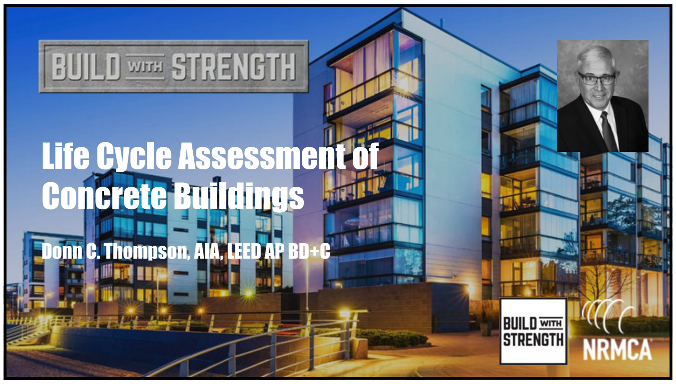


1

About the Course

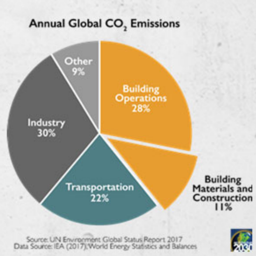
Learning Objectives

- Understand life cycle assessment (LCA) and how it can be used to help measure and reduce the environmental impacts of a building.
- Explore the various stages of life cycle assessment
- Recognize the temporary nature of embodied carbon sequestration
- Understand why it is best to look at full life cycle LCA to better inform material choices
- See the relative comparative environmental benefits of concrete within the LCA context

2

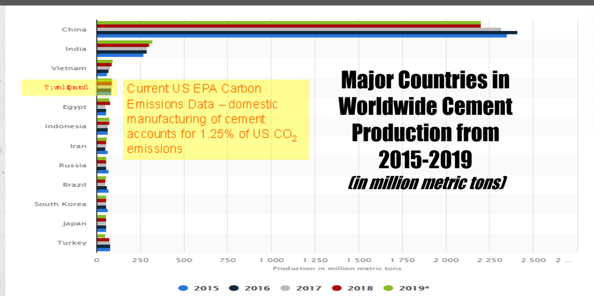
The Challenge

- 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?



3

Worldwide Cement Production



Current US EPA Carbon Emissions Data – domestic manufacturing of cement accounts for 1.25% of US CO_2 emissions

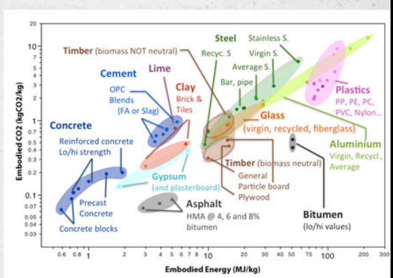
Major Countries in Worldwide Cement Production from 2015-2019

(in million metric tons)

4

Concrete is Environmental Friendly

- A good combination:
  - Low embodied energy
  - Low relative embodied CO_2



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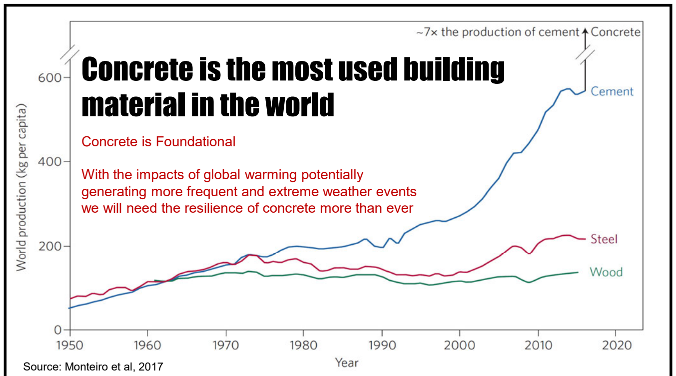


