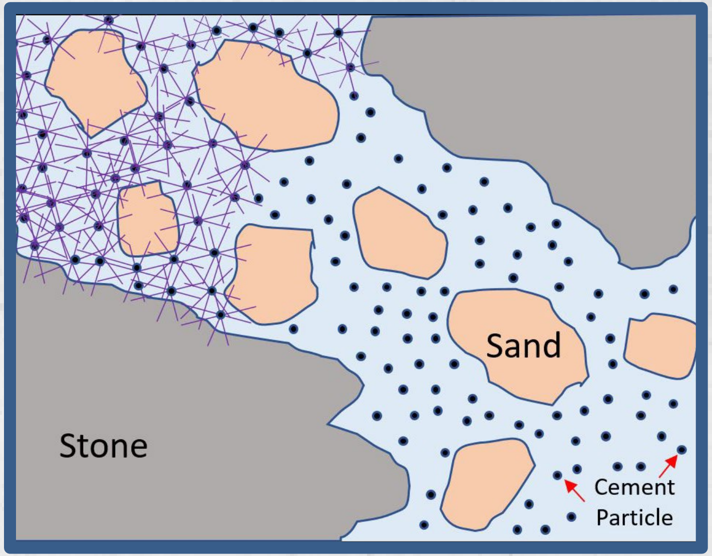
Supplementary Cementitious Materials

- Slag Cement
  - A latent hydraulic material
  - Minimal pozzolanic behavior
- Pozzolan – fly ash, natural pozzolans, silica fume
  - Siliceous or siliceous and aluminous material
  - Little or no cementitious value
  - With moisture reacts with calcium hydroxide
  - Fine form

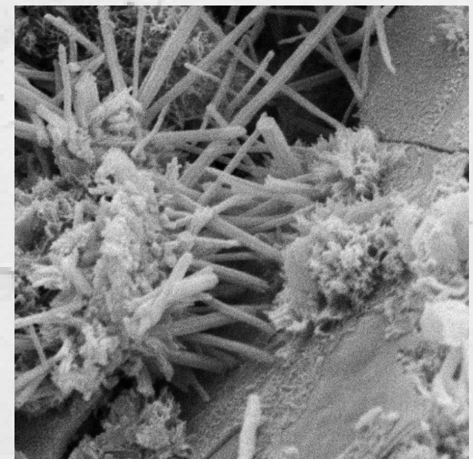


Hydraulic Cement

- Cement reacts with water to form cementitious compounds
- Can set and harden under water



