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Clinker-free cement: calcined clay paves a path to cement decarbonization

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Key messages

- Calcined clay kiln projects, which use a millennia-old technology, are now the subject of renewed interest as a potential cement decarbonization solution.

- New commercial scale calcined clay projects have gone online recently, particularly in emerging markets.

- Calcined clay has the potential to become a strategically important technology in the construction sector especially for regions rich in kaolinitic clay and lacking limestone for clinker production, in addition to providing an emissions reduction pathway.

- Government capital co-investment is less important to the success of many calcined clay projects, unlike for carbon capture, use and sequestration (CCUS), where government funding is critical.

The global production of cement reached 4 billion metric tons (tons) in 2024 (US Geological Survey, 2025). Cement production represents a significant share of global carbon dioxide (CO_2) emissions. According to the International Energy Agency's World Energy Outlook 2025, global direct CO_2 emissions from cement production were approximately 2.3 billion tons CO_2 in 2024 (Table A.4a, p. 418). The report estimates that total global direct CO_2 emissions from energy use and industrial processes were approximately 38 billion tons CO_2 in 2024. Cement production therefore accounted for approximately 6.1% of global direct CO_2 emissions from energy use and industrial processes in 2024. This makes cement production a critical industry for decarbonization to achieve global net-zero goals.

About 60% of the sector's CO_2 output arises from the calcination of limestone: at high temperatures, the limestone breaks down to calcium oxide (CaO), releasing CO_2 (Niu et al., 2025). The remaining 40% comes from fossil fuels, energy and transportation. The CaO is then used to make clinker, the key ingredient in cement, which also requires high temperatures to produce.

Clinker can be used for cement in modern concrete production as a "pozzolanic" material that reacts in the presence of moisture and CaO. Finely ground clay was discovered to be a pozzolanic material 4000 years ago. Today "calcined clay" can be used as a supplementary cementitious material (SCM) to reduce the share of clinker in final cement mixtures.

Calcined clay is derived from kaolin, a type of clay rich in the mineral kaolinite. This material occurs in higher quantities in the humid tropics, such as parts of Africa, the Americas and south Asia. Heating kaolin at 650° to 750°C forms metakaolin or calcined clay, and these temperatures are far lower than the temperatures needed to produce clinker (1500°C). As a result, the use of calcined clay in cement production leads to lower thermal energy requirements. In some cases, the chemical reactions necessary can be achieved by mechanical grinding, lowering emissions of calcined clay even more compared to conventional clinker.

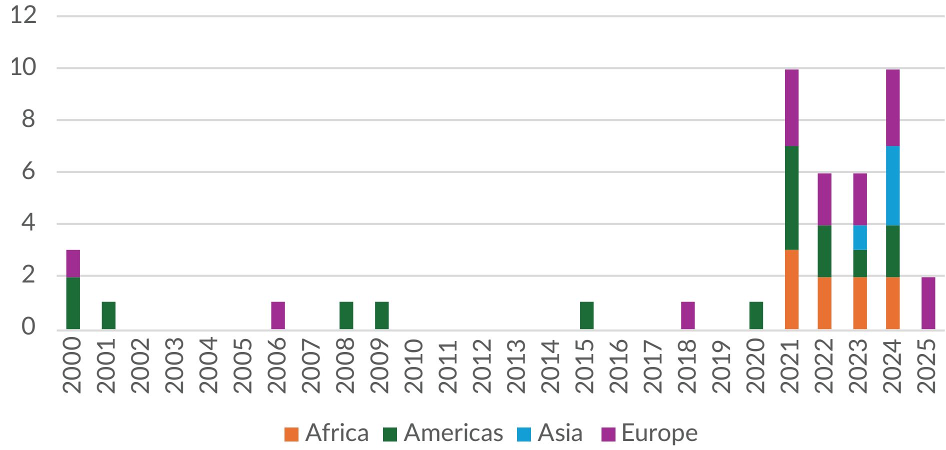
One of the more popular forms of cement produced with lower-emissions technologies has been limestone calcined clay cement (LC3), based on a blend of limestone (15%) and calcined clay (30%). The process can reduce emissions of cement by up to 40% and can be economically competitive with Ordinary Portland Cement (OPC), although cost competitiveness depends on local factors, including local raw material availability, capital costs, and energy prices (see report by Scrivener et al., 2019).