Concrete is the most used building material in the world

Concrete is Foundational

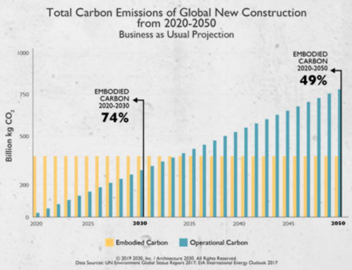
With the impacts of global warming potentially generating more frequent and extreme weather events we will need the resilience of concrete more than ever

Source: Monteiro et al, 2017

6

Forecast: Embodied v. Operational

- Every year
  - 6.13 billion square meters of new buildings are constructed.
  - Generating 373 billion metric tonnes CO_2 per year.
- By 2050
  - embodied carbon emissions and operational carbon emissions will be roughly equivalent.



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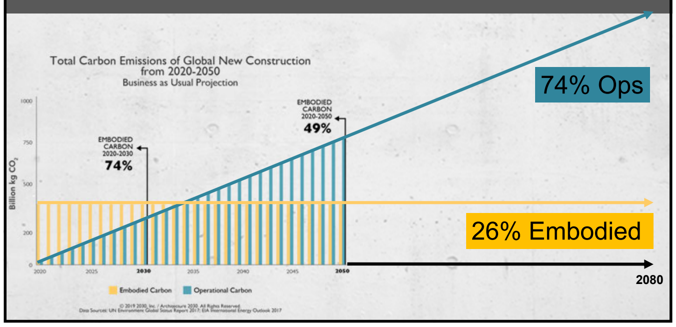
60-yr Forecast: Embodied v. Operational



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What is Whole Building Life Cycle Assessment

An objective process that:

- investigates and evaluates all stages of a product, process, or service
- identifies and measures
  - energy and materials used (inputs)
  - wastes released (outputs)
- assesses the impact of those inputs/outputs to the environment
- evaluate and implement opportunities to affect environmental improvements

Source: USEPA

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Full LCA Scope

- Production Stage: Modules A1 – A3
  - A1 raw material extraction or harvest;
  - A2 transportation of those raw materials to the factory or mill;
  - A3 is manufacturing of the product itself.
  - Together, these modules are often referred to as "cradle-to-gate."
- Construction Stage: Modules A4 and A5
  - A4 is transportation of the product to the construction site;
  - A5 is installation and/or the construction process.

Source: USEPA

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Full LCA Scope

- **Use Stage: Module B (B1 – B7)** These modules include:
  - Maintenance
  - Repair
  - Replacement
  - Refurbishment
  - operational water and energy use for the duration of the building's life.
- **End-of-Life Stage: Module C (C1 – C4)**
  - C1 includes deconstruction and/or demolition;
  - C2 is transportation of waste to the disposal or processing site;
  - C3 is waste processing;
  - C4 is the final disposal of that waste.
- **Modules A1 through C4 (16 total LCA modules) define the system boundary that fully represent the life cycle of the building; this is often referred to as "cradle-to-grave."**

Source: USEPA

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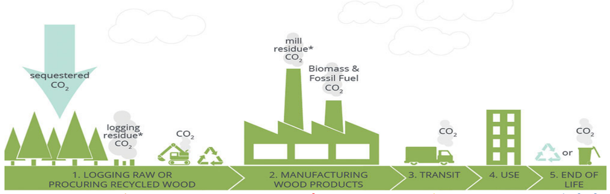
CARBON IMPACTS OF WOOD



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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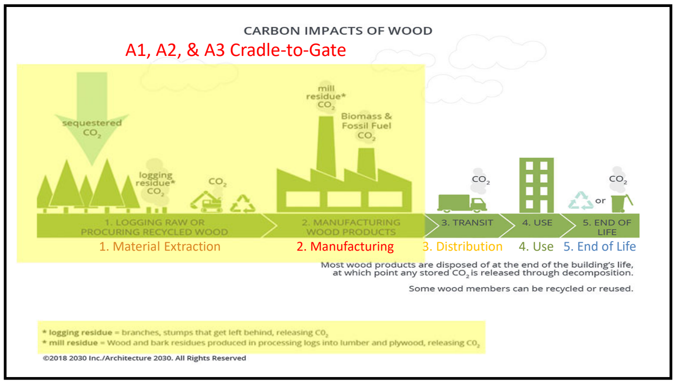