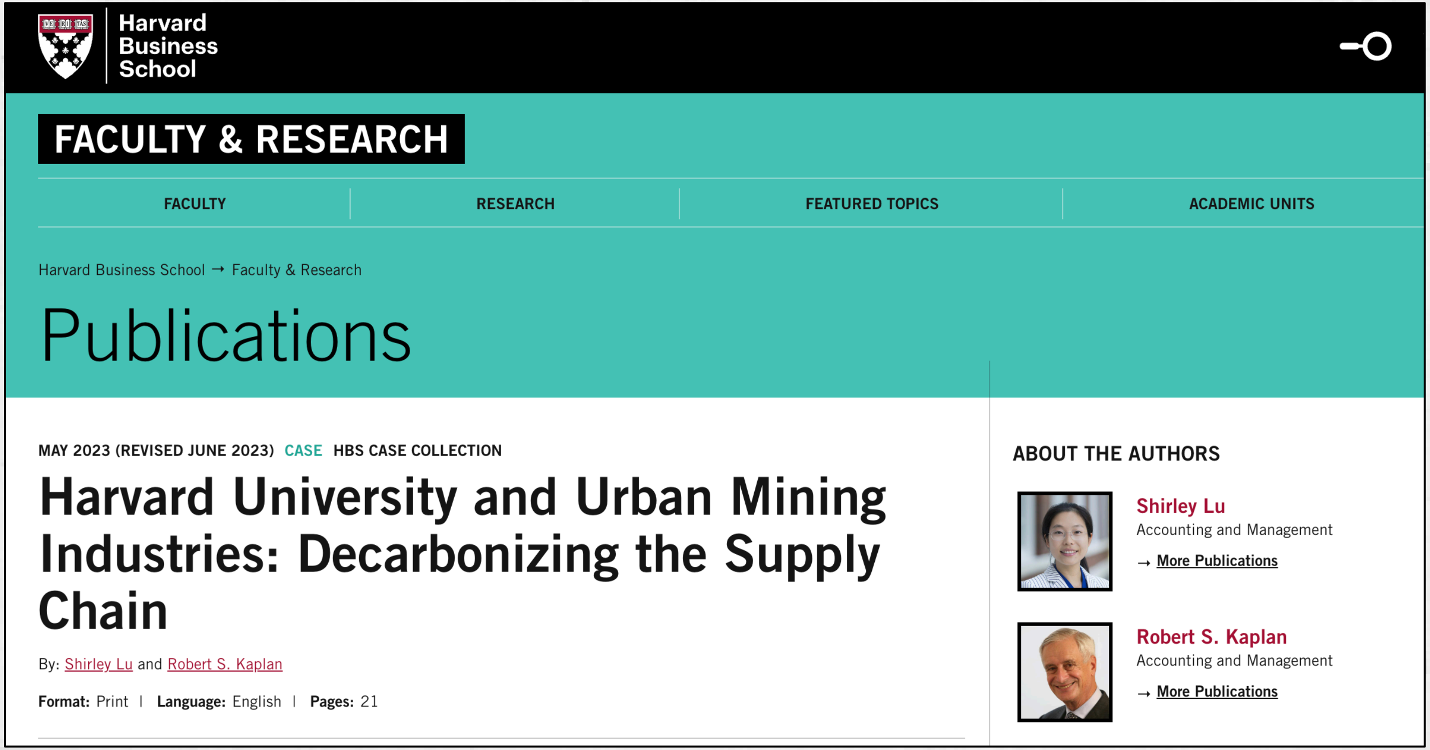
Portland Cement + Water ⟶ C-S-H + CH



Hydration and SCMs

Cement + Water	$\longrightarrow$	C-S-H + CH	Hydraulic
Pozzolan + CH	$\longrightarrow$	C-S-H	Pozzolanic
Slag + Water	$\xrightarrow[\text{Activator (cement)}]{\text{Alkali/lime}}$	C-S-H (no CH)	Hydraulic
Slag + CH	$\longrightarrow$	C-S-H	Pozzolanic

Ground Glass Pozzolans



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Publications

MAY 2023 (REVISED JUNE 2023) CASE HBS CASE COLLECTION

Harvard University and Urban Mining Industries: Decarbonizing the Supply Chain

By: Shirley Lu and Robert S. Kaplan

Format: Print | Language: English | Pages: 21

ABOUT THE AUTHORS

Shirley Lu
Accounting and Management
→ More Publications

Robert S. Kaplan
Accounting and Management
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Ground Glass Pozzolans

JPMorgan’s 60-story Midtown East tower will be NYC’s largest all-electric skyscraper

