WORLD CEMENT

June 2026

FROM LAB TO PLANT

Dr. Dean Forgeron, CarbonCure Technologies, provides insight into what deployment-ready CCUS looks like.

Carbon capture, utilisation, and storage (CCUS) has moved from theoretical potential to active deployment in the cement and concrete industry. Tightening climate regulations, net-zero commitments, and growing commercial evidence have pushed CCUS from the margins of industry conversation to the middle of it.

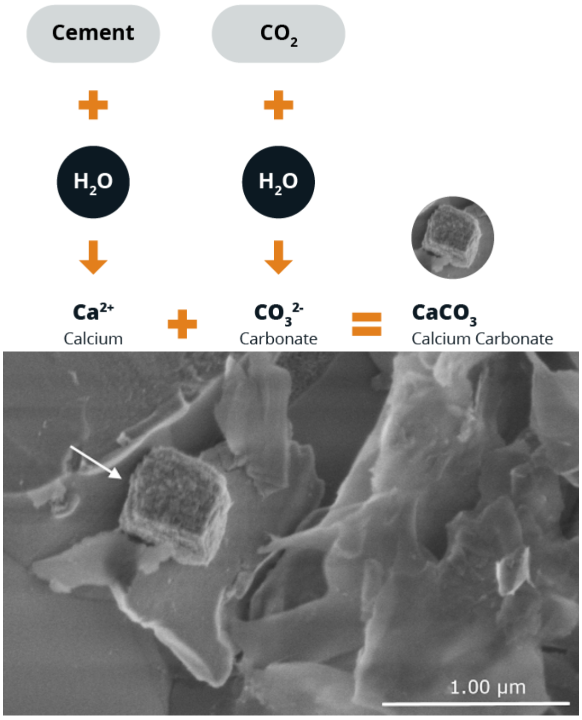
Economics are also accelerating this shift, particularly when it comes to carbon utilisation. Rising costs and supply chain uncertainty have made producers more receptive to technologies that reliably deliver measurable cement reductions, stable production performance, and access to new revenue streams. Cement efficiency, or the ability to achieve equivalent or improved performance with a lower cementitious content, has consequently become a central metric in how producers evaluate their operations.

The industry is no longer asking, 'Can carbon utilisation work in concrete production?' The more relevant question is whether it performs consistently in real manufacturing environments, across material variability, batch-to-batch fluctuations, and plant-to-plant differences. For commercial success, these technologies must demonstrate consistent performance within existing operations and across diverse binder systems, not just under controlled laboratory conditions.

In the case of CarbonCure Technologies, its network of concrete industry partners across two dozen countries has produced more than 11 million loads to date. The deployment enabled carbon mineralisation at scale, reducing cement use across 70.9 million m^3 of concrete and saving more than 764 000 t of CO_2. The result of CarbonCure's solution is a nanoscale reaction translating into measurable cost savings and emissions reduction at a global industrial scale.

CO_2 as a functional ingredient

When CO_2 is introduced at the point of mixing, it reacts immediately within the hydrating cement system, reacting with the dissolved calcium ions to form finely distributed calcium



Micro-image of calcium carbonate ($CaCO_3$) nanomineral at 400 nm.

A CarbonCure valve box and CO_2 tank operating at a ready mix plant.

carbonate ($CaCO_3$). This in-situ formation acts as a distributed nucleation mechanism, providing additional sites for hydration products to form while simultaneously consuming calcium from solution. Together, these effects modify early-stage hydration kinetics – accelerating initial reactions and shaping the development of the cement paste microstructure.

Because the $CaCO_3$ forms during mixing, it becomes uniformly embedded within the evolving matrix and remains permanently bound in the hardened concrete, enabling CO_2 storage in a stable mineral form while maintaining equivalent performance. These effects are validated through targeted testing, including isothermal calorimetry (changes in hydration kinetics), FTIR spectroscopy (carbonate formation), SEM-EDS (distribution of $CaCO_3$), among other techniques used in ongoing mechanism-focused research.

