Innovations and Operations: Sustainability Initiatives in the Concrete Industry

Presenters:

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Course Description

Concrete is a durable, resilient material that can provide many benefits to efficient, sustainable structures in the long term. While concrete does have an up-front CO2 impact, the industry is working to reduce GHG emissions and increase the efficiency of its products.

This presentation will discuss technical innovations to reduce the carbon footprint of concrete and examine current process improvements that are pushing the industry forward to a more sustainable future.

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Learning Objectives

1. **Learn** about attributes, benefits and considerations of using concrete in the holistic design of sustainable structures.
2. **Examine** established and developing technologies aimed at reducing the environmental impact of concrete.
3. **Discover** process improvements, production efficiencies and other producer efforts that are creating GHG reductions today.
4. **Demonstrate** ways that concrete producers are lowering the environmental impact of their products, and how projects are achieving sustainability goals with concrete.

3

Build for Tomorrow

- Climate change is here. The world is changing.
- The recent IPCC report indicates we need to accelerate our efforts to mitigate the impacts of climate change, while also preparing for inevitable change.
- The changing environment means buildings will experience more stress in the coming decades.
- More important than ever to build with both sustainability and resilience in mind.

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What is sustainable design?

"Sustainable design seeks to reduce negative impacts on the environment, and the health and comfort of building occupants, thereby improving building performance. The basic objectives of sustainability are to reduce consumption of non-renewable resources, minimize waste, and create healthy, productive environments."

From the U.S General Services Administration definition of sustainable design

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Building Impact: By the Numbers

According to the United Nations Environment Program, buildings and their construction worldwide account for 36 percent of global energy use and 39 percent of energy-related carbon dioxide emissions each year.

U.S. Energy Administration data from 2018 shows that residential and commercial buildings account for 40 percent of energy usage in the United States.

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Building Impact: By the Numbers

According to USGBC, buildings account for 13.6 percent of potable water use in the U.S. That is the third-largest category, behind thermoelectric power and irrigation.

The building industry consumes 40% of the raw materials flow of the global economy every year.

EPA estimates that 569 million tons of construction and demolition waste were generated in the United States in 2017. That is more than twice the amount of generated municipal solid waste.

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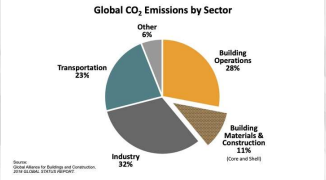
Building Impact: By the Numbers

Buildings account for about 28 percent of global emissions each year, and about 11 percent of embodied carbon emissions.



Data from Architecture 2030

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Working Toward Carbon Reduction

- The concrete industry recognizes the need for immediate reductions in greenhouse gas emissions.
- Numerous new technologies and techniques are emerging to minimize the initial impact of manufacturing concrete.

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What is Embodied Carbon?

Definitions of embodied carbon differ. Some view the embodied carbon of a building as including the entire life cycle of the materials, even the operational phase of the building. A full life-cycle view of embodied carbon would account for impacts of landfilling or recycling materials as well.

Others focus on initial embodied carbon, which are the impacts associated with extracting, manufacturing and transporting materials to the jobsite.

"Carbon" is used to indicate all greenhouse gas emissions, not just carbon dioxide.

Source: BuildingGreen

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Material Matters

All building materials contribute to the carbon footprint of a building in different ways.

- Concrete: It contributes 6 to 11 percent of global carbon dioxide emissions. Most of it comes from the production portland cement, which comprises about 10 percent of the concrete mix. Producing aggregate also requires some energy, mostly from transportation.
- Steel: Manufacturing virgin steel from iron ore is very energy intensive. The global steel sector has a large carbon footprint, contributing upwards of 10 percent of global carbon dioxide emissions.
- Wood: Its manufacture produces fewer emissions than steel and concrete, but there is much debate about the overall impact. More research is needed on the carbon emissions of the logging, processing, transport and maintenance of wood products.

Source: Architect magazine, January 2020

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Looking at the Big Picture, Products and Operation

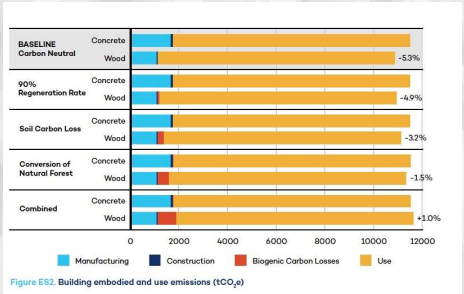

Figure ES2. Building embodied and use emissions (tCO_2e)

Source: International Institute for Sustainable Development report, "Emission Omisissions"

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World of Concrete

- Concrete is the most abundant man-made material in the world.
- Estimates range between 4 and 10 billion tons of concrete produced globally each year.
- Concrete provides durability, resilience, quality and many attributes.
- We need it.
- We need to make it better and less impactful to the environment.

