What is the Institution's concrete technology tracker?

In this article, we introduce the IStructE's new concrete technology tracker, which has been compiled to inform members about the development of lower-carbon alternatives to conventional Portland cement-based concrete.

Introduction

With the urgent need for lower-carbon alternatives to conventional Portland cement-based concrete, the IStructE has launched a tracker to serve as a high-level guide for engineers about current and emerging lower-carbon concrete technologies available in the UK market.

A number of companies are developing technologies, but publicly available information about them is often limited and inconsistent. To bridge this knowledge gap, the authors of the tracker contacted over 20 companies to assess the maturity and expected developments of their lower-carbon concrete technologies by 2030, focusing primarily on embodied carbon and commercial readiness in the UK market.

The authors sought to assess each technology objectively based on the information provided by the individual companies, though it should be noted that this information has not been independently verified.

Engineers should also bear in mind that lower-carbon products are not a substitute for lean design principles: materially efficient design is the first step in the hierarchy of net-zero design.

Technology types

Thirteen technology streams **(Box 1)** have been identified as alternatives to conventional concrete which are expected to reach market deployment by 2030. These streams have been assessed based on their expected embodied carbon and technological/commercial maturity. The tracker also provides a summary of key considerations for designers for each stream, such as code compliance and example products/companies.

The list is not exhaustive, but aims to offer a representative snapshot of current and emerging lower-carbon concrete technologies. It will be updated as the field evolves.

It is not practical to provide a detailed assessment of cost at this stage, but it is expected that most technologies will initially be more expensive than conventional concrete. However, it is assumed that economies of scale will reduce initial premiums over time.

The technologies are not mutually exclusive, and it may be both possible and beneficial to combine technologies. However, combinations should be assessed on a case-by-case basis with advice sought from the supplier and respective technology companies.

Assessment criteria

The assessment criteria used in the tracker focus primarily on expected embodied carbon compared with conventional concrete. The baseline for comparison is set at 300kgCO_2e/m^3, representing the A1–A3 embodied carbon of a C32/40 mix with 25% GGBS replacement, a common specification in the UK.

Technologies are categorised as *low, medium* or *high embodied carbon* relative to this baseline, although due to varying maturity levels, exact values are often uncertain. As technologies progress and undergo trials, the accuracy of these values will improve.

The assessment only considers the embodied carbon of concrete production, not scalability or global emissions impact. Additionally, it excludes the embodied carbon of steel reinforcement.

Commercial readiness

The readiness of these technologies for commercial use in the UK market is also evaluated, categorised into 'research and development', 'demonstration' and 'market deployment' stages. However, predicting development beyond 2030 is challenging, and forecasts are based on responses from technology companies and the authors' own knowledge, serving as indicative rather than precise timelines.

Engineers outside the UK are encouraged to inquire about technology readiness in their local markets, as many technologies may have similar levels of readiness globally.

Find out more

Over the next few pages, we look in more detail at four developing technologies with the potential to deliver significant global reductions in embodied carbon.

To view the full tracker and learn more about all the technologies listed, visit www.istructe.org/resources/guidance/concrete-technology-tracker.

Acknowledgements

The IStructE concrete technology tracker has been authored by Paul Astle and Tom Dillon of Ramboll, Will Arnold of IStructE and Tim Forman of the University of Cambridge, with Dr Fragkoulis Kanavaris of Arup as specialist technical contributor.

Box 1. Technology streams

Group A: Conventional concrete
- →| A1: Optimised conventional concrete
- →| A2: Alternative raw materials
- →| A3: Carbon capture, utilisation and storage (CCUS)

Group B: Clinker replacement
- →| B1: Traditional supplementary cementitious materials (SCMs)
- →| B2: Non-Portland cement – Alkali activated binders (AABs)
- →| B3: Non-Portland cement – Alternative binders
- →| B4: SCM – Calcined clay
- →| B5: SCM - Olivine-based SCMs

Group C: Carbon sequestration within concrete
- →| C1: Carbon-sequestering aggregates
- →| C2: Carbon injection
- →| C3: Carbonation curing

Group D: Other approaches
- →| D1: Performance enhancing admixtures
- →| D2: Biocement

METSEC
DECARB

REDUCING CONSTRUCTION'S CARBON FOOTPRINT

TRUST METSEC

Metsec Decarb, a range of Purlins, Side Rails and Mezzanine Floor Systems utilising the very latest steel making technology. Reducing the CO_2 and carbon footprint of your next project.

The range uses steel made from new, state of the art electric arc furnaces the alternative to burning fossilfuels, in the traditional blast furnace method. It's that simple.

