Concrete as a sustainability solution

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Context: many challenges facing society

Economic
- Insufficient investment in infrastructure
- Clean-up costs from hazards

Environmental
- Climate change
- Waste

Social
- Deteriorating infrastructure
- Affordable housing shortage
- Buildings damaged from hazards
There is insufficient investment in infrastructure

Source: Thacker et al, Nature Sustainability, 2019

Fig. 1 Current infrastructure stock and forecast future needs to 2040. Current stock and forecast future investment needs (2016–2040) were obtained from a previous study. Current infrastructure status using the World Economic Forum (WEF) composite infrastructure score was obtained from a previous study, with full country names given in Supplementary Table 1.

Source: Thacker et al, Nature Sustainability, 2019
Infrastructure is critical to meeting UN sustainable development goals

"Infrastructure either directly or indirectly influence all 17 of the SDGs, including 121 of the 169 targets (72%).”

Thacker et al, Nature Sustainability, 2019
Addressing affordable housing shortage requires more housing

Solutions For A New Housing Crisis

05.24.19 | WORLD CHANGING IDEAS

4 popular, innovative ideas to help fix America’s housing crisis

A new report polled Americans about what interventions they’d support to make sure more people could afford their housing. Here’s what they came up with.

Six possible solutions to the affordable housing crisis
Costs due to hazards are significant

$91 billion estimated losses in 2018

Fourth highest after 2017, 2005, and 2012

https://coast.noaa.gov/states/fast-facts/weather-disasters.html
Cement and concrete are critical to meeting societal goals, but are often viewed as environmental problems.
Concrete plays a role in political dialogues
Quantitative sustainability assessments require a life cycle perspective and trade-off analysis.
Key takeaways

Cement and concrete’s environmental impact can be lowered using today’s technology

A life cycle perspective should be used to evaluate concrete’s environmental impact

Investing in hazard mitigation can pay off

Carbon uptake in concrete over time can be significant
A life cycle perspective should be used to evaluate concrete’s environmental impact.

**Materials Production**
- Use recycled materials
- Improve energy efficiency
- Improve material performance

**Design & Construction**
- Use less (i.e., stronger) material
- Create longer-lasting designs

**Use**
- Reduce building energy consumption
- Reduce vehicle fuel consumption
- Reduce damage from hazards
- Increase carbon uptake

**End-of-Life**
- Enable material recovery
- Increase carbon uptake
Concrete is a low-impact material

Source: Barcelo et al, 2014
Concrete is the most used building material in the world

Source: Monteiro et al, 2017
Concrete is a significant portion of nearly all buildings.
Concrete is a mixture that can be designed to meet performance requirements

Concrete Constituents

- Coarse aggregates
- Fine aggregates
- Binder
- Water
- Admixtures

Performance Requirements

- Early strength
- Late strength
- Stiffness
- Density
- Constructability
- Durability
There are many binders that can be used in concrete
Composition, performance, and availability vary significantly

- Portland Cement
- Natural pozzolans
- Calcined Clay
- Fly Ash
- Granulated Slag
- Post-consumer glass
Cement drives concrete’s environmental impact

3000 psi mixture with no SCMs
Cement manufacture at a glance

Cement is a man-made powder that, when mixed with water and aggregates, produces concrete. The cement-making process can be divided into two basic steps:

1. Clinker is made in the kiln at temperatures of 1,450°C
2. Clinker is then ground with other minerals to produce the powder we know as cement

**Carbon Emissions Reduction Levers**

1. Thermal and electric efficiency
2. Alternative fuels
3. Clinker substitution
4. Carbon capture and storage

Source: WBCSD-IEA Cement Technology Roadmap, 2009
Figure 5: Global direct CO$_2$ emissions in cement production by scenario

KEY MESSAGE: The B2DS would require the cement industry to increase by about 45% the cumulative carbon emissions reductions effort compared to the 2DS, which is the reference carbon emissions reduction scenario for this roadmap’s vision.

Source: WBCSD-IEA Technology Roadmap for the Cement Industry, 2018

RTS: Reference Technology Scenario
2DS: 2°C Scenario
B2DS: Beyond 2DS
Carbon capture and clinker reduction are key strategies

Figure 7: Global cumulative CO₂ emissions reductions by applying the roadmap vision (2DS) compared to the RTS

Note: Cumulative CO₂ emissions reductions refer to the period from 2020 to 2050 and are based on the low-variability case of the scenarios.

