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Industry CPD

Carbon-captured cement

This CPD module, sponsored by Heidelberg Materials, explains how carbon capture and storage is applied to cement production to provide near-zero cement solutions.

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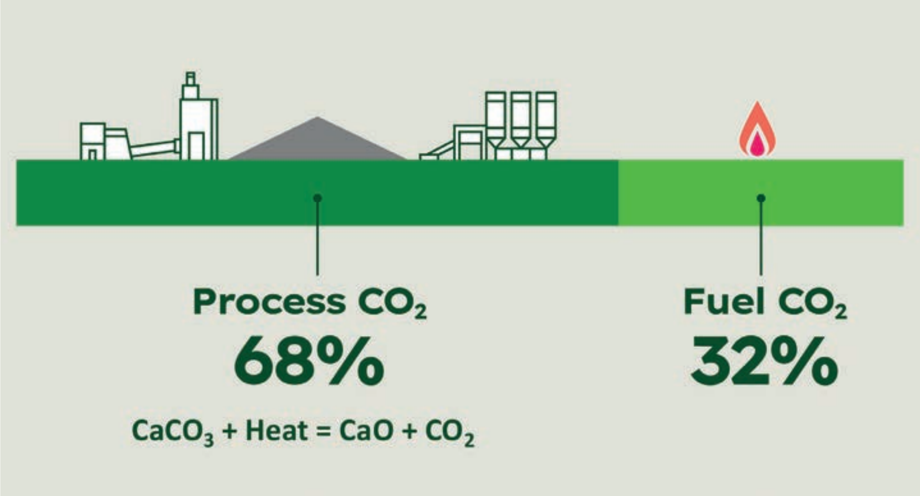
Carbon capture for low-carbon cement

It is a well-known fact that 7–8% of the world's CO_2 emissions stem from the production of cement and, furthermore, about 40% of the world's CO_2 emissions are related to construction. The construction industry has a decarbonisation roadmap which builds on efficiencies and material improvements. One of the improvements relates to the increased use of supplementary cementitious materials (SCMs) such as ground granulated blast-furnace slag (GGBS), fly ash, natural pozzolans and calcined clay in cement and concrete. They can significantly reduce the embodied carbon in cement and concrete but have to be used in combination with Portland cement and, in the case of GGBS and fly ash, will also become a constrained resource. Therefore, the cement industry requires carbon capture and storage (CCS) as a solution on its path to net zero. This article explains the technology behind carbon capture and how it is applied by Heidelberg Materials.



↗FIGURE 1: CO_2 emissions from cement production

Understanding the source of CO_2 emissions from cement production

The main constituent of Portland cement is clinker. Clinker is produced by heating limestone (calcium carbonate, $CaCO_3$) together with silica, alumina and iron sources to temperatures of around 1,400°C, forming calcium silicates, aluminates and ferro aluminates. During this process, limestone undergoes calcination, where $CaCO_3$ dissociates at around 800°C to form lime (CaO) and carbon dioxide (CO_2) **(Figure 1)**.

These emissions are known as *process emissions*. They are unavoidable and account for approximately two-thirds of the total CO_2 emissions from cement production. The remaining third arises from fuel combustion to generate the high temperatures required for the calcination process and the clinker formation. Fuel-related emissions can be reduced through efficiency measures and the use of alternative and biogenic fuels, strategies for which are well developed in the UK cement industry, with fossil fuel substitution being as high as 90% at some cement works. Process emissions, however, cannot be eliminated.

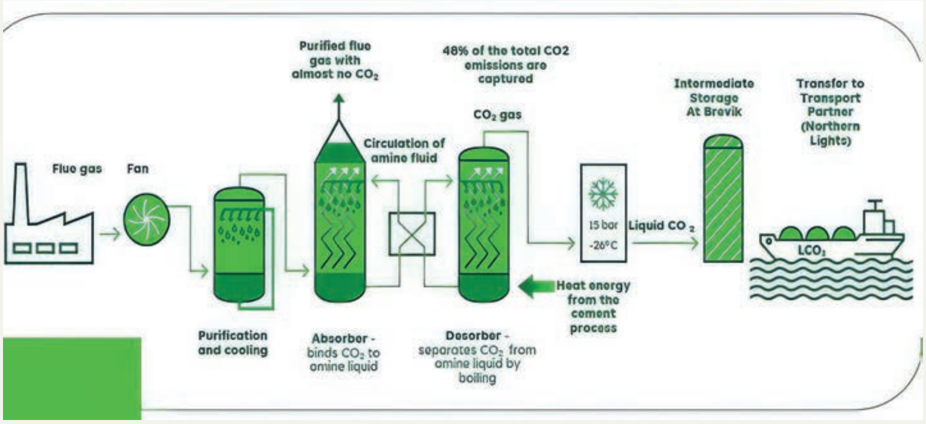
This makes the cement industry a so called 'hard-to-abate' sector. CCS is therefore a critical technology for achieving deep decarbonisation in cement manufacturing. Its importance is increasingly recognised by governments and policymakers, including in the UK, where the Climate Change Committee has described CCS as 'a necessity rather than an option'[1].