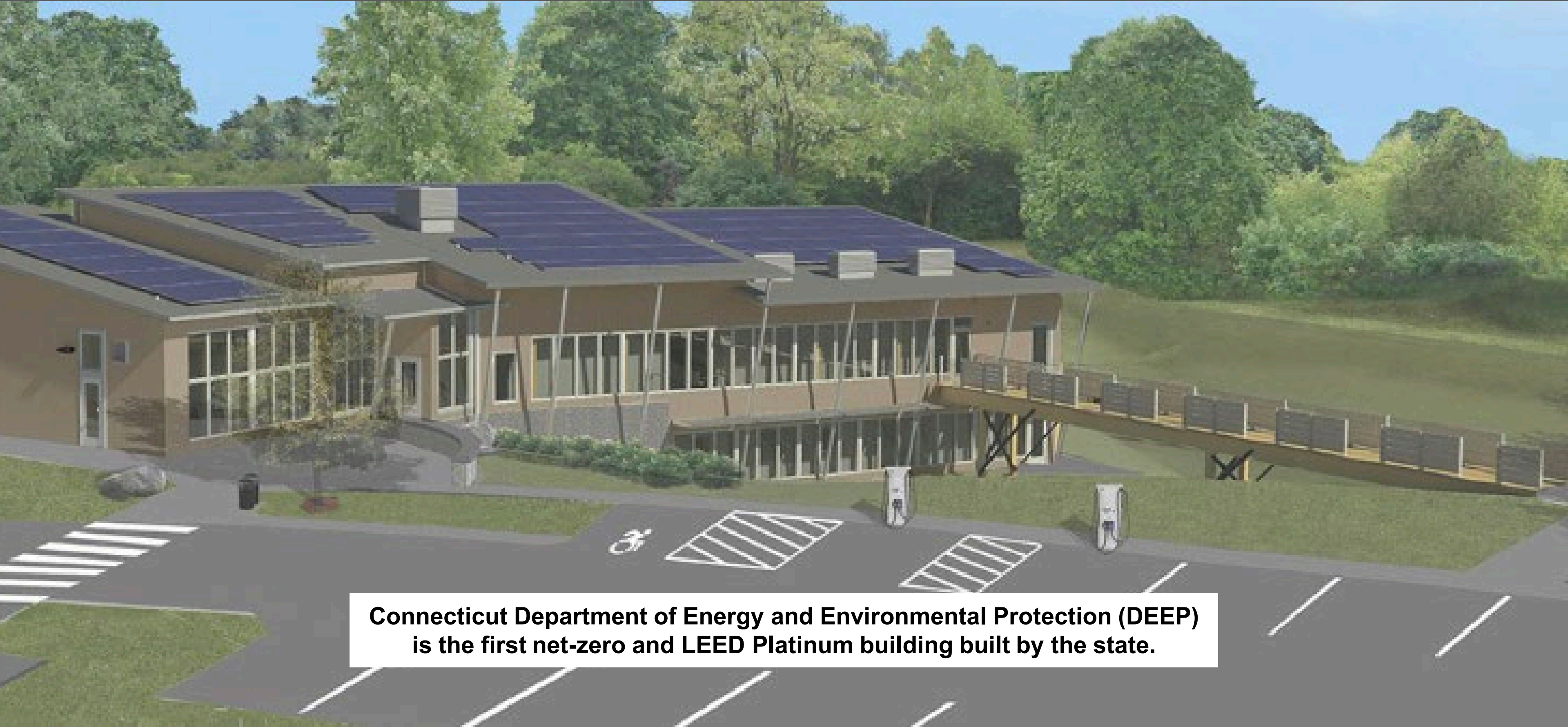
By Devin Gannon April 14, 2022

Rendering: dbox / Foster + Partners

Photo courtesy of spiritofamerica/Adobe Stock

Via 57 West in New York City: This ultra-modern, innovative residential complex was built using structural concrete block, cast-in-place concrete flooring, and precast concrete stairs made with ground-glass pozzolan to help meet sustainability goals.

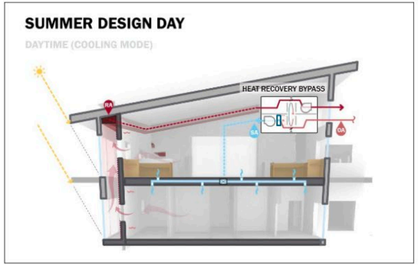
CT DEEP Case Study

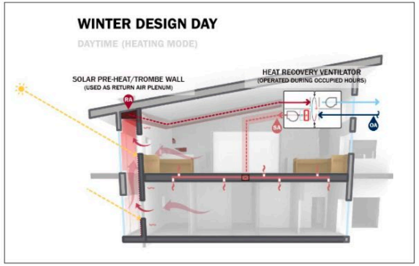


Connecticut Department of Energy and Environmental Protection (DEEP) is the first net-zero and LEED Platinum building built by the state.

CT DEEP Case Study

Images courtesy of Atelier Ten (top); TLB Architecture, LLC (bottom)





The designers for the DEEP project designed a thermal mass wall utilizing concrete made with post-consumer ground-glass pozzolan cement to optimize the site's solar orientation all year round. The Trombe wall provides passive heating and cooling and improves natural ventilation.

40% cement replacement in the structural concrete mixes with a ground-glass pozzolan made from 100% locally recycled post-consumer glass.

Natural Pozzolans

Natural Pozzolans

Limestone Calcined Clay Cement

- Cement made from blending:
  - Limestone
  - Calcined Clay
  - Gypsum
- Low Carbon alternative to OPC
- Developed in late 1990’s in Switzerland
- Well tested/proven
- Its use encouraged by worldwide sustainability and energy organizations

Limestone Calcined Clay Cement

- Blend of Limestone/Calcined Clay
  - Properties comparable to OPC
    - Comparable or even Superior Strength/Durability
    - Improved Workability
    - Easier to place and finish
  - Significantly Lower Carbon Emissions
    - Potential reductions of up to 40 to 50%
  - Production Emission Reductions as well
    - Lower temperatures
    - Lower energy/fuel consumption

Limestone Calcined Clay Cement

- Future of LC3
  - Main ingredients abundant/widely available
    - Calcined clay can be obtained from:
      - A variety of natural clay sources
      - Waste stockpiles
    - Limestone also readily available
  - Suitable replacement for dwindling supplies of fly ash and blast furnace slag

Biochar Concrete

- Type of charcoal produced from organic matter
  - Wood chips
  - Agricultural and Forestry waste
- Created by heating these materials in oxygen-deprived environment called pyrolysis

