
Concrete Innovations:
Pathways to Reducing Carbon Footprint
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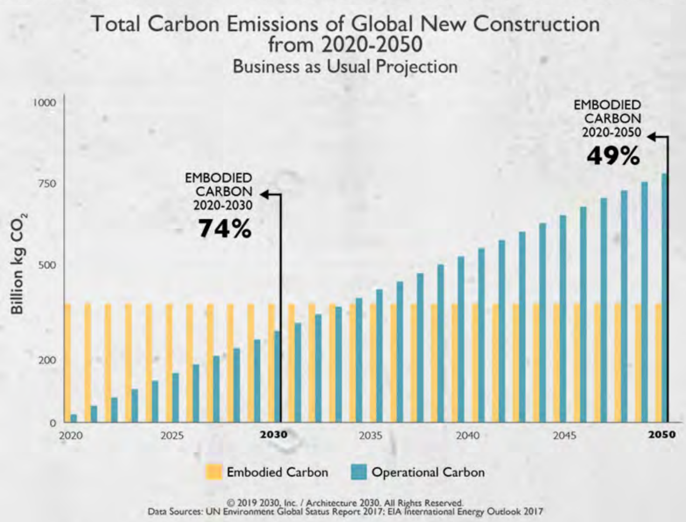
NRMCA
BUILD WITH STRENGTH

# The Problem

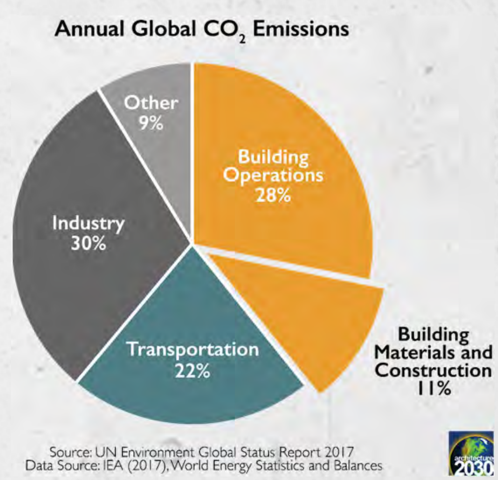
# The Reality

- 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.



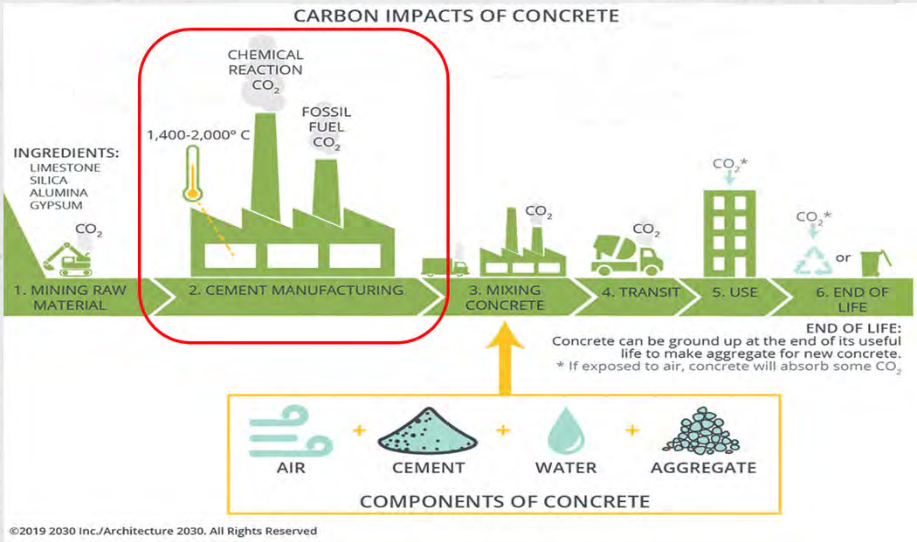

# The Challenge

- 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?