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Concrete is Unique

Formulation influenced by:

- Application
- Design professionals
- Contractors
- Specifications

Can be made:

- Stronger
- Weaker
- Lighter
- More flowable
- Stiffer
- Less Permeable

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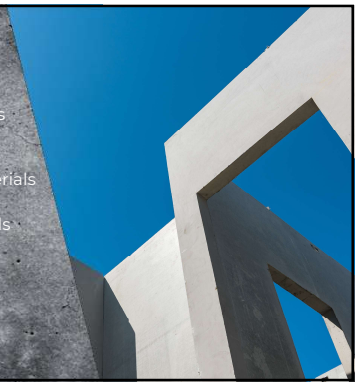
Concrete is Versatile

- Exposed to the elements
- Exposed for architectural reasons
- Economical
- Available everywhere
- Made from most abundant materials on earth
- Usually made from local materials
- Does not rot, rust or burn



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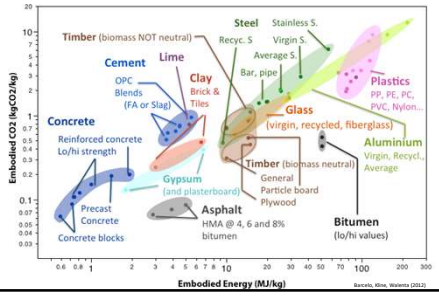
Concrete is Environmentally Friendly



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Used Everywhere where people live, work, learn, & play

- Tallest buildings
- Longest bridges
- Largest buildings
- Busiest airports
- Most efficient rapid transit
- Roadways
- Theaters
- Stadiums
- Schools
- Apartment buildings
- Homes
- Water supply and treatment

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UN Environment Global Status Report 2017

- 3.4 Trillion sq ft by 2060
- 1.4 times existing building stock
- Building designers and owners encouraged:
  - Design disaster resilient buildings
  - Design zero-energy buildings
- At the same time, entire construction industry:
  - Urged to reduce embodied impacts

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Portland cement association
roadmap to carbon neutrality by 2050

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TWO SOURCES OF CARBON DURING CEMENT MANUFACTURING…

$CaCO_3 \longrightarrow CaO + CO_2$ (60%)
$C + O_2 \longrightarrow CO_2$ (40%)

U.S. Cement Industry contribution to global GHG = 0.17% CO_{2eq}

U.S. Cement Industry contribution to U.S. GHG = 1.25% CO_{2eq}

shaped BY CONCRETE

PCA Since 1916 America's Cement Manufacturers

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PCA 2050 Roadmap to Carbon Neutrality

CO2 and Sustainability

Increasing interest in reducing environmental impact of building materials from many groups: designers, regulators, even the public

Concrete is so essential to the way we live, that our industry must do its part to address climate issues

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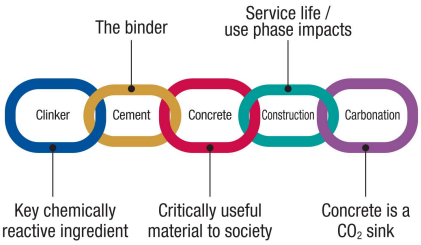
Society will continue to need "The Five 'C's"



THE FIVE "C's"

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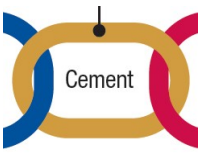
Optimizing Cement

- Right-sizing the amount of clinker in cement
- Using more non-gypsum additions
  - Recognizing the benefits of Portland limestone cements (ASTM C150)
- Choosing the right cement specification for the specific application
- Zero emissions bulk transportation (rail/truck)



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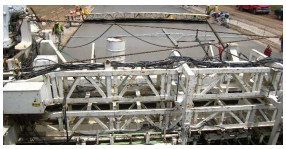
Procuring PLC Concrete

Basics of specifying and ordering

A simple revision to specifications:

- 1:1 replacement of OPC with PLC
- Same suppliers for your ready mix
- Same delivery and placing equipment



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Long Track Record

Blended limestone cements

History of good performance, even at higher limestone contents than the U.S.