Source: WBCSD-IEA Technology Roadmap for the Cement Industry, 2018

**KEY MESSAGE:** Innovative technologies including carbon capture (CO₂ emissions reduction of 48%) and reduction of the clinker to cement ratio (CO₂ emissions reduction of 37%) lead the way in cumulative CO₂ emissions reductions in cement making in the roadmap vision compared to the RTS by 2050.
Significant investments required to limit GHG emissions

Figure 17: Overall cumulative investment needs by scenario by 2050

KEY MESSAGE: USD 107 billion to USD 127 billion are estimated as cumulative additional investments to realise the RTS globally, which would need to increase to between USD 176 billion and USD 244 billion to reach to implement the roadmap vision (2DS).

Source: WBCSD-IEA Technology Roadmap for the Cement Industry, 2018
There are numerous solutions available today for lowering cement and concrete’s environmental impact.

**Cement**
- Alternative fuels
- Energy efficiency
- Clinker replacement
- Cement formulation
- Carbon sequestration at cement plant
- Carbon sequestration in cement production

**Concrete**
- Cement replacement
- Performance-based specifications
- Carbon sequestration in concrete production
- Carbon sequestration in aggregate production

Barriers to adoption: risk aversion and cost
Recommendations for reducing embodied impacts

1. Promote adoption of energy efficiency technologies for new and retrofit cement plants
2. Encourage and facilitate increased use of alternative fuels in cement plants
3. Encourage and facilitate use of blended cements (reduction of the clinker to cement ratio)
4. Support development and deployment of emerging and innovative low-carbon technologies for cement production including carbon capture, storage and utilization
5. Support deployment of performance-based specifications for concrete to spur innovation in concrete mixtures

Adapted from WBCSD-IEA Technology Roadmap for Cement Industry
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Embodied Whole life
## Energy use dominates building life cycle impacts

<table>
<thead>
<tr>
<th>Exterior Wall</th>
<th>Location</th>
<th>Building Type</th>
<th>Embodied Impact</th>
<th>Global Warming Potential (lbs CO2/ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICF</td>
<td>Chicago</td>
<td>Single Family</td>
<td>0</td>
<td>800</td>
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<tr>
<td>Wood</td>
<td>Phoenix</td>
<td>Single Family</td>
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<td>400</td>
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<td>Multi-Family</td>
<td>0</td>
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<td>ICF</td>
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</tbody>
</table>

ICF = Insulated Concrete Forms

Results applicable for this case study only

Ref: MIT CSHub, [Methods, Impacts, and Opportunities in the Concrete Building Life Cycle](#)
Excess fuel consumption dominates pavement life cycle impacts

Asphalt Pavement: 17.5 kton* CO2e/mi
Concrete Pavement: 18.8 kton CO2e/mi

Use 66%
Materials & Construction 26%
Maintenance & Rehabilitation 6%
End-of-Life 2%

Life cycle greenhouse gas emissions for urban interstate pavements in Missouri

Use 72%
Materials & Construction 26%
Maintenance & Rehabilitation 0%
End-of-Life 2%

Pavement design developed by Applied Research Associates (ARA), Inc.; AADTT 8k/day; 6 lanes; MO (wet freeze); MEPDG-based rehabilitation schedule.

*metric tons
Approach to quantify resilience of built infrastructure:
Incorporate quantitative hazard resistance into life cycle cost

Build + Energy Use + Wear & Tear + Hazard Repair + End of Life = Life Cycle

- Raw materials, labor, equipment, & energy
- Electricity, gas, and oil consumption throughout life
- Painting, windows, siding, etc.
- Combines probability of hazard with damage from hazard
- Waste and recycling, labor, equipment, & energy
Hazard repair costs can be higher than initial costs

Payback period for hazard resistant designs is < 5 years

Noshadravan et al, Journal of Construction Engineering and Management, 2017
Breakeven mitigation value can approach **20% of base code cost**

**Online tool** enables exploration of results

https://cshub.mit.edu/bemp-dashboard
Carbon uptake in concrete over time

4.5 GtC has been sequestered in carbonating cement materials worldwide from 1930 to 2013, offsetting 43% of process CO2 emissions.

Factors that affect carbon uptake rate:
• Exposed surface area
• Concrete mixture
• Climate

Source: Xi et al, Nature Geoscience, 2016
Recommendations for reducing life cycle impacts

1. Buildings: enable reduction of energy consumption through energy-efficient design
2. Pavements: enable reduction of vehicle excess fuel consumption through smoother and stiffer pavements
3. Resilience: encourage investment in hazard resistant building and infrastructure design
4. Carbon uptake: request estimates of uptake in concrete structures
Key takeaways

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Carbon uptake in concrete over time can be significant
Come visit MIT for more from the firehose

“Getting an education at MIT is like taking a drink from a fire hose.”

Former MIT President

Additional MIT experts:

- Concrete Sustainability Hub
- MIT Energy Initiative
- Joint Program on the Science and Policy of Global Change
Thank you

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