This mechanism differs from approaches such as limestone filler addition or supplementary cementitious material (SCM) substitution, which modify the composition and reactivity of the binder system. Instead, CO_2 mineralisation operates within the existing system – altering hydration through nucleation and localised calcium consumption rather than replacing components. These approaches are complementary: CO_2 mineralisation can be combined with SCMs and blended cements, including portland limestone cement, to optimise performance in complex binder systems. The primary outcome is improved cement efficiency, with CO_2 functioning as an active component of the hydration process that requires the same level of optimisation and validation as any other mix component.

Addressing common quality control concerns

Quality control in concrete production manages variability, ensuring performance targets are consistently achieved under real plant conditions. CarbonCure is approved as an ASTM C494 Type S admixture, reinforcing its alignment with established industry frameworks and QC practices. The objective is to demonstrate that CO_2 mineralisation enables equivalent performance with reduced cement content and lower embodied carbon. This is achieved by evaluating CO_2 in its final state as part of an optimised mix design, rather than as an addition to a fixed baseline. Mixes are adjusted to target cement reduction, with CO_2 treated as an integrated component. Performance is assessed against the baseline concrete it is intended to replace, ensuring direct applicability to production.

Addressing QC concerns begins with performance evaluation, with compressive strength as the primary focus. Validation follows established QC methods, using replicate batch testing and ACI 214 statistical methods to assess equivalence relative to expected plant and lab variability. Testing is conducted on representative production mix designs to reflect real production conditions, with results evaluated against defined strength targets within normal production variability. This ensures conclusions align with standard QC decision-making and that equivalence is demonstrated under conditions representative of actual plant operations. Other mechanical and durability properties can be subsequently evaluated on the adjusted mix design once strength equivalence is confirmed.

Fresh concrete behaviour is evaluated alongside strength. Slump, air content, and setting characteristics are monitored during testing to confirm compatibility with existing materials and admixture systems. Any required adjustments remain within standard QC practice, enabling integration without operational disruption.

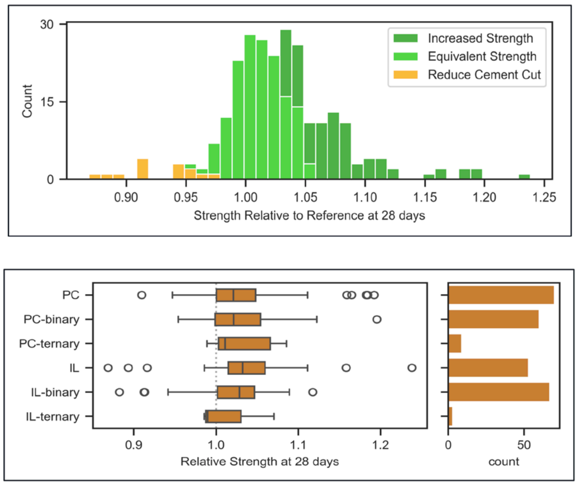
Ultimately, QC teams assess technologies based on production performance. By structuring evaluation around final-state performance, standard QC methods, and mix optimisation toward defined targets, CO_2 mineralisation is assessed not as an external addition but as a validated component of a lower-carbon concrete system.

Mechanism validation

CO_2 mineralisation has been validated through complementary analytical techniques, including nanoscale characterisation of the concrete microstructure. These methods directly confirm the reaction mechanisms, rather than relying solely on performance outcomes.

Validation begins with cement screening testing. Isothermal calorimetry assesses the impact of CO_2 injection on hydration kinetics, while FTIR confirms calcium carbonate formation. This is followed by controlled batch experiments, where control and cement-reduced CO_2 mixes are compared across multiple dosages using representative customer materials. Fresh and hardened properties are measured to confirm that the observed chemical effects translate into concrete performance consistent with industry standards.