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Comparing Extracting Practices

- Extraction of any raw material has impact on the environment
- Natural Resources Canada compared impacts in research study (conducted by Forintek)
  - Logging (wood)
  - Iron ore mining (steel)
  - Aggregate quarrying (concrete)
- Compared extracting industries and determined a damage index

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Comparing Extracting Practices

- The study researched extraction impacts such as –
- Land disruption,
- impact to soil preservation,
- impact to water,
- disruption of wildlife habitat ;
- emissions of heavy machinery ;
- site contamination of extraction ; and
- road construction to gain access

- Many of these impacts are very often not included in an EPD for wood, steel or concrete.

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Comparing Extracting Practices

Building Material Environmental Disruption to Land	Logging 	Iron Ore Mining 	Aggregate Quarrying 
Extent	High to very high	Very low to low	Low to Moderate
Intensity	Moderate	High	Moderate to high
Duration	Variable, complex	High	Moderate
Significance	Very high (some sites)	Very low	Low

Definitions
- Extent: amount of land disrupted by extraction
- Intensity: gauges the degree of disruption
- Duration: length of time before the disrupted area returns to normal, if ever.
- Significance: The importance of the site—the beauty and ecological richness of the site.

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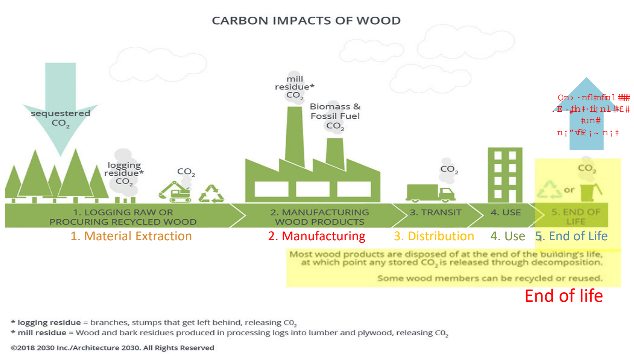

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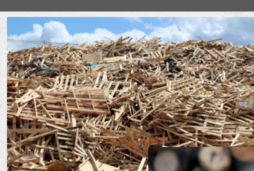
End of Life: Wood Recycling

- Downcycled
  - Pallets, mulch
- Most Landfilled
  - Methane
- Burned for energy
  - 229 MMt CO2 in 2018



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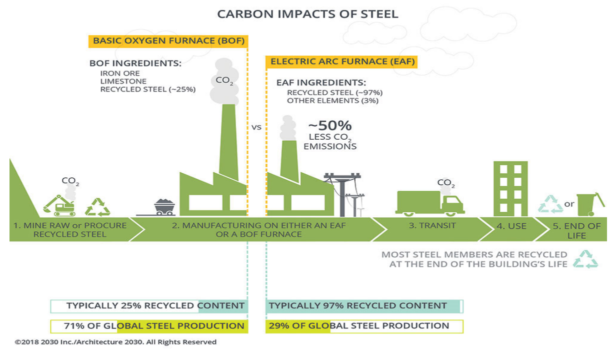

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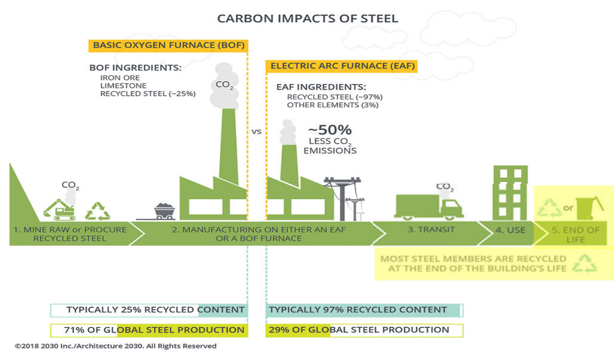