Europeans introduced in the late 1960s

Canada has used them since the late 2000s

U.S. standards in place since 2012 (even earlier as C1157 performance cements)

Market share for blended cements grows as users gain comfort working with them

U.S. is currently using more than 4 MMT/year

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Mix Designs with PLC

Proportioning, batching, and mixing

PLC replaces ordinary portland cement at 1:1 ratio

PLC allows for the same dosages of fly ash or other pozzolans, slag cement

As with any new material, some testing is warranted to confirm effects on fresh and hardened properties

Air content, slump, bleed potential, setting time, compressive strength

Some producers report no adjustments are needed, others tweak proportions or adjust admixture dosages

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Mix Designs with PLC

Typical effects on fresh and hardened properties

Workability	Increase or decrease No significant effect on admixtures
Bleeding	Decreases with increasing fineness Generally of no concern
Setting time (initial, final)	Can be slight decrease w/increasing fineness Not a concern even up to 15% limestone
Heat of hydration	Slight increase at early ages (up to 48 hours) But less significant at later ages
Compressive strength	Can increase slightly Both early-age and long-term strengths
Scaling and freeze-thaw resistance	Use same techniques as with OPC concrete mixes: Proper air-void systems, curing, higher strengths
Sulfate resistance	Use same techniques as with OPC concrete mixes: Low w/cm, min. strength, and MS or HS designations

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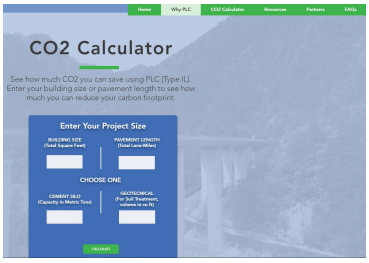
greenercement.com - Your PLC Resource

- Calculators for CO2 savings
  - Basic, advanced
- Benefits of PLC
- Spec language
- Case studies
- PLC availability map
- Industry partners
- FAQs
- Contact an expert
- Mobile friendly



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DOTs Have Embraced PLCs

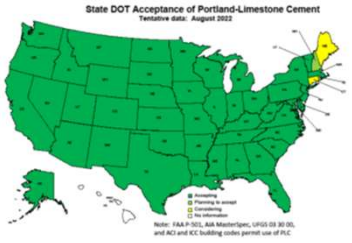
Parallel standards for Type IL

ASTM and AASHTO specifications

Adoption varies by state

ASTM C595 Type IL cement instead of (or as an option to) ASTM C150 Type I portland cement

Or **AASHTO M 240 Type IL cement** instead of (or as an option to) M 85 Type I portland cement



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greenercement.com – PLC Availability

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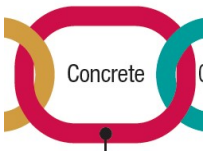
Obstacles to Optimizing Concrete – Institutional Inertia

PRESCRIPTIVE BASED SPECIFICATIONS:

- Limits on how much supplementary cementitious material (SCM) can be used
- Restrictions on the use of fly ash as an SCM
- Minimum requirements for how much cementitious material should be used
- Limits on water-cementitious materials ratio
- Restrictions on aggregate grading



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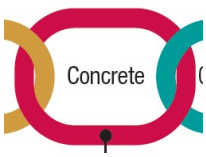
The solution?

- Shift from prescriptive to **performance-based specifications**
- Incentivize innovation with today's products instead of institutionalizing inertia with yesterday's practices
- The right mix using the right materials for the right application to achieve the right performance
- Reduced concrete plant energy consumption/reduced concrete delivery energy consumption
- Breakthrough technologies



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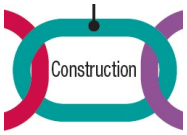
Optimization OF THE BUILT ENVIRONMENT –
Make it about more than the materials



SUSTAINABLE/RESILIENT CONSTRUCTION

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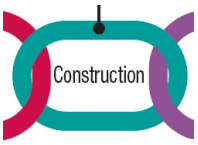
PCA 2050 Roadmap to Carbon Neutrality

Optimizing construction – designers and builders

Advancing design techniques: 3D modeling, virtual reality design, etc.