How does carbon capture work?

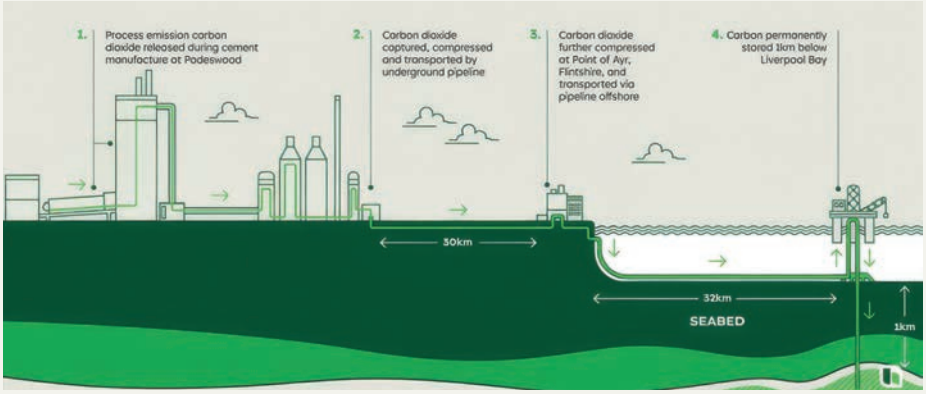
How carbon capture works can be explained by describing the process at the first-ever commercial-scale CCS plant at Heidelberg Materials' Brevik cement works **(Figure 2)**. Since 2025 it produces near-zero carbon-captured cement, known as evoZero, which is now available for the first time across Europe. The next carbon capture plant to come online will be at Heidelberg Materials' cement works in Padeswood in North Wales in the UK in 2029.

At the carbon capture plant in Brevik, Norway, Heidelberg Materials uses proven amine-based capture technology **(Figure 3)**. Following the conventional cement production process, sulphur oxides and nitrogen oxides are first removed from the flue gas. The remaining gas stream is then passed through a washing system using liquid amines, which, at a

↗**FIGURE 2:** Carbon capture plant at Heidelberg Materials' Brevik cement works in Norway



↗**FIGURE 3:** Schematic of carbon capture process at Brevik cement works



↗**FIGURE 4:** Start-to-end schematic overview of CCS for Padeswood cement works in UK

temperature of about 70°C, selectively absorb the CO_2 in the absorber tower. The amines then pass via a heat exchanger into the desorber where they are heated to about 130°C. At this temperature, the CO_2 is released, and the solvent is recirculated via the heat exchanger into the absorber. The CO_2 is then compressed and prepared for transport to permanent geological storage.

Does carbon capture affect cement quality?

Carbon capture does not affect clinker or cement quality. The cement produced under carbon capture conditions is chemically and physically identical to conventional cement, complies with existing standards, e.g. BS EN 197-1[2] for cement and BS EN 206[3] and BS 8500[4] for concrete, and does not require additional product approvals. From the perspective of designers, contractors and asset owners, carbon-captured cement performs in the same way as traditional cement. CCS therefore represents a solution to reduce the embodied carbon in concrete without having to change established mix designs. It is a low-risk route to decarbonisation.

Carbon-captured cement presents, in particular, an opportunity where traditional methods to reduce embodied carbon in concrete prove difficult. For example, the use of SCMs is challenging in applications where early strength gain is important, such as in precast, core walls in high-rise buildings, sprayed concrete, or post-tensioned segmental construction in bridges. Furthermore, carbon-captured cement has a key role to play in combination with SCMs, complementing the carbon reduction from the SCM by decarbonising the Portland cement portion of the mixes with SCMs.