20

EOL: Steel Recycling

- 100% recyclable
- Established recycling infrastructure
- High recycling rate
- Extremely energy intensive

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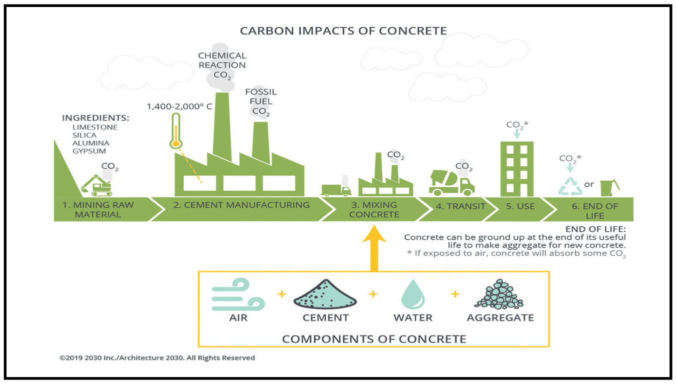

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Concrete vs. Cement

- Local material
  - Raw materials and production
- Minimal processing
  - Efficient operations
- Uses wastes (by-products) from other industries
  - Fly ash, slag
- Resilient / durable / long service life
  - Operational benefits
    - Thermal mass
    - High R-value
    - Low air infiltration
- Recyclable

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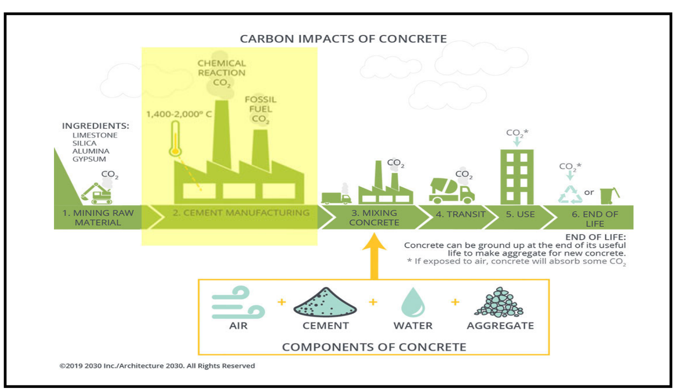

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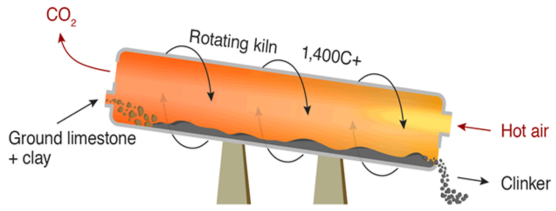
Cement and CO_2

How cement is made



Source: Carbon Brief, Chatham House

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Blended Cements

ASTM C 595

Cement Type	Description	Notes
Type IL (X)	Portland-Limestone Cement (PLC)	5% and 15% percent interground limestone
Type IS (X)	Portland-Slag Cement	up to 70% slag cement
Type IP (X)	Portland-Pozzolan Cement	up to 50% pozzolan. Fly ash is the most common.
Type IT	Ternary Blended Cement	

- (X) identifies the percentage of portland cement replacement
- TIP: Permit ASTM C 595 blended hydraulic cements
- TIP: Permit ASTM C 1157 hydraulic cements

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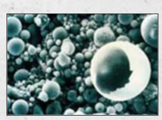
Supplementary Cementitious Materials

- 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
- Slag cement
  - A latent hydraulic material
  - Minimal pozzolanic behavior