Across a large dataset of mixes, most demonstrate statistically equivalent performance. Mixes incorporating CO_2 at



Graphs showing CarbonCure's lab results across hundreds of binder systems.

Images of 1072 West Peachtree in Atlanta.

Images of 300 North Michigan Avenue in Chicago.

~4% cement reduction consistently achieve equivalence with baseline mixes. This has been demonstrated across a wide range of cement and SCM systems spanning North America, Latin America, Asia-Pacific, and EMEA, including ASTM Types I/II and portland limestone cement. The consistency across diverse materials indicates that the mechanism is rooted in fundamental cement chemistry, rather than dependent on a specific binder system.

CarbonCure's collaboration with the MIT Masic Lab further extends this understanding, using in-situ and operando Raman spectroscopy and microscopy techniques to observe carbon mineralisation in real time. This insight enables continued refinement of the technology as it is applied in new markets and to new material systems, supporting adaptation rather than reliance on fixed formulations.

From lab to plant

A technology that performs in the lab must ultimately prove itself in production, where operating conditions, production pressures, and variability differ significantly. Demonstrating consistent performance in this environment is critical for adoption.

CarbonCure's Customer Lab protocol is designed to bridge the gap between lab and production. Prior to hardware installation, CO_2 mineralisation performance is evaluated using plant-specific materials, including local cements, SCMs, aggregates, and admixtures. Since 2023, over 250 cement systems have been assessed using this approach. In 2025, the protocol was expanded to customer and trusted third-party labs across LATAM, EMEA, and APAC, enabling faster, localised validation while maintaining a consistent methodology.

Field deployment confirms that lab-validated performance translates to production environments. 1072 West Peachtree in Atlanta, Georgia – the tallest structure to date built with carbon-mineralised concrete – demonstrates performance in a 60 storey high-rise environment, with concrete supplied by CarbonCure producer partner Thomas Concrete. Across projects, field data show consistent alignment with lab results, with variability managed through standard mix design adjustments and CO_2 dosage optimisation.

Consistency across projects matters more than a single landmark. 300 North Michigan Avenue, a 47 storey high-rise in downtown Chicago, demonstrates this consistency in one of North America's most demanding urban construction environments. Supplied by CarbonCure producer partner Ozinga, the project combined SCMs with CarbonCure Ready Mix technology to reduce embodied CO_2 by hundreds of metric t, equivalent to the carbon sequestered by over 33 000 tree seedlings grown for 10 years.

Over the past decade, CarbonCure has expanded across global regions with diverse climates and operating conditions, from cold climates such as Calgary to the extreme heat of the United Arab Emirates. Supporting this global deployment is a continued focus on consistent in-market testing workflows as validation protocols expand across regional labs and production environments.

This consistency is critical not only for technical validation but for enabling producers around the world to ramp up production with confidence. Stable performance under plant conditions allows producers to achieve target volumes and sustained cement reduction – key drivers of plant-level economics and carbon credit generation.

For producers evaluating carbon utilisation, this combination of validated workflows, field performance, and consistency across operating environments is a critical proof point of a technology ready for scaled implementation.

Looking forward – backed by data

The bar for introducing any innovation into concrete production is high. New technologies, materials, or processes must meet or exceed established performance and quality standards under real-world conditions. CO_2 mineralisation has been developed and validated to meet these standards.

Over the past decade, a growing body of research, performance data, and commercial deployment has demonstrated its reliability – from controlled laboratory studies to large-scale projects across multiple continents. Concrete executives, QC leaders, specifiers, and end users evaluating the technology – whether against conventional practices or alternative cement efficiency approaches – will find a solution supported by consistent technical and commercial validation.

The scientific foundation continues to evolve, while performance data now spans hundreds of binder systems across global regions. What began as a laboratory concept is now delivering measurable cement efficiency in demanding production environments and complex construction projects.

As the broader CCUS landscape evolves, the question is no longer whether CO_2 mineralisation works, but how it can be effectively implemented at scale. ■