Here we present insights on calcined clay kiln projects, based on data from the LeadIT Green Cement Technology Tracker, which monitors carbon capture, utilization and storage (CCUS) and calcined clay kiln projects globally. The insights presented here reflect the 2026 Q2 data update. See the companion report covering CCUS projects published earlier this year (Yeptho & Maltais, 2026); data for both types of projects are updated on the tracker, available for download on the LeadIT website.

State of progress in 2025

After an acceleration in the past few years, 2025 data indicate a slowdown of calcined clay project announcements. The Green Cement Technology Tracker shows new calcined clay kiln projects announced across every continent, as shown in Figure 1, unlike for CCUS, which is almost exclusively present in advanced economies. The global adoption of calcined clay can be explained by its technical simplicity and significantly lower cost compared to CCUS.

Figure 1: Commercial scale calcined clay kiln project announcements by year and continent***



*A project announcement is defined as the first time a project is mentioned or proposed publicly online or in the media. It does not mean that a project has gone online or progress has been made.

**Eight projects in the Green Cement Technology Tracker have undiscernible project announcement dates; of these, five are already operational, two of which are in Europe and the rest in the Americas. In this graph, we have assumed that the announcement dates for the five operational projects are three years prior to their commissioning.

Very few new projects were announced in 2025. This may partly reflect limitations in available data, as some projects do not report a clear announcement date, but it could also indicate a slowdown in project development. Given the uncertainty around the underlying causes, we do not draw firm conclusions from this trend.

Despite this uncertainty about the 2025 trend, calcined clay cement has proven its viability. The majority (over 72%) of all projects in the Green Cement Technology Tracker have been announced at commercial scale, not as pilot or demonstration projects. Over 70% of these commercial scale projects are already operational.

Though seemingly mature, innovation continues in this industry. We see more pilot and commercial scale plants announced in recent years and trials of newer mixes, such as LC3, taking centre stage for many projects and slowly replacing conventional plants.

Calcined clay's economic and strategic value

According to the Green Cement Technology Tracker, the largest currently operational calcined clay plants are concentrated in emerging markets. The top 10 plants are listed in Table 1.

Table 1: Top 10 operational calcined clay production plants in the Green Cement Technology Tracker by annual calcined clay production volume

Project	Project type	Expected calcined clay production at full operation (million metric tons per year)	Total investment (USD, million)	Commissioning year
Holcim Guayaquil (Ecuador)	Brownfield	0.60	–	2025
Vicat CIPLAN Sobradhino (Brazil)	Brownfield	0.54	–	2009
Holcim Saint-Pierre-la-Cour (France)	Brownfield	0.50	50	2023
Cementos Argos Rioclaro (Colombia)	Greenfield	0.45	78	2020
CIMPOR Kribi (Cameroon)	Greenfield	0.40	115	2023
CBI Tema (Ghana)	Greenfield	0.40	110	2025
Votorantim Cimentos Porto Velho (Brazil)	Greenfield	0.37	33	2009
Votorantim Cimentos Nobres (Brazil)	Brownfield	0.32	17	2009
Nova Cimangola Luanda (Angola)	Brownfield	0.30	10	2022
CIMPOR Abidjan (Côte d'Ivoire)	Greenfield	0.30	–	2020