Biochar Concrete

- Added to concrete improves:
  - Mechanical
  - Thermal properties
  - Increased strength/durability
    - Reduced cracking
    - Enhanced resistance to freeze/thaw
  - High porosity/absorbs moisture
    - Reduces concrete weight
    - Improves insulation properties

Biochar Concrete

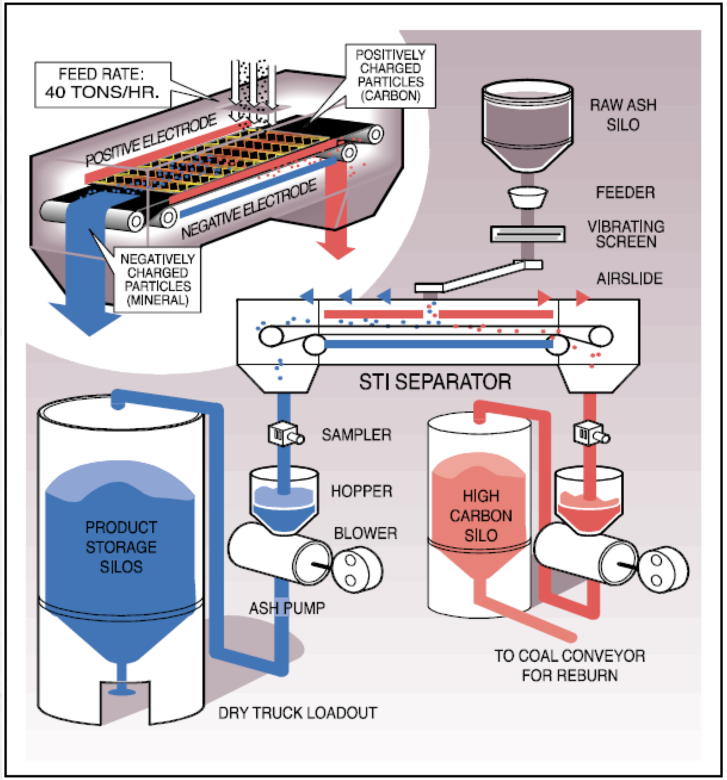
- Accelerated carbonation curing
  - Biochar in concrete provides a larger surface area for carbon dioxide absorption
    - Like natural carbonation with concrete, it mineralizes the CO_2 into calcium carbonate
  - New and cutting edge
    - Additional testing/development of material standards for improved consistency and uniformity

Remy Wines Case Study

- Winery Dayton, OR
  - 5,000 sf slab
  - 100 lbs. biochar/yd
  - Sequestration:
    - 10,230 lbs. of CO_2 equivalent
    - Carbon neutral concrete

Expand the Supply of Fly Ash

- Over 1.5 billion tons of coal ash in landfills
- Some is fly ash
- Several companies have begun to recover fly ash from landfills
- Treat it using a process called “beneficiation” to meet construction standards
  - Reduce amount of unburned carbon
  - Reduce ammonia
  - Adjust particle size

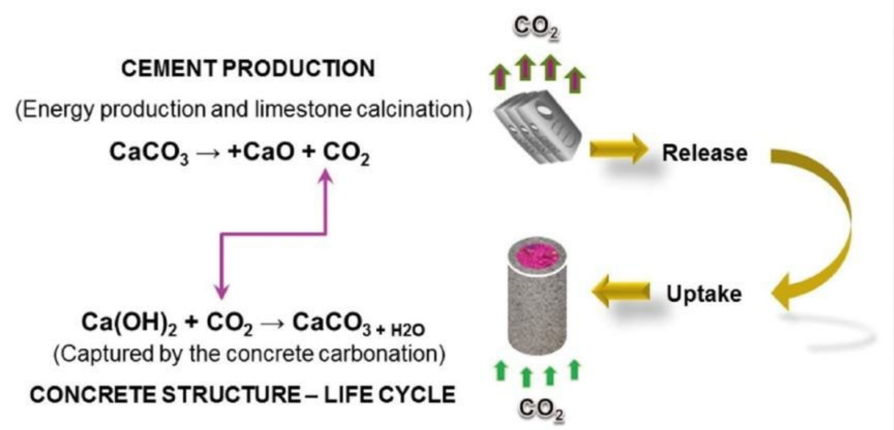


Case Study: 102 Rivonia Road

- Designed with sustainability in mind
- 50% more sustainable than the average office building
- 4-star Green Star SA (South Africa) rating
- Use of fly ash reduced the overall concrete footprint by 30%

Carbon Capture

- Carbonation: carbon dioxide (CO_2) penetrates the surface of hardened concrete and chemically reacts with cement hydration products to form carbonates
- For in-service concrete, slow process
- Given enough time and ideal conditions
  - all of the CO_2 emitted from calcination could be sequestered via carbonation.
  - Real world conditions are usually far from ideal.