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Industry-Wide + Product Specific EPDs
Environmental
Product
Declaration
NRMCA
NRMCA MEMBER INDUSTRY-AVERAGE EPD FOR
READY MIXED CONCRETE
NSF
Certified
Environmental
Product Declaration
CENTRAL
CERATECH
CEMEX
READY-MIXE
CONCRETE

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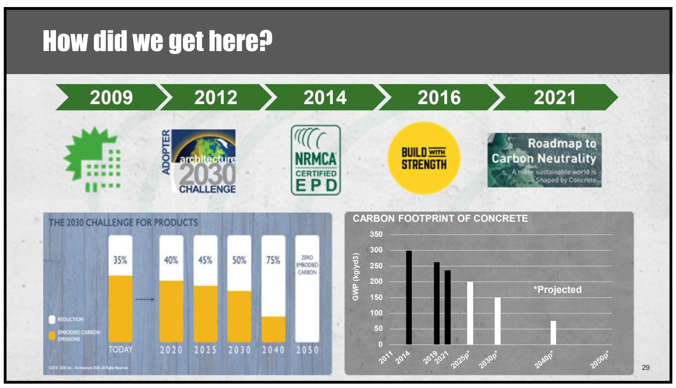
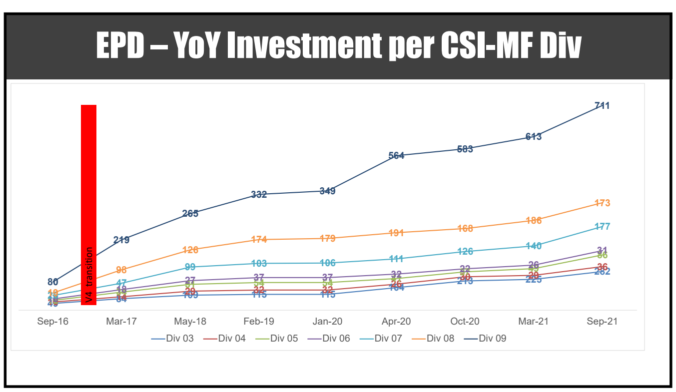
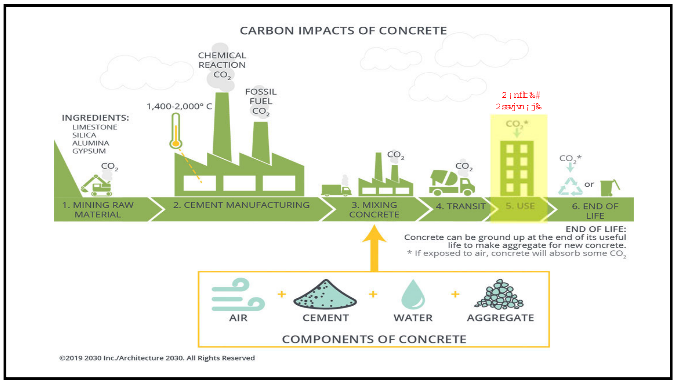

How did we get here?
2009
2012
2014
2016
2021
ADOPTER
architecture
2030
CHALLENGE
NRMCA
CERTIFIED
EPD
BUILD WITH STRENGTH
Roadmap to
Carbon Neutrality
THE 2030 CHALLENGE FOR PRODUCTS
35%
40%
45%
50%
75%
TODAY
2020
2025
2030
2040
2050
CARBON FOOTPRINT OF CONCRETE
GWP (kg/yd3)
*Projected
2011
2014
2019
2021
2025p*
2030p*
2040p*
2050p*
29

29


EPD – YoY Investment per CSI-MF Div
v4 transition
Sep-16
Mar-17
May-18
Feb-19
Jan-20
Apr-20
Oct-20
Mar-21
Sep-21
80
219
265
332
349
564
603
613
711
98
128
174
179
191
168
186
473
99
103
106
111
126
140
177
Div 03
Div 04
Div 05
Div 06
Div 07
Div 08
Div 09