Zero waste, improved scheduling, zero emission delivery and materials handling

Greater energy efficiency for buildings



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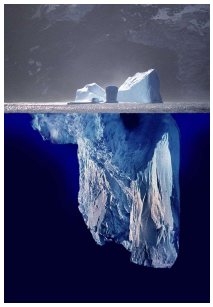
- EMPHASIZE **FULL** LIFE CYCLE
  - Use phase/end of life
    - All under the water line
- EPDs
  - Often stop at Cradle to Gate
  - Embodied carbon only
  - Comparison not based on full LCA



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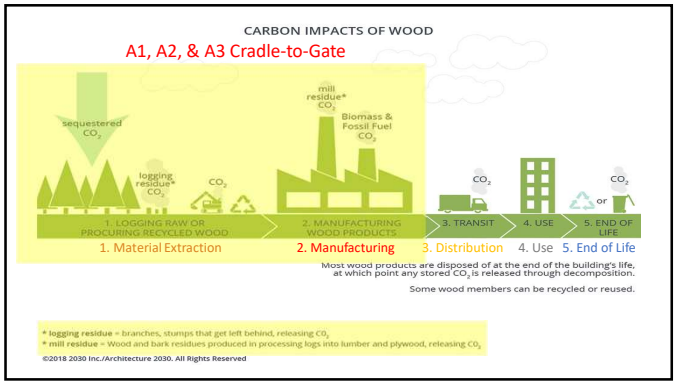
CARBON IMPACTS OF WOOD
A1, A2, & A3 Cradle-to-Gate
sequestered CO_2
logging residue* CO_2
mill residue* CO_2
Biomass & Fossil Fuel CO_2
CO_2
CO_2
or
CO_2
1. LOGGING RAW OR PROCURING RECYCLED WOOD
2. MANUFACTURING WOOD PRODUCTS
3. TRANSIT
4. USE
5. END OF LIFE
1. Material Extraction
2. Manufacturing
3. Distribution
4. Use
5. End of Life
Most wood products are disposed of at the end of the building's life, at which point any stored CO_2 is released through decomposition.
Some wood members can be recycled or reused.
* logging residue = branches, stumps that get left behind, releasing CO_2
* mill residue = Wood and bark residues produced in processing logs into lumber and plywood, releasing CO_2
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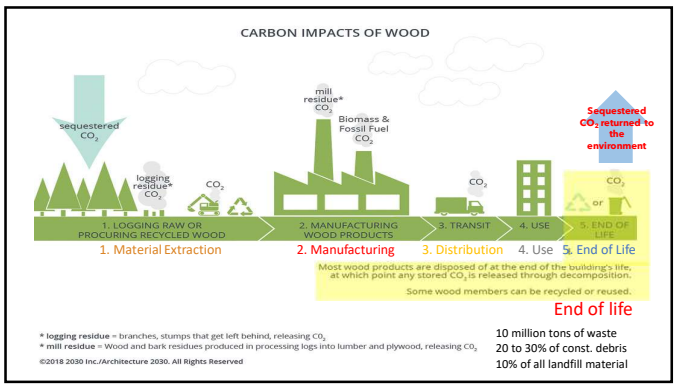
CARBON IMPACTS OF WOOD
sequestered CO_2
logging residue* CO_2
mill residue* CO_2
Biomass & Fossil Fuel CO_2
CO_2
CO_2
or
CO_2
Sequestered CO_2 returned to the environment
1. LOGGING RAW OR PROCURING RECYCLED WOOD
2. MANUFACTURING WOOD PRODUCTS
3. TRANSIT
4. USE
5. END OF LIFE
1. Material Extraction
2. Manufacturing
3. Distribution
4. Use
5. End of Life
Most wood products are disposed of at the end of the building's life, at which point any stored CO_2 is released through decomposition.
Some wood members can be recycled or reused.
End of life
10 million tons of waste
20 to 30% of const. debris
10% of all landfill material
* logging residue = branches, stumps that get left behind, releasing CO_2
* mill residue = Wood and bark residues produced in processing logs into lumber and plywood, releasing CO_2
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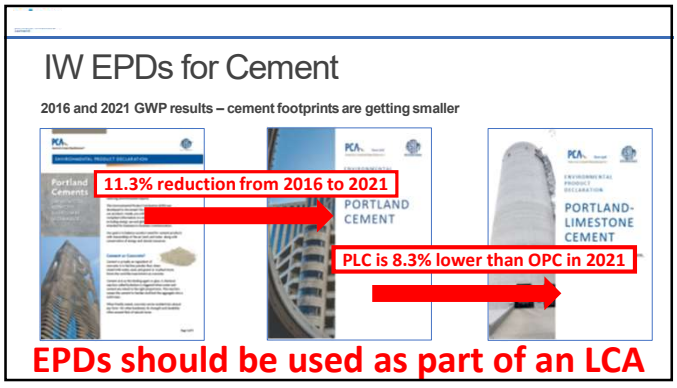
IW EPDs for Cement
2016 and 2021 GWP results – cement footprints are getting smaller
11.3% reduction from 2016 to 2021
PORTLAND CEMENT
PLC is 8.3% lower than OPC in 2021
PORTLAND-LIMESTONE CEMENT
EPDs should be used as part of an LCA