Incorporating evoZero into a project may result in a minimal increase of the total project cost depending on concrete mix design, percentage of SCM, project location, logistics and integration of evoZero. This reflects the added value of achieving ultra-low carbon concrete, while achieving substantial carbon savings in the project, without any impact on performance.

How is the CO_2 transported and stored?

Captured CO_2 can be transported by pipeline, ship, rail or a combination of these methods to suitable storage sites. It is injected deep underground into carefully selected geological formations, either offshore or onshore, such as saline aquifers or depleted oil and gas fields. These formations are sealed by impermeable rock layers that prevent the CO_2 from migrating to the surface.

Extensive monitoring systems are used throughout the life cycle of storage to verify containment and ensure there is no leakage. Over long timescales, the injected CO_2 reacts with surrounding minerals and gradually mineralises, effectively becoming rock.

For CCS to be deployed at scale, suitable infrastructure linking capture sites to storage locations is essential. Where direct pipelines are not feasible, shipping or rail transport provides a practical alternative.

At Heidelberg Materials' Brevik plant, the captured CO_2 is liquefied and transported by ship to an intermediate terminal in northwest Norway. From there it travels via a 110km offshore pipeline to a saline aquifer in the Aurora field, located 2.6km beneath the seabed. In the UK, Heidelberg Materials' Padeswood CCS plant, which is scheduled to become operational in 2029, will connect directly to pipeline infrastructure transporting CO_2 to depleted oil and gas fields in Liverpool Bay for permanent storage **(Figure 4)**.

How is CO_2 leakage addressed?

Decades of scientific research and operational experience support the safety of geological CO_2 storage. Storage sites are selected based on rigorous geological criteria, and monitoring programmes ensure that groundwater, marine ecosystems and biodiversity are not adversely affected. The same geological principles that have kept oil and natural gas trapped beneath impermeable rock layers for millions of years apply to CO_2 storage.

Any leakage associated with CO_2 transport operations is minimal and is fully accounted for in the environmental product declarations (EPDs) of carbon-captured cement products.

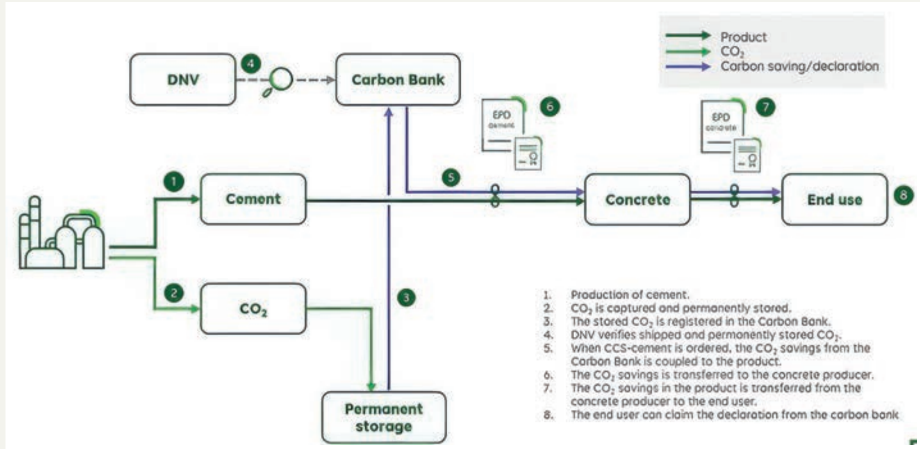
What are the CO_2 capture rates?

Most planned future carbon capture projects are being designed to maximise capture rates close to 95% of the CO_2 associated with cement production. At Brevik the situation is different. The carbon capture process makes extensive use of waste heat generated by the cement production and CO_2 compression. This allows around 50% of the plant's total emissions to be captured without the need for a large additional energy source. A small contribution from an electric boiler is used where necessary. This results in an annual capture rate of about 50%, translating into about 400,000t CO_2/annum captured for the production of approximately 1mt/annum of clinker.