30



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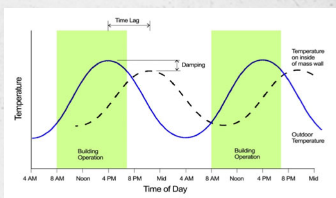
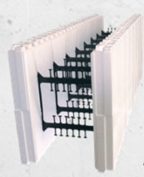
Thermal Mass + Higher Insulation + Tighter Construction

- Increase thermal lag
- Lower peak energy
- Reduce temperature swings





Insulating Concrete Forms:
R = 24 to 26 or higher
Air Infiltration = 0.5 ACH

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Envelope Performance: Thermal Mass

Source: Mapping Thermal Mass Benefit, MIT Concrete Sustainability Hub

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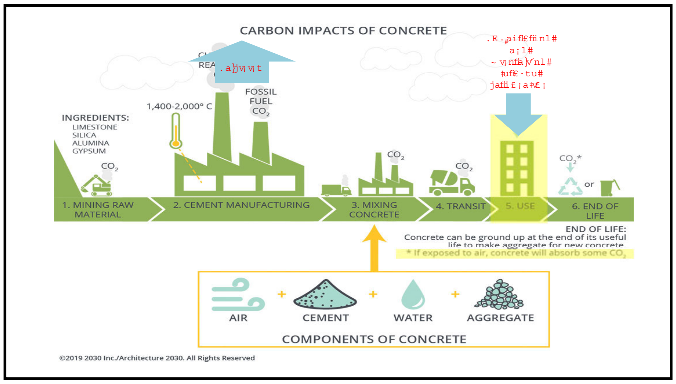

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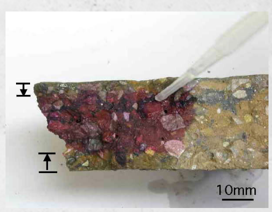
Concrete: CO_2 Absorption and Mineralization

- 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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Concrete: CO_2 Absorption and Mineralization

Carbonation

- "Substantial Global Carbon Uptake by Cement Carbonation" Xi et al.
  - Estimate of regional and global CO2 uptake between 1930 and 2013
    - Cumulative absorption of carbon in concrete
      - 4.5 gigatons
      - Offsets 43% of CO_2 emissions from production of cement

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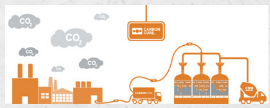
Enhanced Carbonation

- Ejection of liquified purified industrial waste CO_2 during the concrete mixing operation
  - Permanent mineralizing of small amounts of CO2
  - Enhanced concrete strength with less portland cement
- Specialized cements produced at lower temperatures
  - Incorporated into concrete materials cured in CO2 rich curing chambers
  - Mineralizes 5% of CO_2 by weight
  - Claims of carbon footprint reductions of 70%



Courtesy of CarbonCure

Courtesy of Solidia

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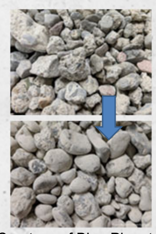
Enhanced Carbonation

- Artificial limestone aggregates
  - Claim of Carbon Negative concretes
  - Aggregates contain more mineralized CO_2 than generated during the manufacturing of the portland cement



Courtesy of Blue Planet

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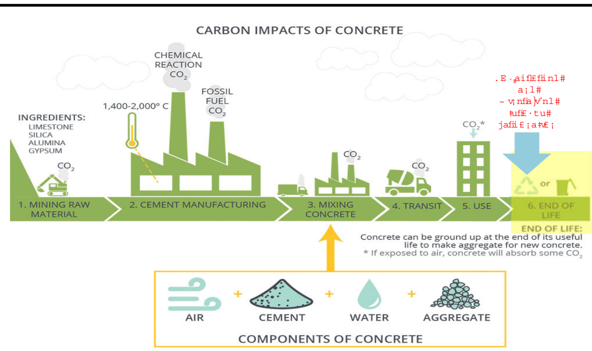