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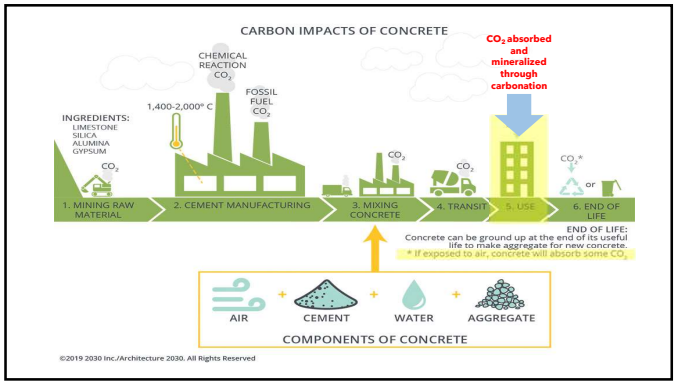

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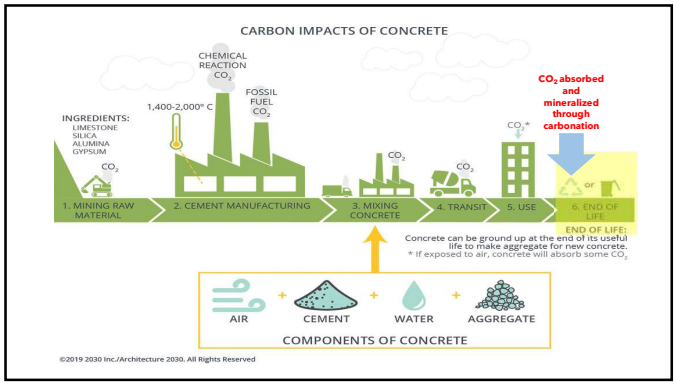

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Climate related weather events require smart construction… and smart construction must be sustainable construction

2021 Kentucky Tornados

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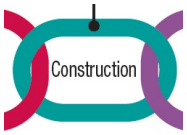
Sustainable construction is resilient



2018 Hurricane Michael Mexico Beach, FL

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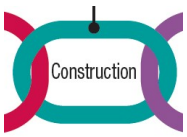
Building back better means concrete construction



2021 Colorado Wildfires

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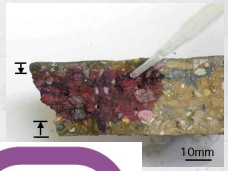
Concrete: CO_2 Absorption and Mineralization

- CO_2 reabsorbed into concrete throughout lifetime
  - Small amount during service life
  - Significantly more from crushed concrete (increased surface area)
- Process is called **carbonation**



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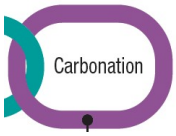
The Pentagon

- Completed January 1943
- 435,000 cubic yards of concrete
- 43,000 tons of steel
- 680,000 tons of sand and gravel
- Still absorbing CO_2 after nearly 80 years
- **Concrete can absorb 10% of the CO_2 emissions generated during the manufacture and transportation of both cement and concrete**
- Understand this and better quantify it
- And find ways to increase it



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Carbon Capture - Enhanced Carbonation

- Permanently mineralized CO_2
  - Company claims carbon-negative concrete is achievable
  - Aggregates in one cubic yard of concrete
    - 3,000 lbs
    - 44% of its weight would be sequested CO2
      - 1,320 lbs.
      - Offset more than the CO2 generated in the manufacture of the 600 lbs of cement

Courtesy of Blue Planet

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Three Main Goals

1. Reduce the use of traditional Portland cement.
2. Offset or mitigate the carbon emitted in the production of concrete.
3. Increase strength while reducing material use

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Supplementary Cementitious Materials (SCMs)

Supplementary cementitious materials can be used to reduce cement content. Some common SCMs include:

- **Fly ash**. A coal byproduct. Commercially available fly ash is a finely divided residue that results from the combustion of pulverized coal and is carried from the combustion chamber of the furnace by exhaust gases.
- **Slag Cement.** A glassy, granular material formed when molten, iron blast-furnace slag is rapidly chilled - typically by water sprays or immersion in water - and subsequently ground to cement fineness. Slag cement is hydraulic and can be added to cement as an SCM.
- **Silica fume.** A finely divided residue resulting from the production of elemental silicon or ferro-silicon alloys that is carried from the furnace by the exhaust gases. Silica fume, with or without fly ash or slag, is often used to make high-strength concrete.