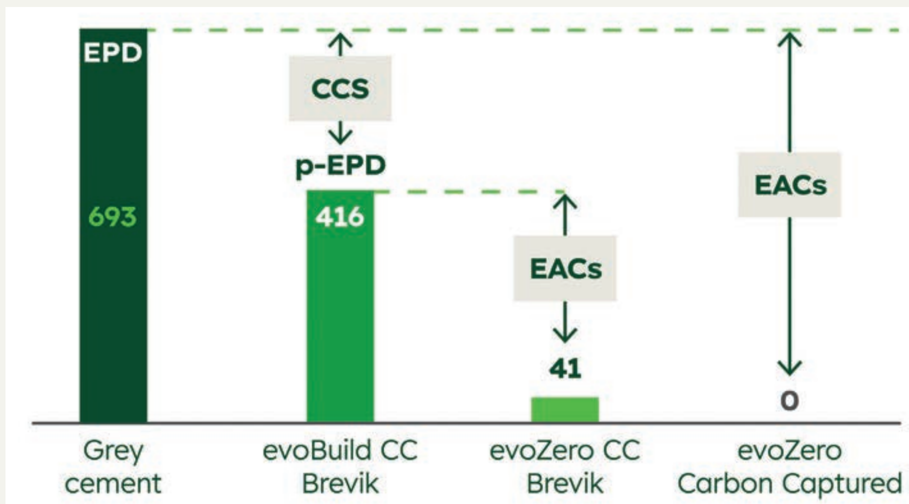
Future CCS projects are expected to operate with significantly higher capture rates. At Heidelberg Materials' Padeswood plant, capture rates of approximately 95% are planned. This results in about 800,000t of CO_2 being captured, for an annual production of about 700,000t of clinker, and put into permanent storage every year. This will be enabled by an on-site combined heat and power (CHP) plant that will provide additional heat, with the CHP emissions also captured as part of the overall system. Capture rates above 95% with liquid amines as solvent would lead to inefficiencies in the process.

Are there other carbon capture technologies?

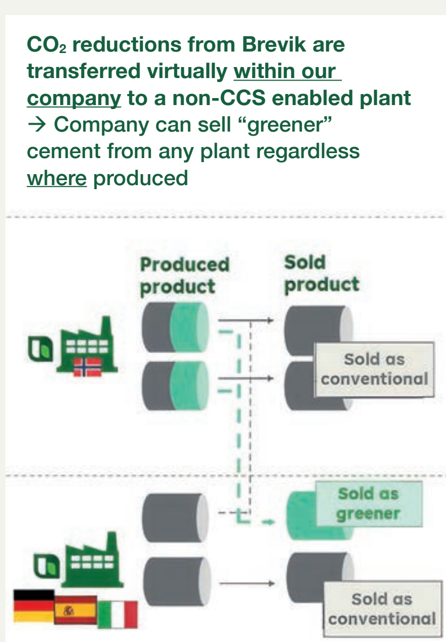
The amine technology is proven at scale and was therefore the technology of choice for the first commercially operated CCS plants. However, it is an energy-intensive process and Heidelberg Materials is involved in several pilots testing the feasibility and viability of alternative lower-energy technologies. It tested, for example, a different solvent technology in a small-scale pilot at its cement works in Ketton in the UK. A large pilot plant with a 50,000t/annum capacity is being built at its Devnya cement works in Bulgaria testing the OxyCal technology where fuel is burned with pure oxygen instead of air, and a 100,000t/annum pilot plant at the Ennigerloh cement works in Germany where CO_2 is being kept separate from the fuel gases in the process. Both latter technologies render the CO_2 capture easier. At a lower technology readiness level are metal organic frameworks (MOFs) which act like sponges which absorb CO_2 at a certain temperature and release it at a different temperature.



↗**FIGURE 5:** Flow chart from carbon capture to issue of EACs to end-user



↗**FIGURE 6:** Carbon reduction options for CEM I 52,5N with carbon capture



↗**FIGURE 7:** Mass-balance credit approach

How is the CCS attribute monitored and allocated to products?

Environmental Attribute Certificates (EACs) are instruments to track environmental benefits associated with climate mitigation activities such as CCS and are already well established in other sectors, such as renewable electricity supply. For each tonne of clinker produced in Brevik under verified CCS conditions, EACs are generated based on the amount of net permanently stored fossil CO_2 per tonne of clinker. EACs also allow decoupling the environmental benefit from the physical product. Once the benefit is allocated to another cement – for example, in another country – via EACs, the original physical cement is sold without that CCS-based benefit. While the CO_2 benefits are transferred via EACs, there is no risk of double counting because each certificate is linked to verified permanently stored CO_2, tracked in Heidelberg Materials' Carbon Bank on a distributed ledger, and can only be allocated once, with third-party assurance provided by DNV.

