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Material Efficiency as a Means to Lower Environmental Impacts from Concrete

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POLICY BRIEF

National Center for Sustainable Transportation

Material Efficiency as a Means to Lower Environmental Impacts from Concrete

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Issue

Concrete is a key component of the built environment. However, the manufacture of cement-based materials, such as concrete, produces over 8% of worldwide anthropogenic greenhouse gas (GHG) emissions. The largest contributor to the GHG emissions from concrete is associated with the manufacture of conventional cement, which reacts with water to "glue" rock fragments (aggregates) together to make concrete. Using supplementary cementitious materials (SCMs), such as fly ash, to reduce cement content in concrete is one option for reducing GHG emissions. Unfortunately, there is limited availability of the most popular SCMs and shifting to others can cause increased environmental impacts and/or costs.

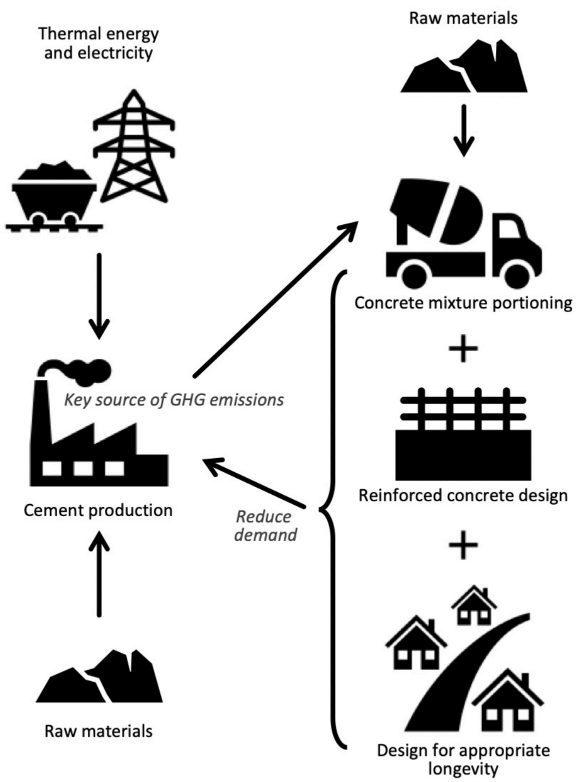

Figure 1. Methods considered to more efficiently use cement and concrete, thus leading to lower emissions from material production

While reducing impacts from material production is an important strategy, structural design can also mitigate the environmental impacts of concrete. Designing infrastructure in a manner that uses concrete more efficiently, and thus lowers consumption while meeting the same system demands, holds promise for reducing GHG emissions while avoiding unintended consequences. Changes in concrete properties and reinforcement, where applicable, can affect the total material required and GHG emissions from material production while remaining within design requirements. For example, more durable concrete that needs less frequent replacement can contribute to less concrete production over time. With the right tools, decision makers can select designs that lead to reductions in the environmental impacts of the infrastructure system being engineered.

Researchers at the University of California, Davis developed an initial methodology to evaluate implications of design decisions on the environmental impacts of concrete systems using a multi-criteria selection process to assist decision-makers (Figure 1). They demonstrated the methodology with a case study evaluating a built Caltrans pavement overlay for which comparisons of the GHG emissions and costs of various design alternatives were examined.

Key Research Findings

Appropriate selection of concrete properties, reinforcement ratio, and desired longevity can reduce GHG emissions and costs. Designing for higher strength is more important in some contexts (e.g., columns) than others. GHG reductions can be achieved through use of lower-strength concrete where appropriate. Lowering the reinforcement ratio of steel to concrete while remaining within design constraints can also reduce GHG emissions when concrete members contain rebar, as long as lower reinforcement causes only a limited increase in the volume of concrete. Steel production causes large environmental impacts, and rebar can be the primary source of GHG emissions for certain reinforced concrete member designs. Finally, there can be substantial cost savings from limiting material replacement if the appropriate performance over a longer period can be achieved, as can be the case through appropriate use of concrete constituents.

Prescriptive designs that are commonly used for concrete can lead to over-use of cement. These design methods specify factors such as allowable cementitious content in concrete. However, improved understanding of several factors associated with concrete has shown that they currently lead to inefficient use of cement in many cases. While there can be a wide range in the over-use of cement, preliminary estimates suggest that using performance-based rather than prescriptive design could result in up to 30% lower emissions per volume of concrete needed.

Material efficiency—meeting performance requirements while using less material—should be a key component of decarbonization strategies. Readily implementable methods are available to support more efficient use of cement and concrete. For example, using longer curing times for concrete can take advantage of later-age strength development and reduce the total quantity of cement needed. Further, where possible, weighing changes in material attributes relative to their GHG emissions from production and the volume of material required can lead to emissions reductions without relying on new technologies.

Policy Implications

This work shows that the efficient use of concrete is a critical lever to mitigate GHG emissions. Performance-based design methods, as opposed to prescriptive design, can support the use of concrete that meets performance requirements with lower emissions from production. Further, using design metrics that address material efficiency, where applicable, can support the use of concrete with lower emissions from production.

Future research in this area should apply this methodology to more complex systems to identify the most desirable suite of measures for reducing the environmental impacts of infrastructure construction.

More Information

This policy brief is drawn from "Transformation of Engineering Tools to Increase Material Efficiency of Concrete," a report from the National Center for Sustainable Transportation, authored by Sonoko Ichimaru Watanabe, Kanotha Kamau-Devers, Patrick R. Cunningham, and Sabbie A. Miller of the University of California, Davis. The full report can be found on the NCST website at https://ncst.ucdavis.edu/project/transformation-engineering-tools-increase-material-efficiency-concrete.

For more information about the findings presented in this brief, contact Sabbie A. Miller at sabmil@ucdavis.edu.

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