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Mitigating CO_2 Emissions from California's Concrete Infrastructure

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Issue

Concrete is one of the main construction materials used for infrastructure. For the State of California to reach its goal of achieving carbon neutrality no later than 2045 while continuing to build necessary infrastructure, greenhouse gas (GHG) emissions from concrete must be reduced. In 2021, California consumed approximately 77 million tons of concrete, which generated roughly 21 million tons of CO_2 emissions. These emissions are primarily from the manufacturing of cement, which is the main binder in concrete that "glues" aggregates (crushed rocks) together.

California's policies require significant reduction of emissions from cement and concrete. Senate Bill 596 (Becker) creates a strategy for cement GHG emissions to be net-zero by 2045, and Assembly Bill 43 (Holden) proposes to cut GHG emissions from materials used in new buildings by 2035. Meeting these targets will require new technologies for producing cement and concrete, with reductions possible at every stage of the cement life cycle (Figure 1). Complementary changes in building design and use will also be necessary.

Researchers from the University of California, Davis reviewed key, rapidly implementable strategies to mitigate CO_2 emissions from cement and concrete used in state funded infrastructure projects. The research included performing a series of analyses to determine emissions reduction pathways throughout the cement life cycle, highlighting the potential to reduce emissions by designing new infrastructure for increased material efficiency.

Key Research Findings

Reduction in CO_2 emissions from concrete can be achieved through improvements at all stages of the product's life cycle. This includes engineering design for more efficient use of cement and concrete, improving cement manufacturing, proper concrete mixture design and material specification, elongating functional use of materials (i.e., the service life), and proper end-of-life management. To date, most CO_2 emissions mitigation strategies, including those involving infrastructure design and use, focus on earlier rather than later phases of the life cycle.

Systematic integration of sustainability into building and infrastructure design (not just material selection) may be needed to meet deep decarbonization goals. Lower-emission alternatives in concrete must be carefully matched to their intended application to avoid requiring more cement, increasing maintenance, or reducing building lifespans. Significant emissions savings can come from engineering and design of structures. Extending the useful life of structures reduces emissions by requiring less-frequent replacement, in some cases by over 25%. Emission performance standards or incentives must focus on life-cycle emissions to limit unintended consequences.

Common prescriptive concrete mix designs can lead to over-use of cement. Requirements that call for a prescribed amount of cement rather than for a level of concrete performance can lead to the use of more than necessary amounts of cement, resulting in higher costs and CO_2 emissions. Codes prescribing a minimum cement content, as well as a maximum

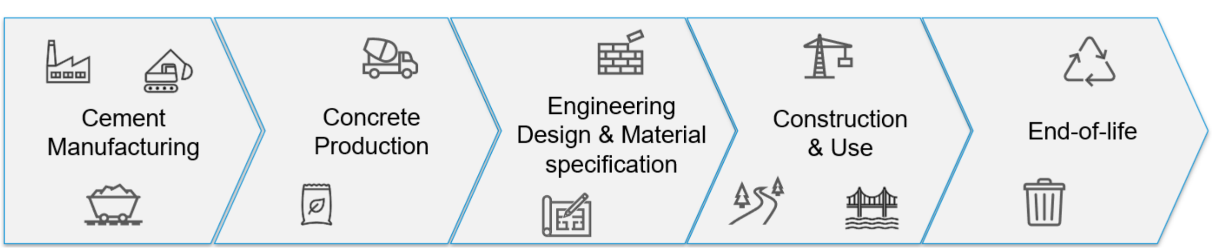

Figure 1. Key stages in the cement life cycle.

cement replacement rate with supplementary cementitious materials, restrict the ability to design the concrete mixture to reduce emissions and can even have a negative effect on the concrete performance. Therefore, performance-based specifications should be used where possible.

Appropriate use of supplementary cementitious materials in concrete can lead to 11–34% CO_2 emissions savings. These benefits are achieved by replacing 30–50% of cement, thus avoiding emissions from cement production. Using a higher content of appropriate supplementary cementitious materials in coastal regions, where concrete structures are commonly exposed to aggressive salts that may cause deterioration, is one way to improve durability.

Different concrete mixtures may be desirable for different structural applications. Concrete mixtures can be optimized using life-cycle performance-based specifications, where desired material properties are specified instead of cement content. This optimization can lead to increased durability, strength, and service-life. Selection of concrete mixture proportions (ingredients) to achieve desired properties while reducing CO_2 emissions can result in up to 50% CO_2 emissions savings.

Engineering design can mitigate CO_2 emissions through more efficient use of reinforcing steel and the selection of the correct concrete mixture. Optimization of strength and quantity of reinforcing steel in new concrete structures can result in over 20% potential CO_2 emissions savings. These methods for CO_2 reductions are not considered in current design standards. This may be in part because a clear and practical definition of how to integrate performance-based specifications to reduce GHG emissions throughout a material's life cycle has yet to be established.

Policy Implications

Combining concrete mixtures with lower CO_2 emissions with efficient structural design to minimize materials used can reduce CO_2 emissions from building new infrastructure. The following are interventions to help achieve these reductions.

- Develop a framework to establish benchmarks and reduction targets for CO_2 emissions from infrastructure applications across their full life cycle.
- Improve collaborations among different stakeholders—including clients, engineers, contractors, and material manufacturers—to establish an exchange of data necessary for developing benchmarks and targets.
- Modify code to add CO_2 reduction to existing design parameters of safety, quality, cost, and timeliness of construction.
- Enact policy to consider shifts in material use, including designing infrastructure to be in use longer and recycling construction materials.
- Codify and use performance-based specifications of concrete to increase the demand for concrete with lower emissions, while meeting performance requirements.

More Information

This policy brief is drawn from "Near-term pathways for decarbonizing global concrete production" by Josefine Olsson and Sabbie Miller of the University of California Davis in collaboration with Mark Alexander of the University of Cape Town. This paper can be found at https://doi.org/10.1038/s41467-023-40302-0. Aspects tied to end-of-life concrete handling were informed by "Parameters Driving Concrete Carbonation at its End-of-Life for Direct Air Capture in Transportation Projects," a report from the National Center for Sustainable Transportation, authored by Kelli Knight and Sabbie Miller of the University of California, Davis. The full report can be found on the NCST website at https://ncst.ucdavis.edu/project/utilizing-concrete-its-end-life-direct-air-capture.

For more information about the findings presented in this brief, contact Josefine Olsson at jaolsson@ucdavis.edu.

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