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Natural Carbonation

- 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

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Where WBLCA is Cited

- Codes
  - IgCC
- Standards
  - LEED
  - ASHRAE 189.1
  - Green Globes
  - Living Building Challenge
- State codes
  - CalGreen
  - Minnesota B3

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LCA Software Tools

- Embodied Carbon Calculator
  - EC3
- WBLCA
  - Athena
  - Tally
  - One Click
- In-house SE embodied carbon tools
  - Beacon (Thornton Tomasetti)
  - Concrete LCA Tool (ZGF)

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Comparative Life-Cycle Assessment

- Comparative LCA
- Quantifying Environmental Impacts of Structural Material Choices Using Life Cycle Assessment
- Tally LCA software
  - Cradle to Gate and Cradle to Grave
  - 60-year life cycle

MAGNUSSON KLEMENCIC ASSOCIATES
Structural + Civil Engineers

Source: Quantifying Environmental Impacts of Structural Material Choices Using Life Cycle Assessment: A Case Study
D. Davies, L. Johnson, B. Doepker, and M. Hedlund, Embodied Carbon in Buildings, Springer International Publishing AG 2018

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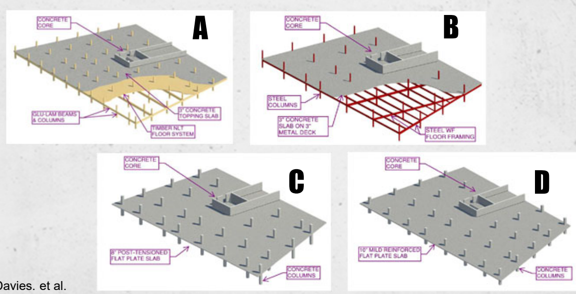
4 Structural Solutions Compared



D. Davies. et al.

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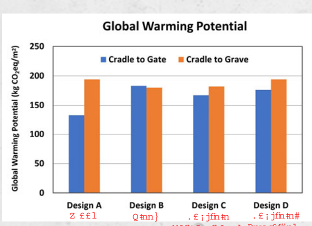
LCA Results



Global warming potential for Cradle to Gate and Cradle to Grave for four design scenarios. Adapted from Davies

- Making a decision on a sustainability "winner" with LCA information should not be the only consideration.
- All materials involve tradeoffs
- Designers should choose materials that are most materially efficient for the intended building use, and then optimize and economize.

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Conclusion

- LCA is a valuable tool for assessing the environmental impact of buildings
- Extremely important to include the cumulative operational stage of a building life cycle
- Concrete buildings can offer energy savings and significant reductions in carbon emissions
- Concrete buildings are more energy efficient, therefore cumulatively reducing operational environmental impacts of buildings over their entire life cycle
- Exposed concrete can absorb and permanently remove CO_2 from the environment

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www.buildwithstrength.com/design-center

- Structural system recommendations
- Cost comparisons
- Specification review
- Design/construction team collaboration

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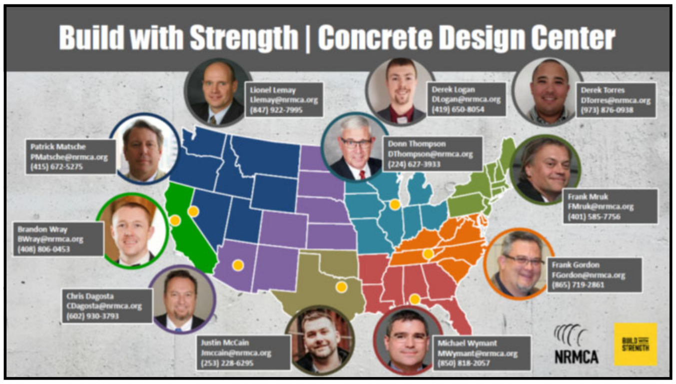
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