Carbon Capture cont'd

- Carbonation depends on:
  - Exposure to air
  - Surface orientation
  - Surface-to-volume ratio
  - Binder constituents
  - Surface treatment
  - Porosity
  - Strength
  - Humidity
  - Temperature
  - Ambient CO_2 concentration.

Carbon Capture cont'd

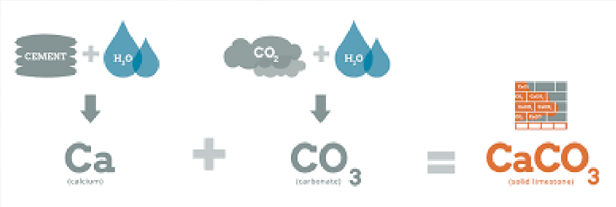
- CO_2 uptake are greatest when the surface-to-volume ratio is high
- When concrete has been crushed and exposed to air.
- Article "Substantial Global Carbon Uptake by Cement Carbonation," Nature Geoscience
  - Estimates cumulative CO_2 sequestered in concrete is 4.5 Gt 1930-2013
  - 43% of the CO_2 emissions from production of cement
  - Carbonation of cement products represents a substantial carbon sink.

Natural Carbonation

- Enhance carbonation at end-of-life and second-life
- Crushed concrete can absorb more CO_2 over short period
- Leave crushed concrete exposed to air for 1-2 years before re-use

Enhanced Carbonation

- Inject CO_2 into concrete
- Creates artificial limestone
- Sequesters small amount of CO_2
- Enhances compressive strength
- Reduces cement content
- Enhances durability



725 Ponce, Atlanta

- 360,000 square feet of office space
- 48,000 cubic yards of carbonated concrete
- Concrete sequestered 680 metric tons of CO_2
- The amount of CO_2 absorbed by 800 acres of U.S. forest each year

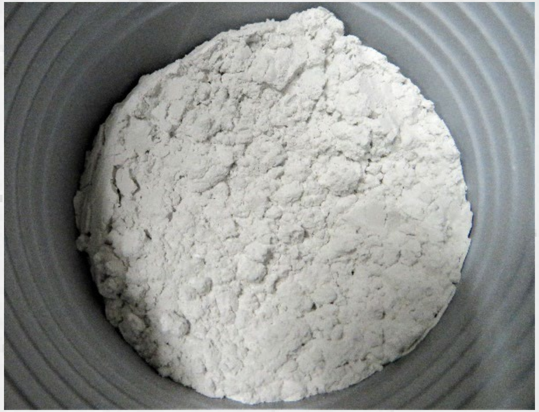
Enhanced Carbonation

- Specially formulated cement
- Significantly reduces CO_2 emissions
- Uses less limestone, fired at lower temperatures
- Produces 30% less greenhouse gases
- Concrete cures in contact with a CO_2 atmosphere in curing chamber
- Sequesters CO_2 equal to 5% of its weight
- Claims concrete's carbon footprint is reduced by 70%

Enhanced Carbonation

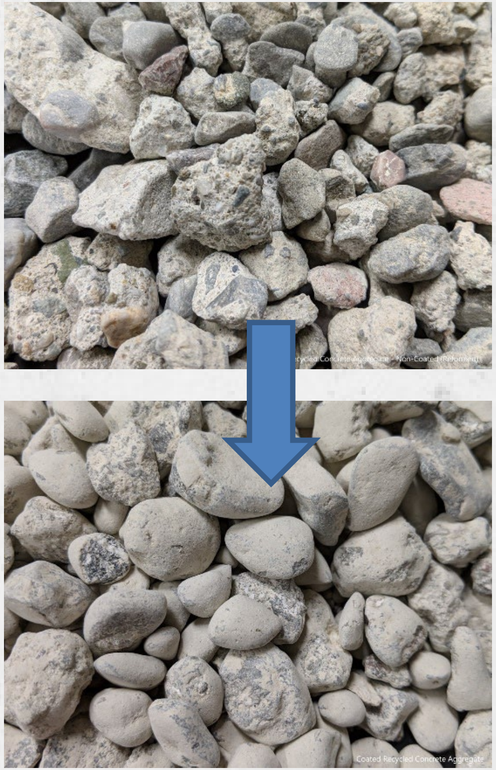
CO_2 treated fly ash (or other SCM)

- Infuse CO_2 under pressure
- Combines to make carbonates
- Increases compressive strength by 32%
  - Reduces cement demand
- Reduces chloride permeability
  - Increased durability
- Eliminates between 50 to 250 kg of CO_2 per metric ton of product
- Does not have any impact on air entrainment