- No greenwashing
- No mass balance approach
- No carbon offsetting
- No allocation of green energy
- Project specific Environmental Product Declarations available which accurately calculate the project savings on embodied carbon.

Contact us for further details.

#TRUST METSEC

voestalpine Metsec plc
www.metsec.com

voestalpine
ONE STEP AHEAD.

Lower-carbon concrete technologies

Limestone Calcined Clay Cement

What is the technology?

Limestone Calcined Clay Cement (LC3) is a blended cement type that replaces half of the carbon-intensive clinker used in ordinary Portland cement (OPC) with calcined clay and ground limestone. Calcined clay reacts with lower-grade limestone, which simplifies access to raw materials for making LC3.

Overall, LC3 is a dramatically lower-carbon option than conventional cement. It is also more cost-effective and lasts longer, all while providing excellent early strength. After just seven days, LC3 performs better than conventional cement, and it maintains parity through 90 days.

LC3 makes use of local resources, as clays are widely available in all geological settings across the globe. Clays that contain kaolinite, which are the most suitable clay types for LC3, are particularly abundant in countries in the Global South, where most new construction will occur in the coming decades.

LC3 complies with a number of standards around the globe – including EU 197-5 (Europe), ASTM C595 (North and South America), NC1208 (Cuba), IS 18189:2023 (India), PS 5586-2023 (Pakistan) and GB175-2023 (China) – but many current standards may have to be updated from a prescriptive to a performance-based approach.

IS 18189:2023 is an exclusive Indian Standard for LC3 which was released by the Bureau of Indian Standards in 2023. The code provides comprehensive guidelines and specifications for the production, testing and usage of LC3 in concrete. It is a game-changer for decarbonising concrete in the most populous country in the world.

© LC3 PROJECT

Why does this result in a carbon saving?

The most carbon-intensive part of cement is the production of clinker, which requires heating limestone to very high temperatures (around 1450°C) to make the material reactive. Producing clinker releases CO_2 in two ways: first, it burns to reach the desired temperature; second, even more CO_2 (around 60% of emissions) is released when limestone is chemically broken down.

LC3 addresses both sources of CO_2 emissions. First, it replaces half of the carbon-intensive clinker with calcined clay and ground limestone, neither of which have process emissions. Second, the clay is calcined at a much lower 800°C, which reduces emissions and uses less energy. LC3 can reduce CO_2 emissions by up to 40% compared with OPC.

Current state of R&D/ commercialisation

LC3 technology is entirely in the public domain, and the LC3 Project based at EPFL in Switzerland does not commercialise cement directly. The purpose of the LC3 Project is to facilitate an industry-wide shift in the way cement is made around the world.

Today, around 10Mt a year of LC3 is made by early adopters, including major cement manufacturers such as Holcim, Cementos Argos, Heidelberg Materials and Cimpor, although there are no calcined clay plants yet in the UK.

There is ongoing research into optimisation of the concrete mix design, its mechanical and durability properties, and its fresh-state properties. This includes collaboration with structural engineers on application of LC3 in real-scale structural elements.

Prototype structures

Around 30 demonstration structures have been built to date, including a masonry house in Jhansi, India made with 98% LC3, which saved 15.5t of CO_2. Other examples include the use of LC3 by Cementos Argos in Columbia for buildings, roads, viaducts and tunnels.

Find out more

https://lc3.ch/

Expected embodied carbon

The embodied carbon of LC3 is 150kgCO_2e/m^3 for C32/40 concrete with 250kg/m^3 binder content.

Lower-carbon concrete technologies

Seratech – ultraMAFIX™

What is the technology?

Seratech's carbon mineralisation process sequesters CO_2 from industrial flues using naturally abundant magnesium silicates (olivine). This simultaneously produces two separate product streams:

1) ultraMAFIX™ – a supplementary cementitious material (SCM) which is predominantly amorphous silica and chemically similar to existing SCMs, such as fly ash and ground granulated blast-furnace slag (GGBS). This SCM can be introduced at a batching plant for ready-mix concrete and so no changes are required to normal concreting practices.

ultraMAFIX™ is very reactive, resulting in high early strengths. It meets the chemical and physical definitions and performance requirements for a 'P'-class pozzolan (BS 8615-1 and EN 197-1), and can be used in a CEM II or CEM IV mix, replacing up to 55% of the Portland cement in concrete.

2) magCARB™ – a magnesium carbonate binder that allows CO_2 to be sequestered within the built environment. This is perfectly suited for concrete bricks and blocks, and can be used to replace 100% of the Portland cement. The blocks can be made in existing factories with minimal changes to production equipment and processes, and are able to deliver a CO_2 saving of 80% versus business as usual.

