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CONCRETE SOLUTIONS GUIDE

Carbon as a Service

Sequestering CO_2 in Concrete

At the cutting edge of concrete innovation is technology that enables concrete to capture and store carbon dioxide. Sequestering CO_2 in concrete traps carbon dioxide through the process of mineralization. Sequestration takes place in one of two ways: either injecting CO_2 into the concrete during the mixing process or curing concrete in a CO_2-rich atmosphere. In both cases, carbon dioxide diffuses into the fresh concrete and transforms the gaseous CO_2 into solid calcium carbonates ($CaCO_3$).[1] This process has the potential to confer co-benefits including improved strength and cure time.

Unlike the other technologies in this guide, carbon sequestration in concrete is not yet mature. Further research and development are necessary to achieve scalable results that maximize positive outcomes for embodied carbon. With additional optimization, this technology has the potential to transform the role of concrete in the global carbon cycle, and it merits attention from stakeholders even at this early stage.

Key Takeaways

Carbon sequestration via CO_2 curing is an immature technology, and applications with consistently positive and verifiable climate benefits have yet to be deployed at scale.[2]

Available data suggests that CO_2 sequestration in mixing cement is more promising than CO_2 sequestration in curing.[3]

The electricity required to deploy CO_2 sequestration via curing is a crucial factor in determining the net impact of these technologies on the embodied carbon content of concrete.[4]

For both mixing and curing, CO_2 injection may offer co-benefits in the form of improved compression strength and cure times.

Opportunity

CO_2 sequestration in concrete has the added benefit of improving concrete performance while reducing embodied carbon. For CO_2 injection during mixing, the main benefit is enhanced compressive strength that allows for improved performance. Additional testing of this application may demonstrate the ability to reduce the cement content of a CO_2-rich mix, further increasing emissions performance. Scaling up this technology may be assisted by the spread of performance-oriented specifications (see **Solution 1**), which could empower concrete producers to create innovative mixes to take advantage of strength gains from CO_2 mineralization.[5]

Aside from mixing, curing concrete in a CO_2-rich atmosphere can be used for precast concrete products, such as roadside barriers and retaining walls, where the curing environment is controllable. In this application, CO_2 replaces steam as a method for increasing the rate of strengthening. Carbonation typically improves compressive strength by 20% in the first 24 hours, compared with unaccelerated curing. CO_2-rich curing also reduces the permeability of the precast concrete, thereby improving its durability (e.g., resistance to sulphate attack).

Considerations

The co-benefits of both of these approaches are complicated by uncertainties about their net impact on the embodied carbon of the final product. The most recent science suggests that, for presently available technologies, carbon injection in curing is likely to lead to a net increase in embodied carbon. Available data suggests carbon injection in mixing can produce a consistent reduction in embodied carbon although strength reductions in some instances can more than offset the benefit.[6]

The uncertainty in this landscape stems from the immaturity of carbon capture technology, direct mineralization processes, and the associated infrastructure required to transport and deliver captured CO_2 to market. The future viability of this technology is closely linked to the market trends in carbon capture and storage, and to future process innovations in how captured CO_2 is deployed in the concrete sector.

There are limits to the amount of CO_2 that can be sequestered in concrete. Concrete's strength is derived from the reaction of calcium silicates with water. As a result, only a small portion of the silicates are available for reaction with CO_2. Currently, the amount of CO_2 sequestered is also limited by the cost of delivering CO_2 to a construction site.

One of the greatest challenges in this technology revolves around CO_2 use. A recent review accounting for the upstream emissions of CO_2 used in concrete found that in many cases, the emissions (and energy use) from utilizing the CO_2 can offset any sequestration benefit, ultimately causing more climate harm than good.[7] This review also highlighted the uncertainties of how this process affects strength during curing, potentially requiring the use of additional portland cement to maintain integrity, which eliminates any gains from directly sequestered CO_2.

These findings are not unexpected, given that CO_2 can consume some of the active strengthening component (calcium silicate) in cement, and the research highlights the need for precise dosing during curing and mixing. However, if the correct dosing of CO_2 can consistently result in a strength benefit, it may be possible to reduce the cement content of a given concrete mixture, thereby lowering embodied carbon. Further research on the optimal CO_2 curing protocol will be needed to determine whether strength gains can be consistently achieved. Looking ahead, future opportunities could include synergistic applications of CO_2 mineralization during curing and mixing of cement blended with SCMs (see **Solution 2**), or using carbonation to improve the performance of RCAs (see **Solution 4**).