Enhanced Carbonation

- Combine industrial CO_2 emissions with metal oxides
- CO_2 absorbed construction aggregate (limestone)
- 44% by mass permanently eliminated CO_2
- Substrate is small rock particles or recycled concrete
- Carbon-negative concrete is achievable
  - 1 yd^3 of concrete contains 3,000 lbs of aggregate
  - Roughly 1,320 lbs of sequestered CO_2
  - Offsets considerably more than the amount of CO_2 generated during cement production (roughly 600 lbs per yd^3)



Conclusion: The Future of Concrete

- Anticipated population growth
- Ever expanding built environment
- Increased concrete demand

- Continued innovations
  - lowering environmental impacts
  - Improving performance
  - Expanding range of applications

www.BuildWithStrength.com/design-center

- Structural system recommendations
- First cost comparisons
- Operating cost comparison
- Design/construction collaboration
- Specification review
- Carbon footprint

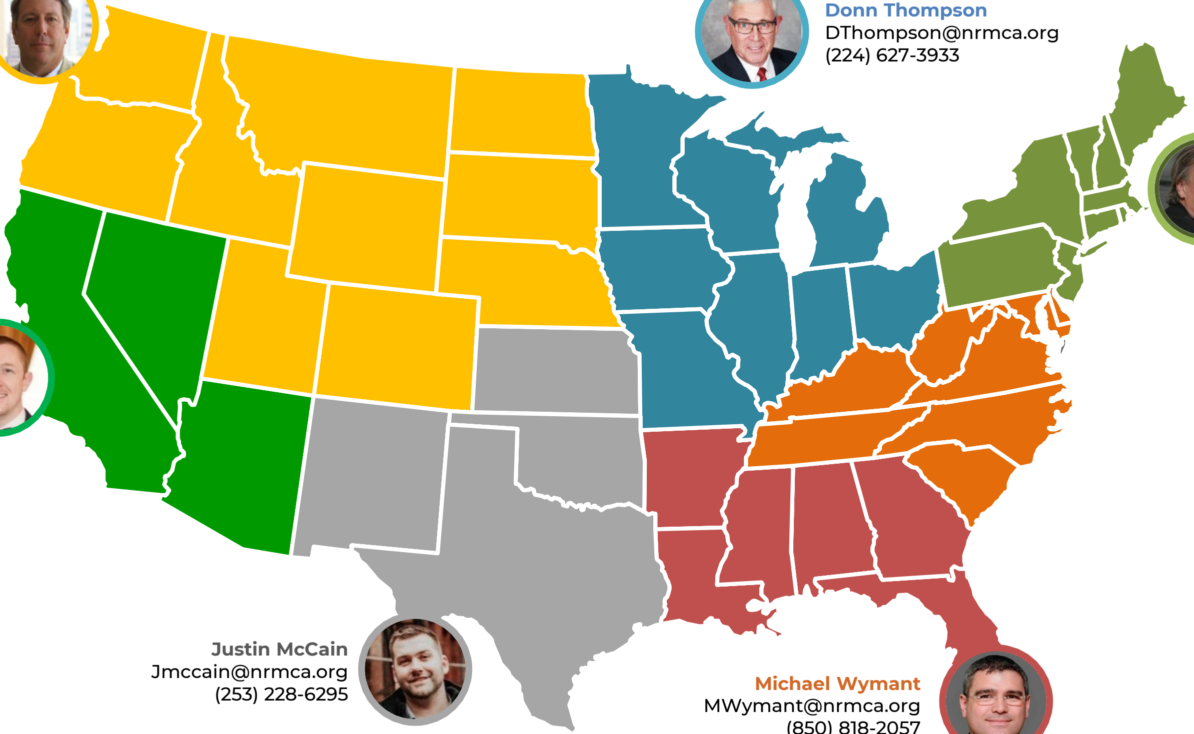
Concrete Design Center

Patrick Matsche
PMatsche@nrmca.org
(415) 672-5275

Donn Thompson
DThompson@nrmca.org
(224) 627-3933

Frank Mruk
Fmruk@nrmca.org
(401)585-7756

Brandon Wray
BWray@nrmca.org
(408) 806-0453



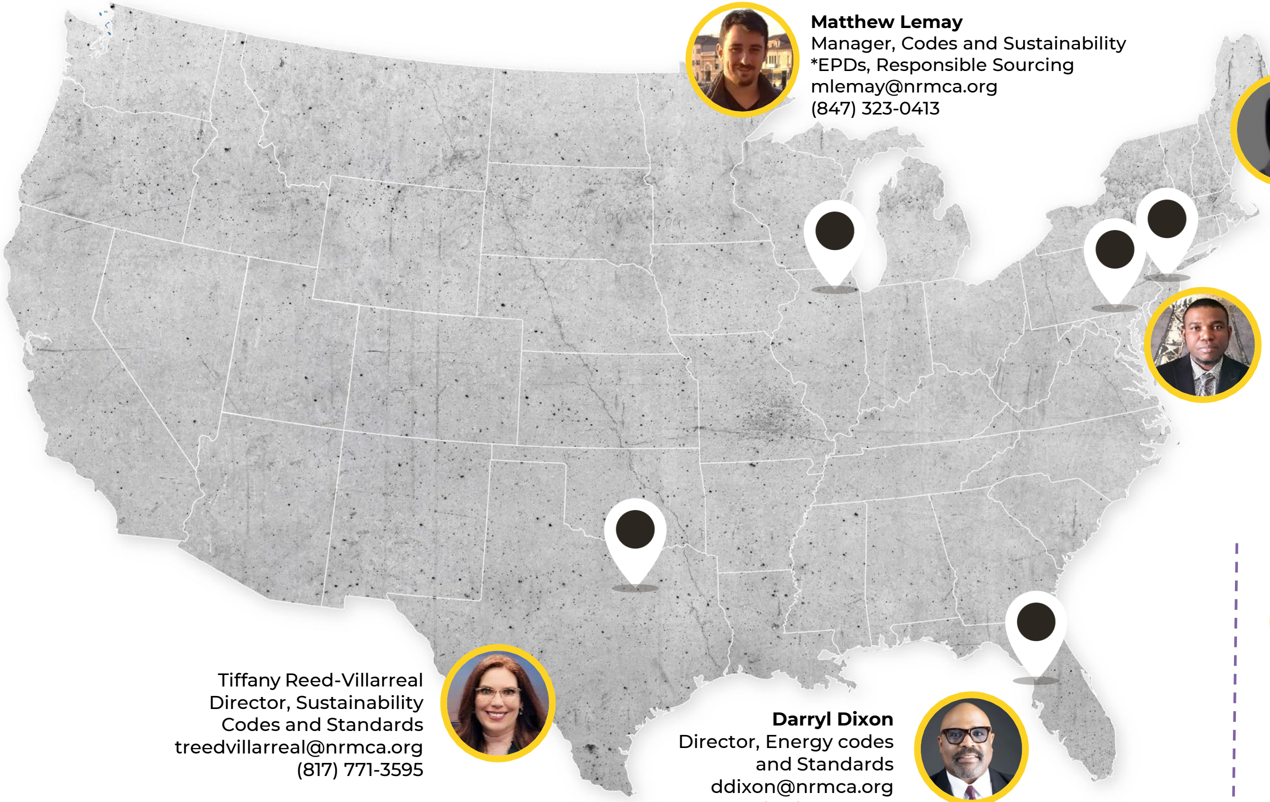
Justin McCain
Jmccain@nrmca.org
(253) 228-6295

Michael Wymant
MWymant@nrmca.org
(850) 818-2057

Lionel Lemay
Llemay@nrmca.org
(847) 922-7995

Derek Torres
DTorres@nrmca.org
(973) 876-0938

Codes and Standards



Matthew Lemay
Manager, Codes and Sustainability
*EPDs, Responsible Sourcing
mlemay@nrmca.org
(847) 323-0413

Shamim Rashid-Sumar
SVP Codes and Standards
*Fire safety, resilience, team leader
ssumar@nrmca.org
(917) 484-1960

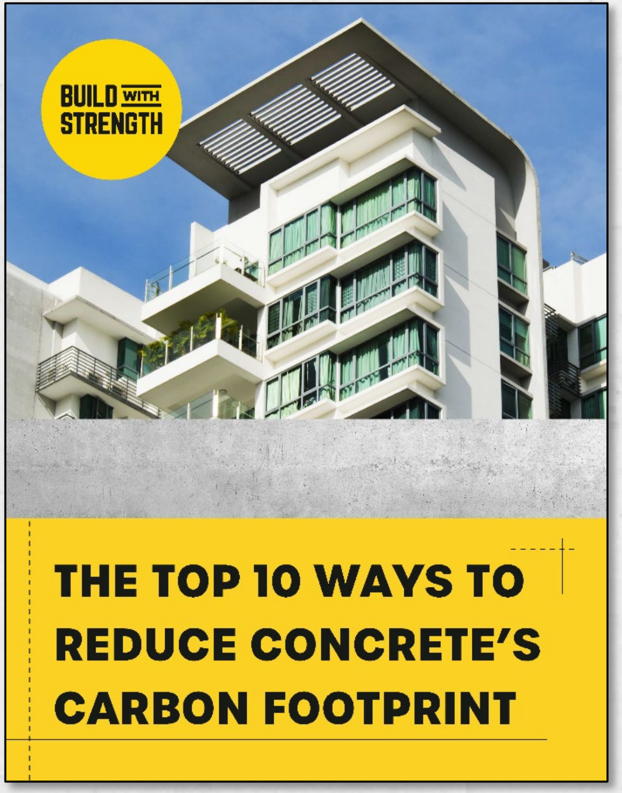
Julian Mills-Beale
Director, Codes and Standards
*Civil/structural, resilience
jmills-beale@nrmca.org
(484)633-7452