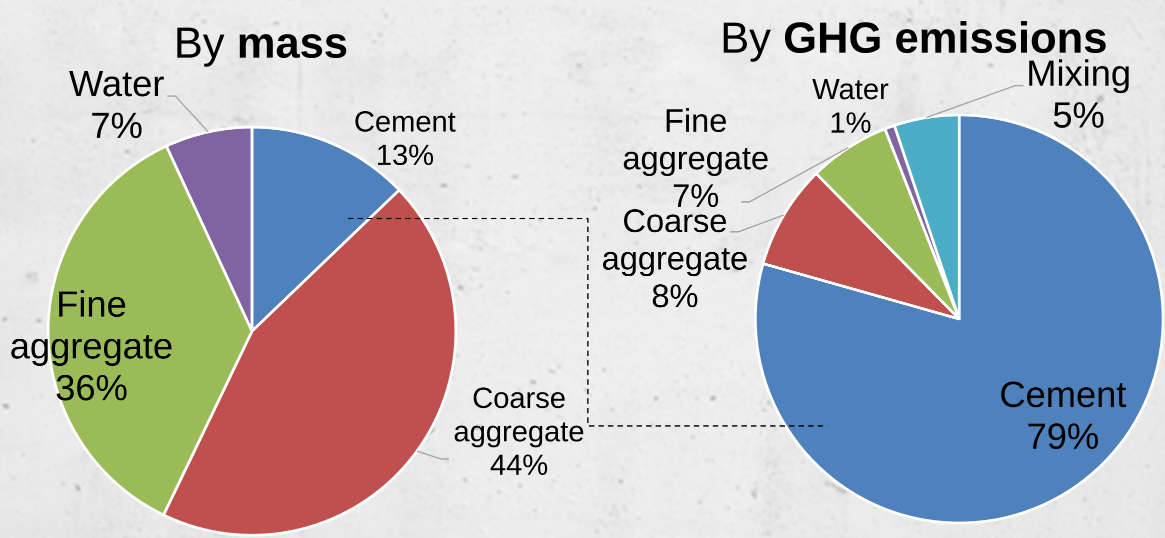


# The Challenge




## Cement drives concrete's environmental impact




3000 psi mixture with no SCMs

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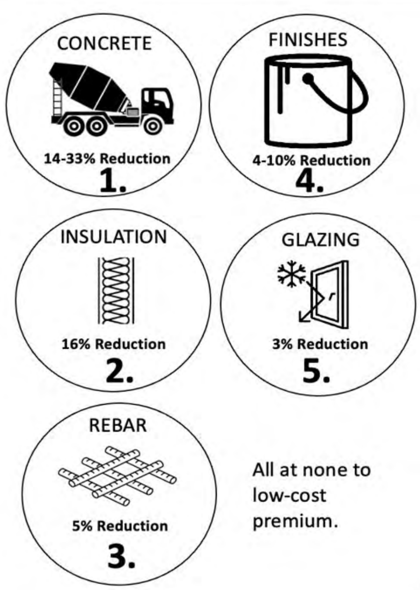
# The Solutions

## Concrete Innovations

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

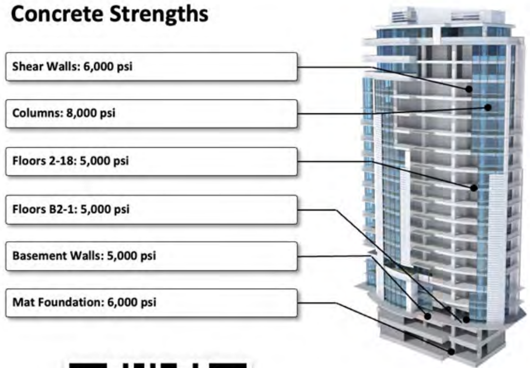
# More Efficient Concrete Mixtures




**Communicate Carbon Reduction Goals**

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

# More Efficient Concrete Mixtures




NEW NRMCA CARBON BUDGET CALCULATOR

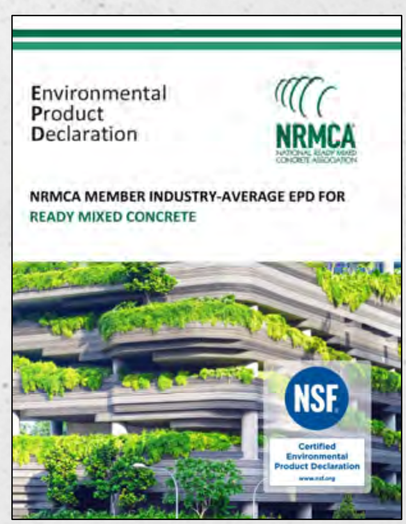
## Set a Carbon Budget

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


# 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

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# 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