Why does this result in a carbon saving?

This technology reduces CO_2 emissions in several ways:

- If the process is implemented in a cement kiln, the Scope 1 emissions from Portland cement production (fuel burning and limestone decomposition) can be sequestered, resulting in Portland cement with an emissions reduction of up to 94% versus business as usual.
- ultraMAFIX™ can be used to replace up to 55% of the Portland cement in ready-mix and precast concrete (depending on the application), reducing the quantity of Portland cement needed.
- The high reactivity of ultraMAFIX™ could lead to a reduction in binder content in concrete.
- magCARB™ can be used to replace 100% of the Portland cement in concrete products, including concrete blocks.

Current state of R&D/ commercialisation

Seratech is currently fundraising to build its first pilot. Operational from 2025, this facility will be capable of sequestering 200t of CO_2 per year.

© HELENE SANDBERG

Materials from this will be used for comprehensive testing regimes and demonstration projects with key industrial partners.

After this, a large-scale industrial pilot will be built and operational from 2027. This will have the capacity to sequester 20 000t of CO_2 per year, and the materials from this facility will be sold for use in commercial projects.

Prototype structures

To date, Seratech has produced architectural pieces containing ultraMAFIX™ concrete (London Design Festival 2022) and magCARB™ bricks (EcoCity 2023).

Find out more

www.seratechcement.com

Expected embodied carbon

Currently C32/40 concrete can be produced at 21kgCO_2e/m^3 with 30% of the Portland cement replaced by ultraMAFIX™.

Over time, further decarbonisation of electricity production and supply chains (Scope 2 and 3 emissions), as well as increasing the use of biomass to heat cement kilns, will result in this value reducing further and potentially becoming negative.

The value above is calculated as the sum of the cradle-to gate emissions of the individual components in the mix design. When determing the CO_2e of decarbonised Portland cement (using Seratech's process), ultraMAFIX™ and magCARB™, the system boundary is defined around a cement kiln with integrated Seratech facility. The total emissions (residual Scope 1, Scope 2 and Scope 3) are assigned to the three products by economic allocation.

Lower-carbon concrete technologies

Cambridge Electric Cement

What is the technology?

Cambridge Electric Cement (CEC) is a *recycled* cement clinker. CEC is revolutionary because it enables the full recycling of cement. It utilises existing steel recycling furnaces, using recovered cement paste (RCP) as a replacement for the lime that would traditionally be used in such a process. The co-production process avoids both the kiln-related energy and calcination process emissions from conventional cement production. The resulting slag can be made to meet existing Portland clinker specifications, offering the first potentially zero-emissions, circular and fully scalable alternative to existing cement production.

Why does this result in a carbon saving?

CEC uses the heat from steel recycling in an electric-arc furnace as the energy source for clinkering. This eliminates the need for the cement kiln and reduces the energy-related emissions in clinker production. In addition to this, the CEC process uses recycled cement (RCP) as a feedstock. This RCP material can be re-clinkered without emitting CO_2, eliminating the remaining process emissions in clinker production.