Achieving near-zero embodied carbon with mass balancing

Near-zero embodied carbon cement can be delivered even when capture rates are below 100% using a chain-of-custody model known as mass-balance credit method[5]. This approach attributes EACs non-proportionally to specific cement volumes.

To ensure credibility and prevent double counting, Heidelberg Materials has implemented a secure digital carbon accounting system **(Figure 5)**. It operates on a public distributed ledger and records 'deposits' in a third-party audited Carbon Bank only when two conditions are met: the verified production of one tonne of clinker under carbon capture conditions, and the permanent geological storage of the corresponding CO_2. Both are independently assured by a third-party verifier.

All deposits in the Carbon Bank already account for emissions generated by the CCS operations themselves. As with a financial account, EACs first need to be deposited and can then be withdrawn when CCS-cement is supplied to customers.

Physical and virtual supply models

The physical model delivers carbon-captured cement produced at Brevik with a near-zero global warming potential (GWP) through a combination of EPD-based reductions and EACs, while the virtual model delivers 'zero-carbon' cement by fully offsetting the EPD GWP of any local physical cement with EACs generated from CCS at Brevik **(Figure 6)**. The latter approach is known as mass-balance credit approach **(Figure 7)**. Independent verification ensures that no overselling or double counting occurs. The virtual model comes with the benefit of avoiding CO_2 emissions associated with transport, which, in the case of cement being transported from Norway to the UK, adds about 10kg eCO_2/t of cement.

Looking ahead

CCS needs to rapidly expand globally, and projects such as Brevik and Padeswood demonstrate how CCS can be successfully integrated into cement production today. As more cement CCS facilities come online, it is anticipated that a global registry for CO_2 deposits and withdrawals will emerge, replacing Heidelberg Materials' current Carbon Bank, enabling even greater transparency and consistency across markets.

By combining CCS with robust chain-of-custody models, near-zero embodied carbon cement is now available, providing a practical pathway for the construction sector to meet its net-zero ambitions using the lowest-carbon cement currently achievable.

REFERENCES

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2) British Standards Institution (2019) *BS EN 197-1:2011 Cement – Composition, specifications and conformity criteria for common cements*, London: BSI

3) British Standards Institution (2026) *BS EN 206-1:2026 Concrete – Specification, performance, production and conformity – Performance, requirements, factory production control and assessment criteria for individual values*, London: BSI

4) British Standards Institution (2023) *BS 8500-1:2023 Concrete. Complementary British Standard to BS EN 206 – Method of specifying and guidance for the specifier*, London: BSI

5) International Organization for Standardization (2026) *ISO 22095-2:2026 Chain of custody. Part 2: Requirements and guidelines for mass balance*, Geneva: ISO

Questions

To claim your CPD certificate, answer the questions online at **www.istructe.org/industry-cpd**. This module will close on 31 October 2026.

1) What is the main reason carbon capture and storage (CCS) is essential for cement decarbonisation?
a) Fuel-related emissions cannot be reduced
b) Cement quality deteriorates without CCS
c) Process emissions from calcination cannot be eliminated
d) CCS reduces the need for clinker production

2) Which statement best describes the impact of carbon capture on cement performance?
a) It has no effect on cement quality or compliance
b) It improves early strength significantly
c) It weakens the final concrete strength
d) It requires new design standards

3) How is captured CO_2 from the Brevik cement plant ultimately and permanently stored?
a) Released into the atmosphere after purification
b) Stored in pressurised tanks at the plant
c) Injected into geological formations such as saline aquifers
d) Converted into liquid fuels for reuse

4) What is the purpose of Environmental Attribute Certificates (EACs) in CCS cement?
a) To declare the cement's strength properties
b) To physically improve cement composition
c) To regulate cement transport emissions
d) To allocate the environmental benefit of captured CO_2 separately from the product

5) Why is carbon capture considered essential even when supplementary cementitious materials (SCMs) are widely used for cement and concrete decarbonisation?
a) SCMs increase the amount of clinker required in cement and concrete production
b) Portland cement clinker remains necessary when using SCMs, and its process emissions cannot be avoided
c) SCMs cannot be used in structural concrete applications
d) SCMs produce higher embodied carbon than conventional cement

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