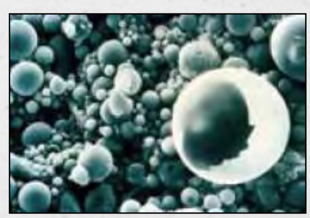
- TIP: Permit ASTM C 595 hydraulic cements
- TIP: Permit ASTM C 1157 hydraulic cements

# 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)

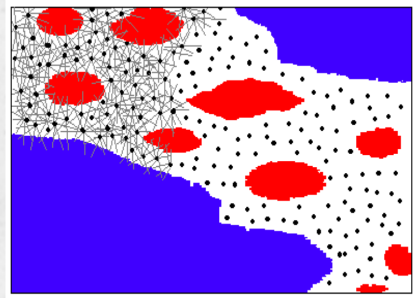
# Supplementary Cementitious Materials

- 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



**Cement + Water** → **C-S-H + CH**

the good stuff (C-S-H) — not so good stuff (CH)

# Hydration and SCMs

| | | |
|---|---|---|
| Cement + Water → C-S-H + CH | | Hydraulic |
| Pozzolan + CH → C-S-H | | Pozzolanic |
| Slag + Water → C-S-H (no CH) | Alkali/lime Activator (cement) | Hydraulic |
| Slag + CH → C-S-H | | Pozzolanic |

# Ground Glass Pozzolans

Harvard Business School

**FACULTY & RESEARCH**

FACULTY | RESEARCH | FEATURED TOPICS | ACADEMIC UNITS

Harvard Business School → Faculty & Research

## 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

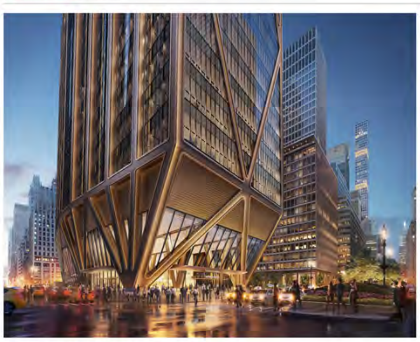
Shirley Lu
Accounting and Management
→ More Publications

Robert S. Kaplan
Accounting and Management
→ More Publications

# 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

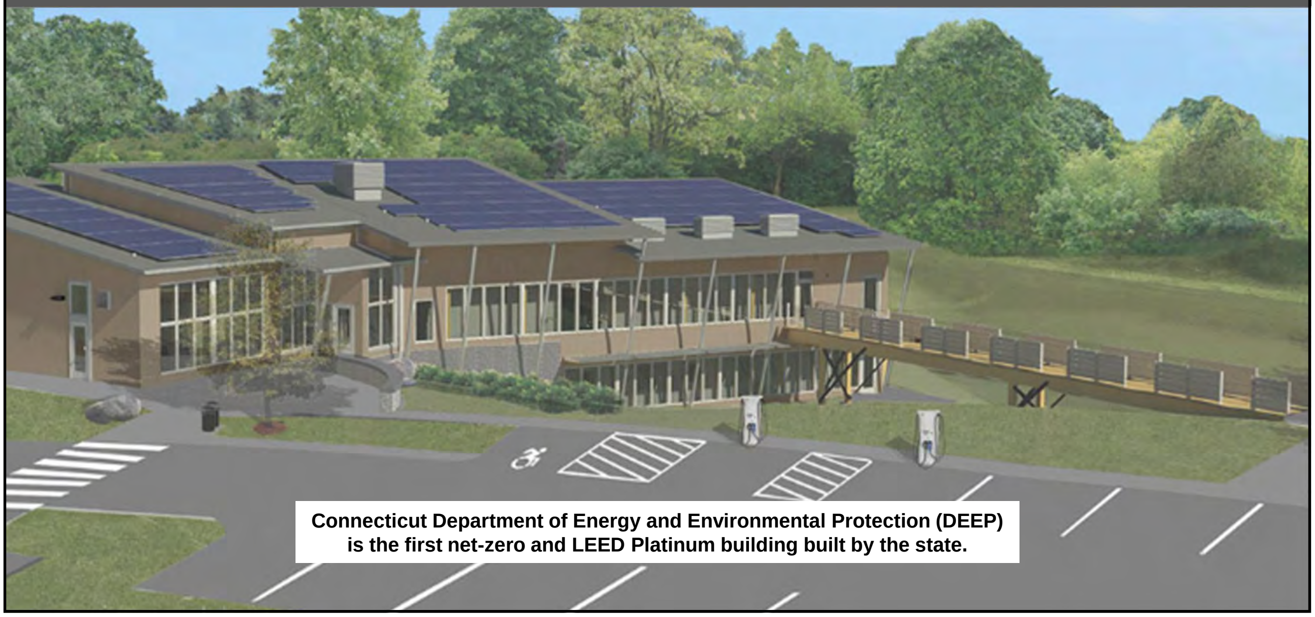
Anthony Rapp of 'Rent' lists East Village condo for $3.85M