Source: Portland Cement Association (PCA)

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BioChar

- Waste-derived carbon-based material that sequesters carbon.
- Can be generated from wood material or bio solids…even manure!

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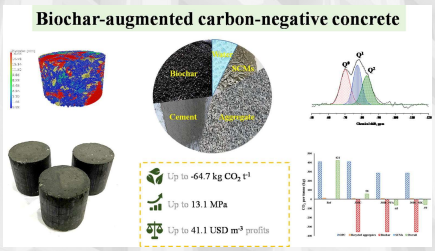
BioChar



From a report, "Biochar-augmented carbon-negative concrete" published in Chemical Engineering Journal in March of 2022.

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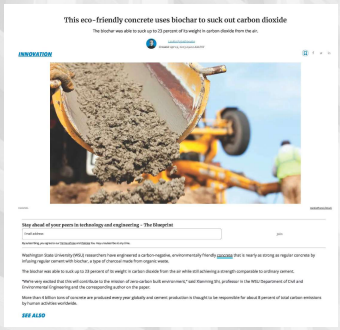
BioChar

INTERESTING ENGINEERING



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Calcium Carbonate Aggregates

- Synthetic limestone made from industry CO2 and calcified water.
- Will continue to reabsorb CO2 throughout its life.
- Can bring about as much as a 40 percent reduction in CO2.
- Working to scale up.
- Blue Planet

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Calcium Carbonate Aggregates

"Blue Planet System's idea is to capture carbon dioxide emissions from power plants and other sources, and use the CO_2 to manufacture the aggregate which goes into making concrete. If successful, the firm claims that the end result is a double win: first, carbon dioxide from the production of energy is diverted from being emitted into the atmosphere, and is instead sequestered; and second, the synthetic aggregate results in reduced emissions that would have been associated with the production of cement and concrete by conventional means.

As for the cement, [Blue Planet] has pioneered a way to manufacture cement which mimics the way that corals build reefs. Cement and coral reefs are both limestone, and therefore the issue involves how to make limestone in a way that does not produce large emissions of carbon dioxide. Thus far, corals do it successfully, and humans do not. Limestone is calcium carbonate, which can be produced as a chemical combination of carbon dioxide, oxygen, and calcium."

Forbes

-- "Cement, Concrete, Blue Planet, And Climate Change: Taking Lemons And Making Lemonade," Forbes, March 31, 2022

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Recycled Glass

- New York-based Urban Mining Industries has been advancing a new use for recycled glass in the form of Pozzotive, a ground glass pozzolan used in concrete production.
- Ground glass can assume cement-like qualities when it reacts with a combination of water and cement.
- In most mixes, Pozzotive can replace 20 or 30 percent of cement.

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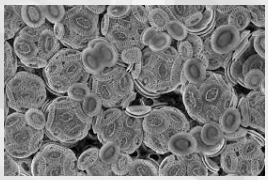
Microalgae



- That's right. Algae.
- To make portland cement limestone is extracted from large quarries and burned at high temperatures, releasing large amounts of carbon dioxide
- Some species of single-cell calcareous microalgae can biololgically grow limestone through photosynthesis, just like growing coral reefs.
- Creates a net carbon neutral way to make portland cement

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Microalgae

- Research being done by University of Colorado, Boulder and University of North Carolina Wilmington.
- 1 to 2 million acres of open pond systems would be needed to grow enough microalgae-producing limestone to meet the demand for cement production (about 90 million tons annually) in the United States.
- For context, about 100 million acres of land is used to grow corn in the U.S.
- Would need 1 percent of that grow enough algae-generated cement.

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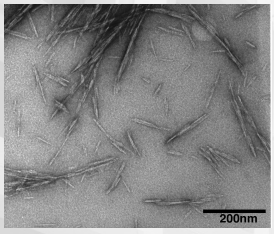
Cellulous Nanomaterials (CN)



- "Cellulose nanomaterials (CNs) are a new class of cellulose particles with properties and functionalities distinct from molecular cellulose and wood pulp, and as a result, they are being developed for applications that were once thought impossible for cellulosic materials." – U.S. Forest Service
- The nanoparticles are small, significantly smaller than the cement particles, so when they mix with the cement particles, they're small enough that they absorb to the surface of the cement particles, strengthening the final product.

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Cellulous Nanomaterials (CN)

- Material strength increased by 20 percent and greenhouse gases cut by 1/3.
- Cellulose fibers in concrete increase freeze-thaw durability and provide a good finished surface
- Used to improve impact resistance and increase surface durability.