Although key questions remain about the future of this technology, the technology continues to show promise. Early-stage technologies, such as carbonation of recycled concrete aggregate, CO_2 sequestration of alternative magnesium-based binders, CO_2 dissolution in concrete mixing water, and CO_2 mineralization of aggregates, are currently being developed and have the potential to unlock significant decreases in embodied carbon.

Related Solutions

1. Know Your Numbers: Performance-oriented specifications

2. Mix It Up: Supplementary cementitious materials (SCMs)

4. Embrace Circularity: Concrete Recycling

State of the Market

Although several companies have developed carbon sequestration techniques over the years, only a few have reached commercialization.[8] Blue Planet, Carbon Engineering, CarbonCure, Solidia, and Svante are currently providing leading carbon capture, utilization, and storage (CCUS) technologies in the built environment, each with different roles.

Company	Technology Type	Description
CarbonCure	CO_2 injection during mixing for ready-mix concrete applications	CarbonCure sells a technology that injects carbon dioxide captured from industrial processes into portland cement along with water. This is completed without major implementation barriers, as a "Valve Box" connects to a CO_2 tank stored on-site and injects a precise quantity of CO_2 into the concrete during the mixing phase. With around 300 producers using its technology already, the company has an ambitious expansion plan to reach a 500 Mt CO_2 reduction goal.
Solidia	CO_2 curing of precast concrete products	Solidia's technology involves mixing a cement powder with sand and then filling in open spaces with water and carbon dioxide. Founded in 2008, Solidia received the support of cement majors like LafargeHolcim and of the US Department of Transportation's Federal Highway Administration. Lafarge and Solidia developed a reduced CO_2 cement that, together with a proprietary concrete mix design and a specialized curing process utilizing CO_2, purportedly creates concrete with up to a 70% lower carbon footprint than traditional portland cement systems.
Blue Planet	CO_2 mineralization of aggregate prior to concrete mixing	Blue Planet uses CO_2 as a raw material for making carbonate rocks that can be used in place of natural limestone rock. The company is in the process of building a plant in Pittsburgh, California, and recently completed a successful test project at San Francisco International Airport.
Carbon Engineering	CO_2 capture and supply	Carbon Engineering uses a direct air capture (DAC) technology that can capture CO_2 directly from the atmosphere and supply it to multiple sectors that use CO_2.
Svante	CO_2 capture and supply	Svante, like Carbon Engineering, uses a carbon capture technology that enables circularity and reduction within supply chains by capturing CO_2 directly from the cement kiln.

Endnotes

1. M. T. Khan et al., "Curing of Concrete by Carbon Dioxide," *International Research Journal of Engineering and Technology*, vol. 5, no. 4 (April 2018).

2. Dwarakanath Ravikumar et al., "Carbon Dioxide Utilization in Concrete Curing or Mixing Might Not Produce a Net Climate Benefit," *Nature Communications*, vol. 12, no. 1 (February 8, 2021): 855, **https://doi.org/10.1038/s41467-021-21148-w.**

3. Ibid.

4. Ibid.

5. "New Low-Carbon Innovations in Cement and Concrete Production," CarbonCure, November 24, 2020, **https://www.carboncure.com/concrete-corner/new-low-carbon-innovations-in-cement-and-concrete-production/.**

6. Ravikumar et al., "Carbon Dioxide Utilization in Concrete Curing or Mixing Might Not Produce a Net Climate Benefit," 2021.

7. Ibid.

8. Kristin Majcher, "What Happened to Green Concrete?" *MIT Technology Review*, March 19, 2015, **https://www.technologyreview.com/2015/03/19/73210/what-happened-to-green-concrete/.**

Charles Cannon, Valentina Guido, and Lachlan Wright, ***Concrete Solutions Guide: Six Actions to Lower the Embodied Carbon of Concrete,*** RMI, 2021, http://www.rmi.org/concrete-solutions-guide/.

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