TAKE A TOUR

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.

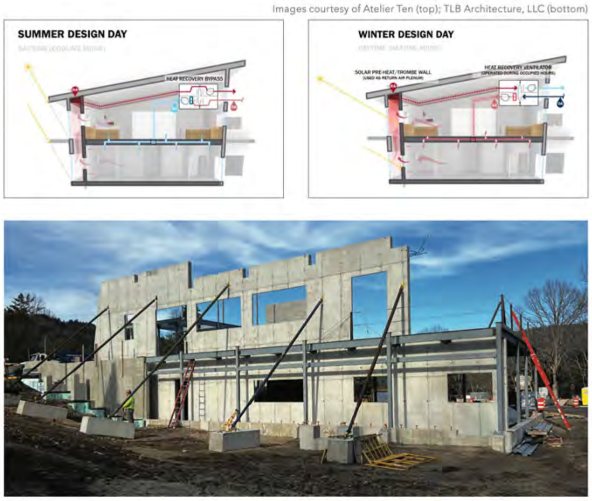
# CT DEEP Case Study



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.**

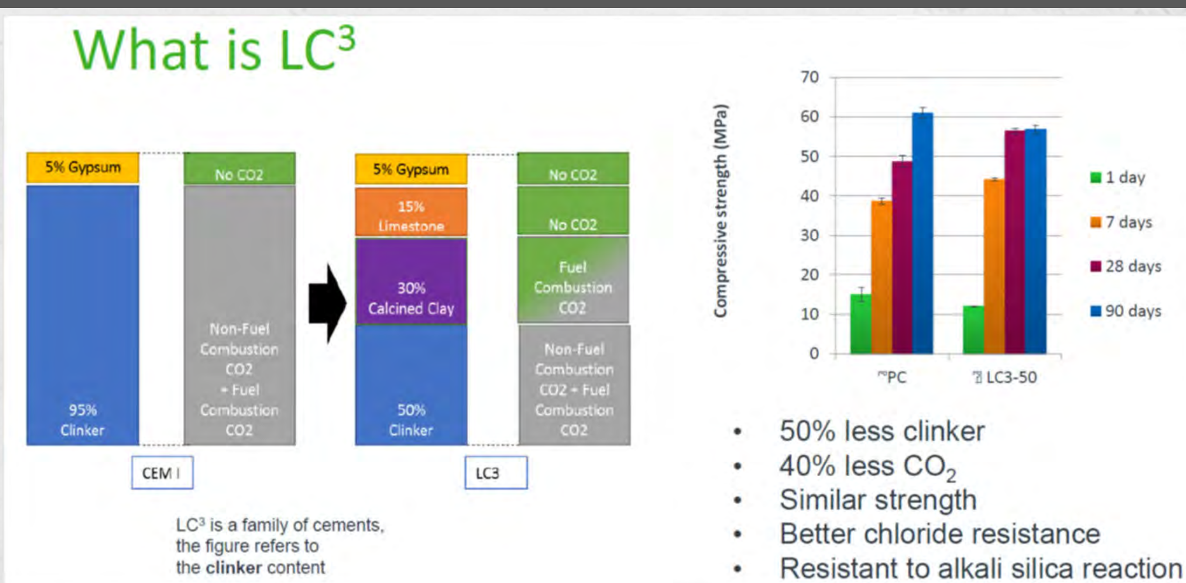
## Natural Pozzolans

## Natural Pozzolans

# Limestone Calcined Clay Cement LC$^3$

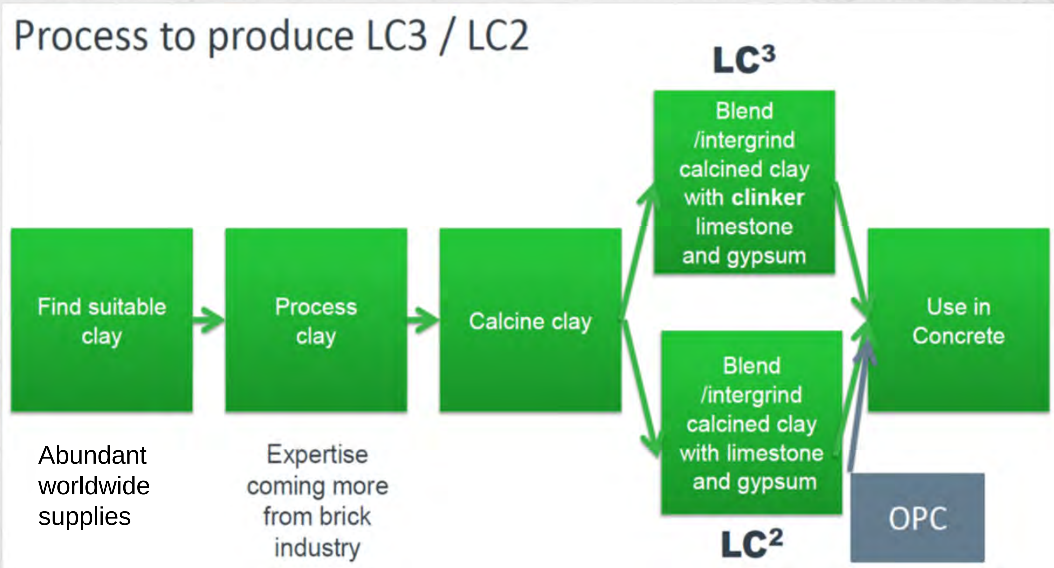
- Cement made from blending:
  - Limestone
  - Calcined Clay
  - Gypsum
- Low Carbon alternative to OPC
- Developed in late 1990's in Switzerland
- Well tested/proven
- Its use encouraged by worldwide sustainability and energy organizations