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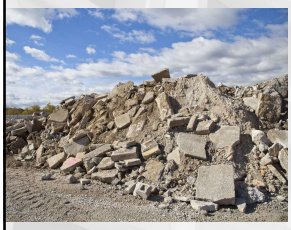
Recycled Aggregate



- Old, unneeded concrete can be recycled and used to create recycled aggregate.
- In most cases, recycled aggregate will be used as a subbase material, but it can also be paired with virgin materials and reused as an aggregate in new concrete.
- Recycled concrete aggregates contain not only the original aggregates, but also hydrated cement paste. This paste reduces the specific gravity and increases the porosity compared to similar virgin aggregates. Higher porosity of RCA leads to a higher absorption.

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Carbon Capture

- A team at Purdue proposes adding small amounts of nanoscale titanium dioxide to the cement paste that makes up concrete. The team found that titanium dioxide, a powdery substance known best for its uses in sunscreen, paints, plastics and food preservatives, enhances concrete's natural ability to sequester carbon dioxide.
- Researchers at the University of Michigan are working on composite that is engineered to react with CO_2 and form minerals so that the greenhouse gas can be stored in the concrete rather than become a byproduct. Lab experiments showed that CO_2 curing significantly improves the concrete's strength and durability, though results can vary depending on the concrete mixes and procedures.

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Carbonation Sink

- Around half of the carbon emissions from cement production are reabsorbed by the material when used in buildings and infrastructure, according to the latest IPCC climate report.
- The "cement carbonation sink" absorbs an estimated 20 million tonnes of carbon every year, according to an overlooked section of the report published earlier this month ahead of the Cop26 climate conference.
- "Direct CO_2 emissions from carbonates in cement production are around four per cent of total fossil CO_2 emissions," says the full version of the Sixth Assessment Report from the Intergovernmental Panel on Climate Change.
- "The uptake of CO_2 in cement infrastructure (carbonation) offsets about one half of the carbonate emissions from current cement production."

Source: Dezeen, August 24, 2021

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Ultra High Performance Concrete (UHPC)

- Ultra-High Performance Concrete (UHPC) is a cementitious, concrete material that has a minimum specified compressive strength of 17,000 pounds per square inch (120 MPa) with specified durability, tensile ductility and toughness requirements.
- UHPC building and bridge members will use materials more efficiently while also being able to span farther. Lower consumption of construction materials will be good for the environment because of its potential to reduce carbon dioxide emissions.

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Ultra High Performance Concrete (UHPC)

- **Traditional Precast:** 5,000 psi minimum strength and 700 psi flexural strength. Products include wall panels, column covers, self- supporting pieces and insulated/loadbearing walls, thickness ranges from 5" to 12"
- **UHPC:** 14,000-17,000 psi minimum compressive strength, flexural strength is approximately 1,400 and greater. Products include rain screens, grand entrance cladding, urban furniture and interior solutions, thickness ranges from ½" to 3" maximum.

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Ultra High Performance Concrete (UHPC)

UHPC contributes to sustainable construction by doing more with less material.

Strong and Durable
- Greatly reduced water-cement ratios
- 5X compressive strength, with higher density
- Longer life cycle

Sustainable
- Reduction of materials and weight — up to 70%
- Reduces overall carbon emissions from manufacturing / transportation
- Reduces consumption of natural resources

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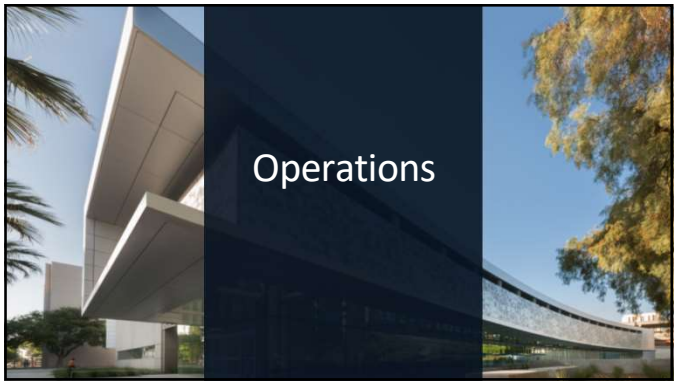

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Concrete Industry Operations Objectives

1. Track LCA data.
2. Emphasize product transparency
3. Improve processes for efficiency and sustainability.

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Types of Life Cycle Assessment

Cradle to gate - An assessment of a partial product life cycle from manufacture to the factory gate, i.e., before it is transported to the user or consumer. The use and disposal phases of the product are usually omitted.

Cradle to grave - Cradle to grave cycles or assessments is an assessment that tracks the life of a product from the point of creation until the disposal of the product takes place.