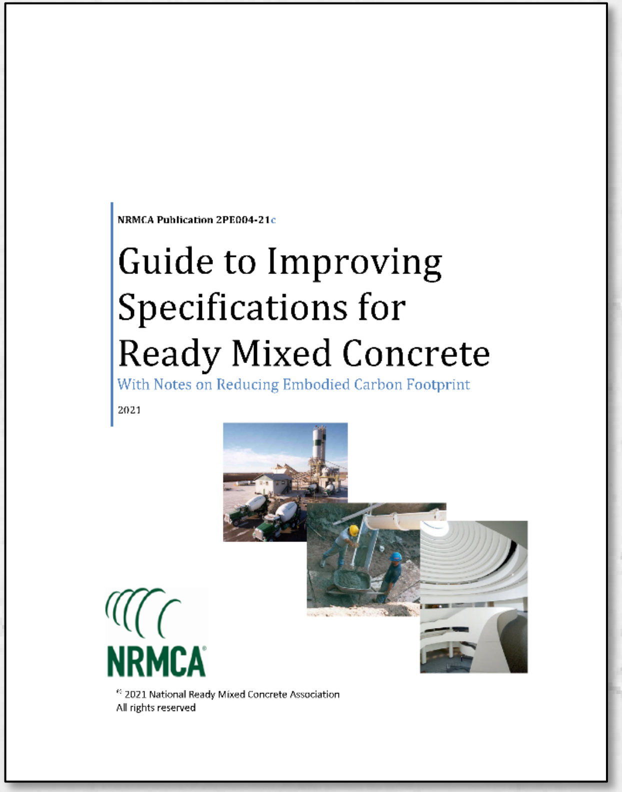
Lionel Lemay
EVP, Structures and Sustainability
llemay@nrmca.org
(847) 922-7995

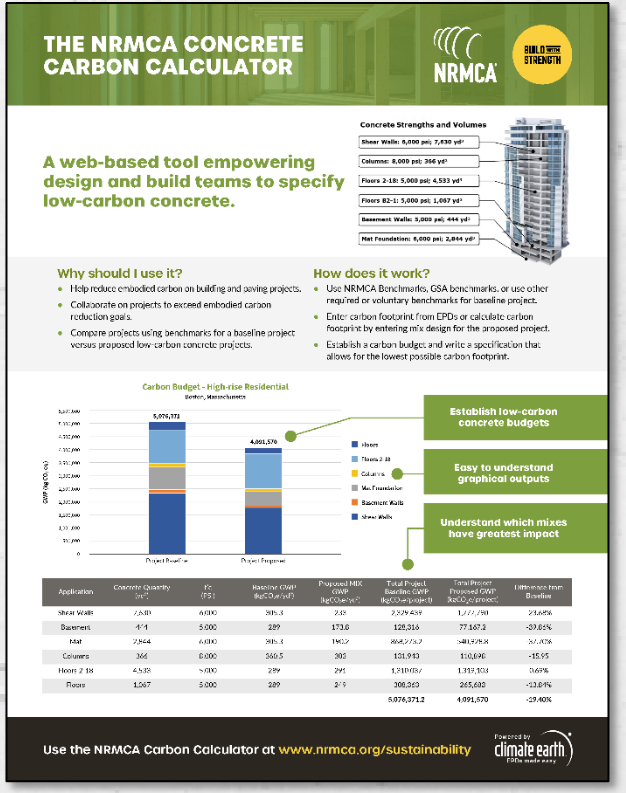
Tiffany Reed-Villarreal
Director, Sustainability
Codes and Standards
treedvillarreal@nrmca.org
(817) 771-3595

Darryl Dixon
Director, Energy codes and Standards
ddixon@nrmca.org
(813) 727-9324

www.nrmca.org/sustainability







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Questions?

Donn Thompson
dthompson@nrmca.org