# Limestone Calcined Clay Cement LC$^3$




Source: Karen Scrivener, FREng, EPFL, Switzerland

# Limestone Calcined Clay Cement $LC^3$




Source: Karen Scrivener, FREng, EPFL, Switzerland

# Limestone Calcined Clay Cement $LC^3$

- 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

Source: Karen Scrivener, FREng, EPFL, Switzerland

# Limestone Calcined Clay Cement LC$^3$

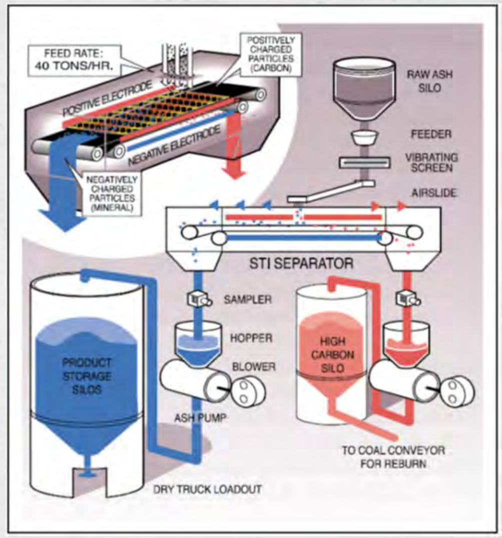

Source: Karen Scrivener, FREng, EPFL, Switzerland

# Limestone Calcined Clay Cement LC$^3$

- 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
  - ASTM C595/C595M already cover blended cements such as LC3 (Ternary type IT)