Cradle to cradle - A design protocol that advocates the elimination of waste by recycling a material or product into a new or similar product at the end of its intended life, rather than disposing of it.

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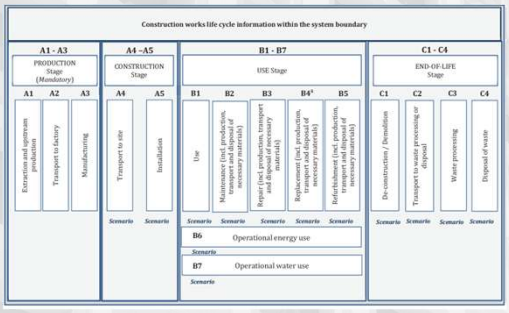
Life-Cycle Stages



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Product Transparency

LEED v4 encourages a degree of product transparency that requires industries and manufacturers to develop:

- Product Category Rules (PCR)
- Product Life Cycle Assessments (LCA)
- Environmental Product Declarations (EPD)

epd Environmental Product Declaration

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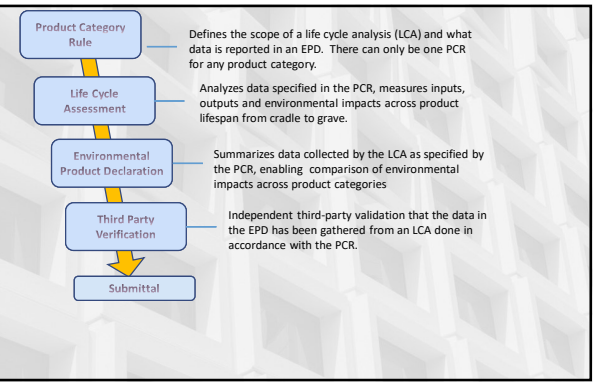

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EPDs

1. EPDs are being developed, both industrywide and company or product specific.
2. Collaboration between industry and government is key.
3. We are all working toward more sustainable, resilient structures.

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Plant Performance

- Many individual companies throughout different segments of the concrete industry are showing leadership and finding ways to improve their facilities and processes.
- Goals and techniques vary, but following are examples of what some producers in the precast industry are doing.

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Wells

- Based in Minnesota, with plants in Colorado, Illinois and Wisconsin.
- Actively working on energy conservation, carbon reduction, sustainable building design and waste management methods across all its facilities.
- Production facilities use fly ash, which reduces the amount of embodied carbon in their concrete mix by up to 10 percent.
- Developing and sharing EPDs.

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Wells

- Retired three outdated production facilities, replacing them with new sustainable precast manufacturing facilities that are more energy efficient and reduce raw material waste.
- Work with carbon capture firms to mineralize and insert reclaimed gas into the concrete mix during production.
- New cladding system, Infinite Facade, uses approximately 65 percent less concrete than typical precast spandrel construction in multi-story buildings.
- Lighter weight panels also help reduce the size of the structure needed to support the exterior enclosure, further reducing the overall embodied carbon impact.

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Knife River

- Headquartered in North Dakota with locations in 14 states.
- Currently building a new state-of-the art precast manufacturing facility in Washington.
- New facility is seeking Concrete Sustainability Council (CSC) certification.
- Zero untreated water emissions from process waters.
- Wasted concrete will be recycled on site.

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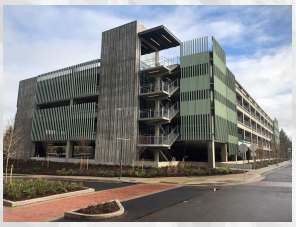
Knife River

- Ultramodern concrete batch plant with better controls allowing for optimized mix designs to reduce carbon footprint by as much as 20 percent on certain mixes.
- Utilization of an electric concrete delivery system eliminates the use of diesel engine driven delivery equipment.
- Roof designed to support future utilization of solar power.
- Site is laid out to minimize wasted transportation and accommodate long-term growth of the business.



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Concrete Industry Resources

- The Precast/Prestressed Concrete Institute (PCI), **pci.org**
- National Ready Mixed Concrete Association (NRMCA), **buildwithstrength.com**
- NEU: an ACI Center of Excellence for Carbon Neutral Concrete, **www.neuconcrete.org**

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Summary

Concrete is a durable, efficient material that inherently provides the versatility and resiliency needed to meet the multi-hazard requirements and long-term demands of high performance structures.

Beyond excellent lifetime performance, the concrete industry is innovating and working tirelessly to reduce it's carbon impact in the short term. Promising new techniques and technologies enable us to build for tomorrow.

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