Current state of R&D/ commercialisation

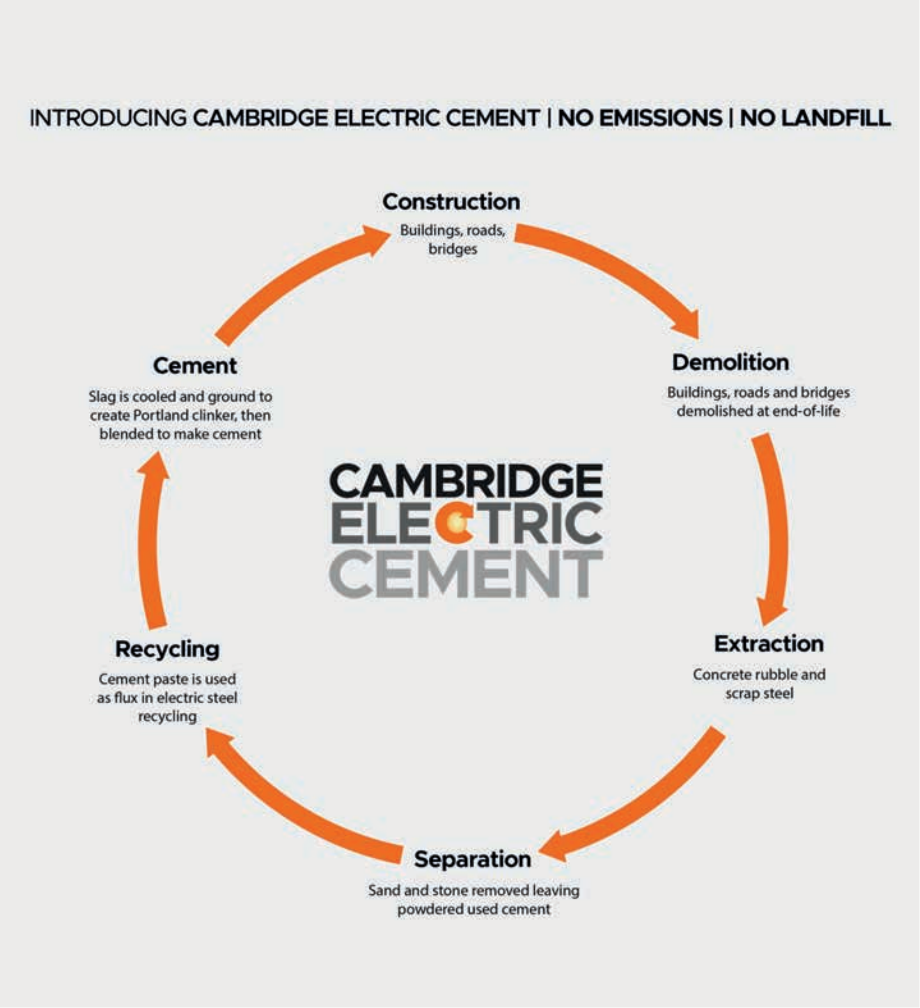
CEC is expected to be commercially available to advanced customers in 2025. The commercialisation of CEC is accelerated since it will comply with existing cement standards and can be used initially as a drop-in solution with Portland clinker.

Prototype structures

To date, CEC has been tested in mortar bars. The first prototype structure will be built later in 2024 as part of the collaborative Innovate UK project Cement 2 Zero.

Find out more

https://cambridgeelectriccement.com/



© CAMBRIDGE ELECTRIC CEMENT

Expected embodied carbon

The CEC process has a broad operating window: the carbon reduction depends on the amount of recycled cement used and the quality of the steel being recycled. This gives an embodied carbon range of between 75kgCO_2e/m^3 and 150kgCO_2e/m^3 for C32/40 concrete with the potential for even lower values due to further blending.

> **CEC USES THE HEAT FROM STEEL RECYCLING IN AN ELECTRIC-ARC FURNACE AS THE ENERGY SOURCE FOR CLINKERING**

© BRIMSTONE

Lower-carbon concrete technologies

Brimstone cement

What is the technology?

Brimstone has developed a decarbonised process for producing ordinary Portland cement (OPC) and supplementary cementitious materials. This breakthrough process has the potential to transform the global cement industry, which is today responsible for 7.5% of CO_2 emissions.

Instead of carbon-heavy limestone, which releases carbon dioxide when processed, Brimstone's process uses a calcium silicate rock with no embedded carbon dioxide. This avoids the chemical reactions that represent most carbon emissions from the conventional cement industry.

In July 2023, a third-party lab validated that the cement made with Brimstone's process meets ASTM C150 standards for OPC, the key regulatory requirement for OPC in the USA (and other countries adhering to the standard). The achievement affirms that Brimstone's process produces cement that is identical in all respects – performance, safety, and composition – to OPC produced through the conventional, carbon-intensive process.

Why does this result in a carbon saving?

As noted above, the majority of carbon emissions in traditional cement production come from the source rock, limestone. Brimstone avoids these emissions from the start by using a different source rock – calcium silicate – which has no embedded CO_2.

In addition, Brimstone's process produces magnesium-based by-products that naturally and permanently absorb carbon from the air. This offsets remaining emissions and makes the process extremely low-carbon, or even carbon-negative, depending on the energy source used.

As the first company to produce industry-standard OPC without process emissions, Brimstone has cleared a viable pathway to eliminating the cement industry's carbon footprint.

Current state of R&D/ commercialisation

Brimstone is currently advancing plans for its pilot plant, which will be located near Reno, NV. This will be the first production-scale manufacturing facility producing decarbonised Portland cement. The company is simultaneously selecting locations for its subsequent commercial demonstration and industrial plants. Brimstone is also in discussions for partnerships and potential offtake agreements with construction, real estate and corporate partners.

Prototype structures

No structures have yet been built with Brimstone's cement, but at full industrial scale, Brimstone's OPC can be used anywhere conventional cement is used, including roads, bridges, buildings, dams, and other forms of infrastructure.

Find out more

www.brimstone.com/

Expected embodied carbon

Brimstone isn't currently sharing embodied carbon numbers publicly, but states that its process is extremely low-carbon, or even carbon-negative, depending on the energy source used.