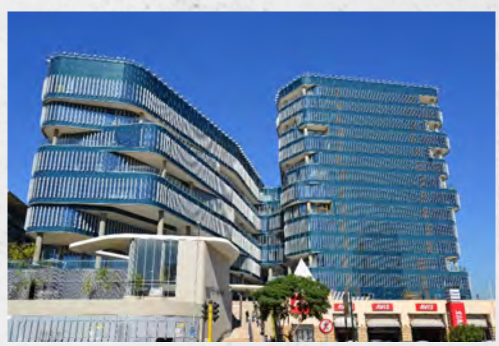
# Expand the Supply of Fly Ash

- 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



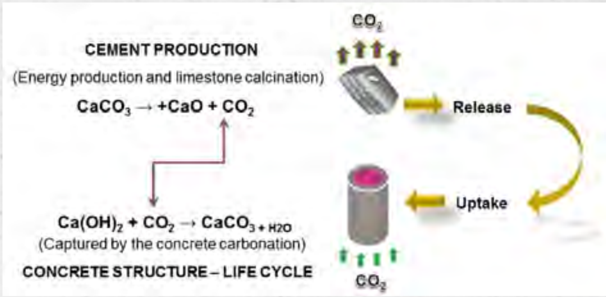

# Fly Ash Case Study: 102 Rivonia Road

- 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%



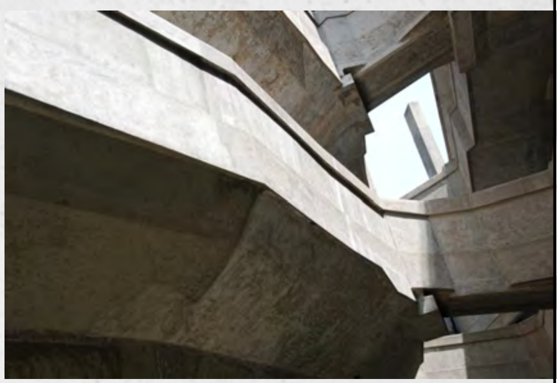
# Carbon Capture

- 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 mineralized via carbonation.
  - Real world conditions are usually far from ideal.




# Carbon Capture cont'd

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



# Carbon Capture cont'd

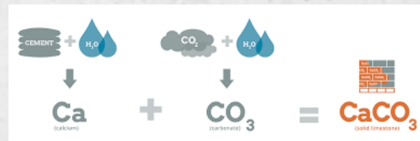
- Article "Substantial Global Carbon Uptake by Cement Carbonation," Nature Geoscience
  - Estimates cumulative $CO_2$ sequestered in concrete is 4.5 Gt 1930-2013
  - 43% of the $CO_2$ emissions from production of cement
  - Carbonation of cement products represents a substantial carbon sink.

# Natural Carbonation

- $CO_2$ uptake are greatest when the surface-to-volume ratio is high
- When concrete has been crushed and exposed to air.
- 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
- Mineralizes a small amount of $CO_2$
- Enhances compressive strength
- Reduces cement content
- Enhances durability




## Enhanced Carbonation: 725 Ponce, Atlanta

- 360,000 square feet of office space
- 48,000 cubic yards of carbonated concrete
- Concrete mineralized 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
- Mineralizes $CO_2$ equal to 5% of precast weight
- Claims concrete's carbon footprint is reduced by 70%

# Enhanced Carbonation

**$CO_2$ treated fly ash (or other SCM)**

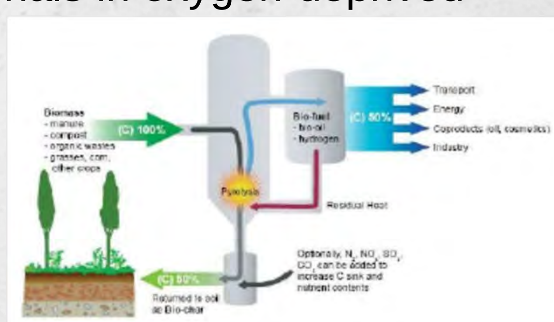
- Infuse $CO_2$ under pressure
- Combines to make carbonates
- Increases compressive strength by 32%
  - Reduces cement demand
- Reduces chloride permeability
  - Increased durability
- Eliminates between 50 to 250 kg of $CO_2$ per metric ton of product
- Does not have any impact on air entrainment

# 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 mineralized $CO_2$
  - Offsets considerably more than the amount of $CO_2$ generated during cement production (roughly 600 lbs per $yd^3$)

# 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




**Source: Harn Wei Kua, National University of Singapore**

## 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

# Biochar Concrete

**PIONEERING WORKS IN BIOCHAR CONCRETE**

**Choi et al. (2012)** found that a dosage of 5% by weight of cement (wt.%) of hardwood biochar improved the compressive strength of mortar by 10-12%.

- Schmidt (2014) then initiated several onsite demonstration projects in which biochar-containing wall plaster was used in several locations in the Ithaka Institute in Sion, Switzerland.
- Ahmad et al. (2015) studied bamboo biochar produced at 850°C, at a heating rate of 60 °C/min for 1 hour; biochar improved compressive strength of biochar-cement pastes by 40-50%, toughness by 103% and flexural strength by 66%.
- Restuccia and Ferro (2016) found adding biochar up to 1 wt.% increased the fracture energy of cement-based composites by 61%

**Source: Harn Wei Kua, National University of Singapore**

# Remy Winery Case Study

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

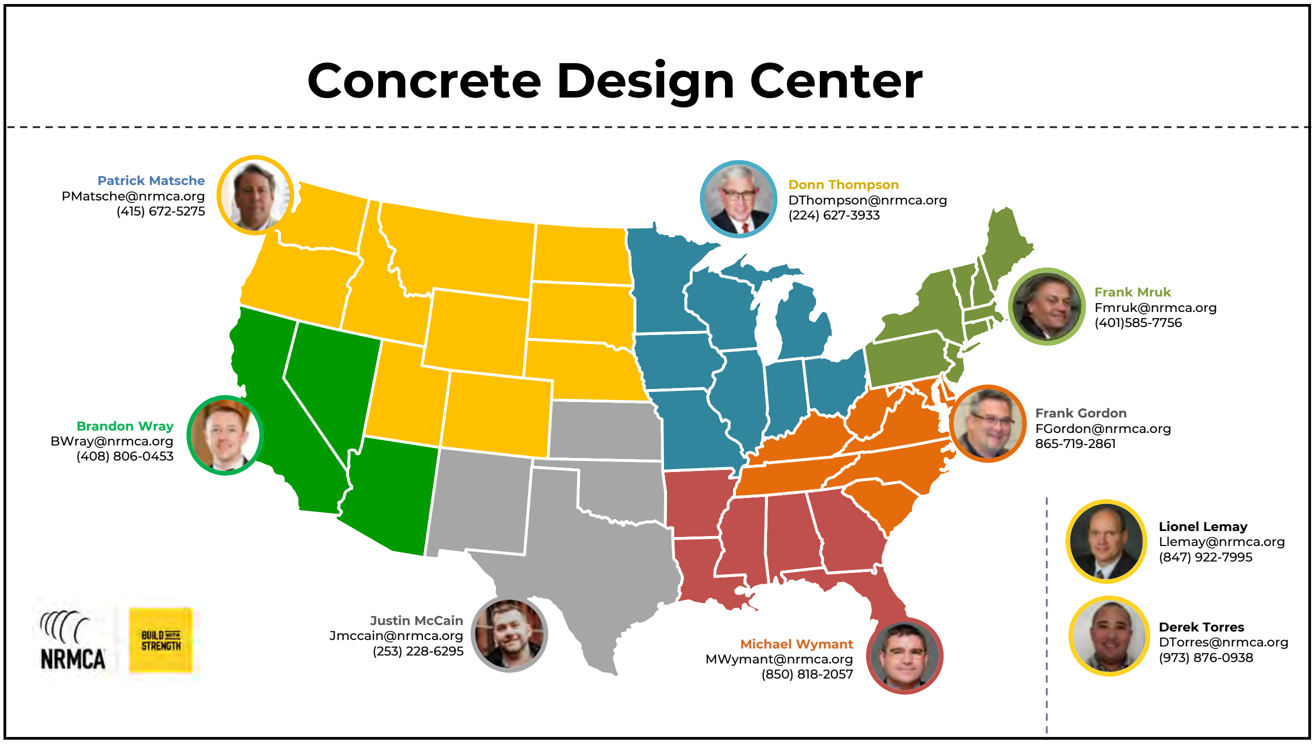
# Conclusion: The Future of Concrete

- 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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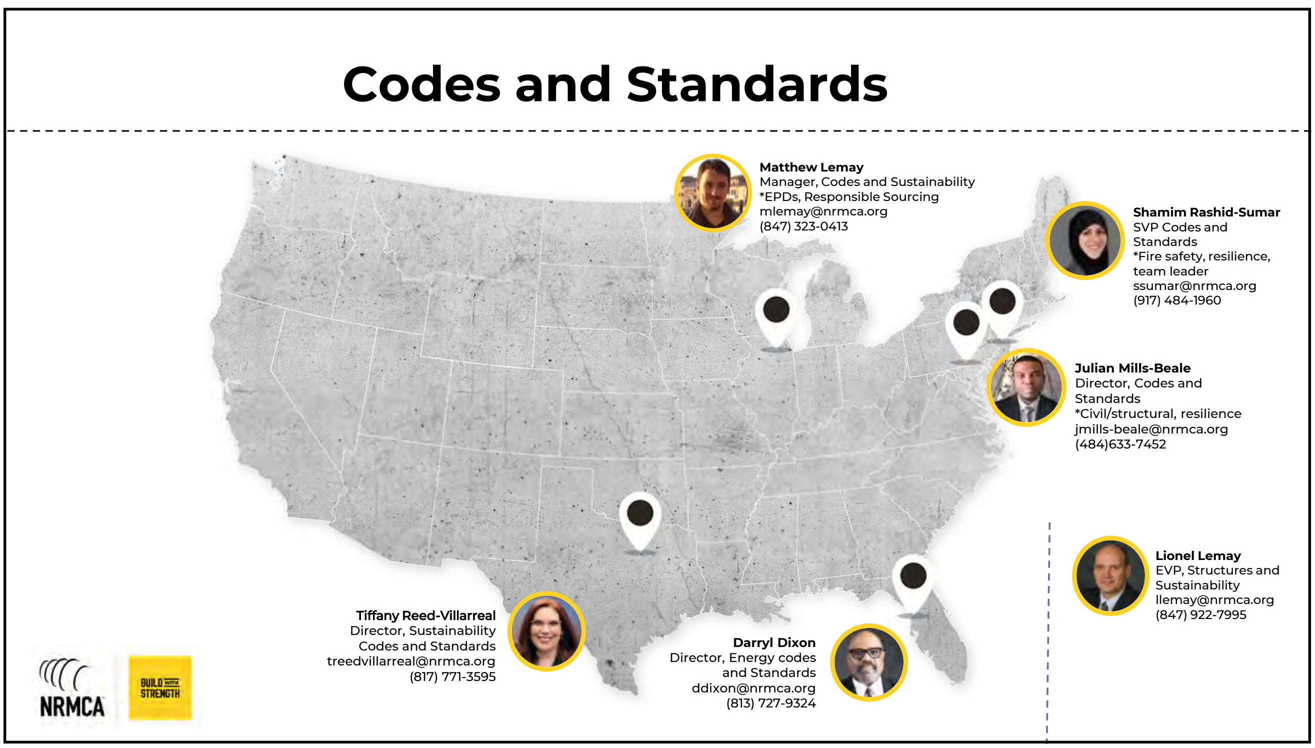
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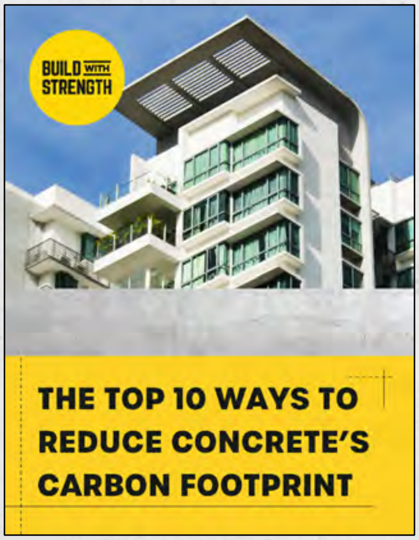
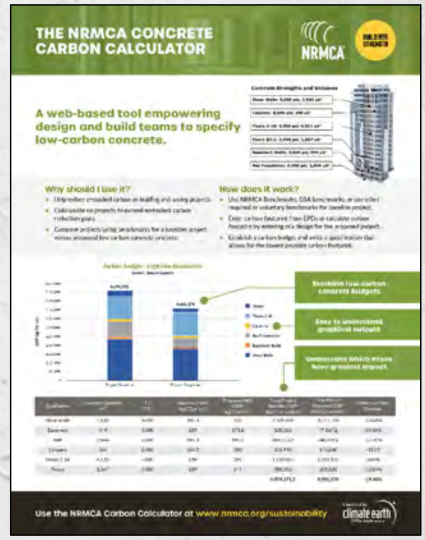
## www.nrmca.org/sustainability








## Concrete Innovations:
## Pathways to Reducing Carbon Footprint

Questions?

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