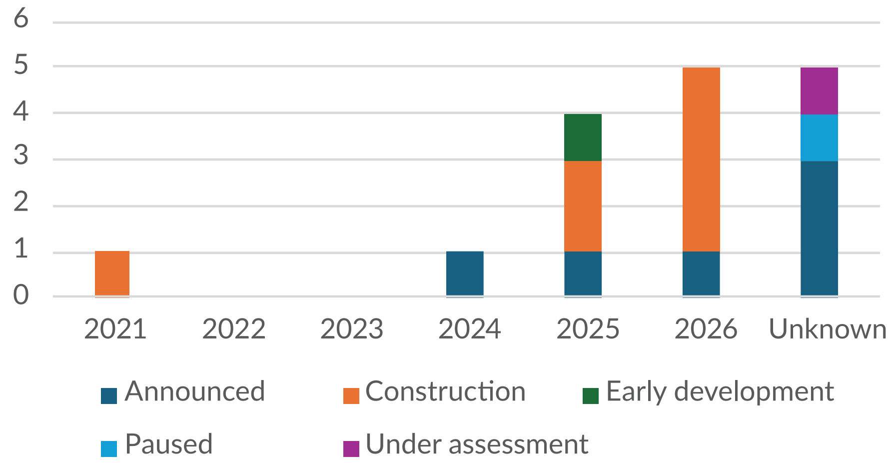
The largest plants that have gone online are located in Africa and South America. Many of the host countries have large concentrations of kaolin.

Nowhere is this clearer than in Ghana, which is the second largest importer of clinker (USD 288 million), after the European Union (EU). Imports made cement both expensive and emission-intensive, associated with the transportation of clinker. In 2025, Heidelberg Materials and CBI Ghana partnered to start production of calcined clay in Tema, Ghana, to reduce the clinker content in the final cement mix. A second large-scale calcined clay plant (1280 tons per day) in the same location, owned by CIMPOR Ghana, was scheduled to go online in 2025, but it is unconfirmed if this plant has started production yet. Both these plants indicate the strategic direction that Ghana has taken to reduce its dependence on clinker imports and take advantage of having rich kaolin deposits in the region.

Promising pipeline, possible slowdown

We expect at least six more projects to go online in 2026, should the intended commissioning goals be achieved. This includes major projects in Africa, Europe and the Americas. When all projects in active development are taken into consideration (i.e. projects not operational or paused), we find 14 projects currently in the pipeline that collectively represent at least USD 405 million of publicly disclosed investments and a total calcined clay manufacturing capacity of 3.3 million tons per year. This calcined clay manufacturing capacity, if successfully added, will take the total global calcined clay manufacturing capacity to 9.2 million tons per year.

Figure 2: Commercial scale calcined clay projects under development by planned commissioning year and project status



The five projects planned to go online in 2026 are listed below:

- PPC Riebeek West is a retrofit project at PPC's integrated plant in the Western Cape, South Africa, with a planned calcined clay production capacity of 365 000 tons per year, feeding into a 1.5 million-ton-per-year cement plant. The ZAR-3-billion (~USD 182 million) reconstruction is targeted for commissioning by end of 2026.

- A greenfield commercial calcined clay plant in Côte d'Ivoire will be developed by Yeshi Group's CIMCI under an engineering, procurement and construction (EPC) contract with CNBM Sinoma CBMI Construction, featuring a suspension calcination line with 1200 tons per day, paired with a 0.5-million-ton-per-year cement grinding unit, targeted for commissioning by end of 2026.

- CIMAF's existing Ouagadougou facility in Burkina Faso has a planned retrofit with a capacity of 900 tons per day of calcined clay and built under EPC contract by AVIC International Beijing with Humboldt Wedag (KHD) technology. The USD-50-million unit had its foundation stone laid in August 2024, with completion originally expected by August 2026.

- CIMAF has a second planned retrofit in its existing Bobo-Dioulasso cement plant in Burkina Faso, financed in part by a USD-37.4-million International Finance Corporation green loan. The project was scheduled for completion by mid-2026, a target that has now passed without a confirmed commissioning announcement.

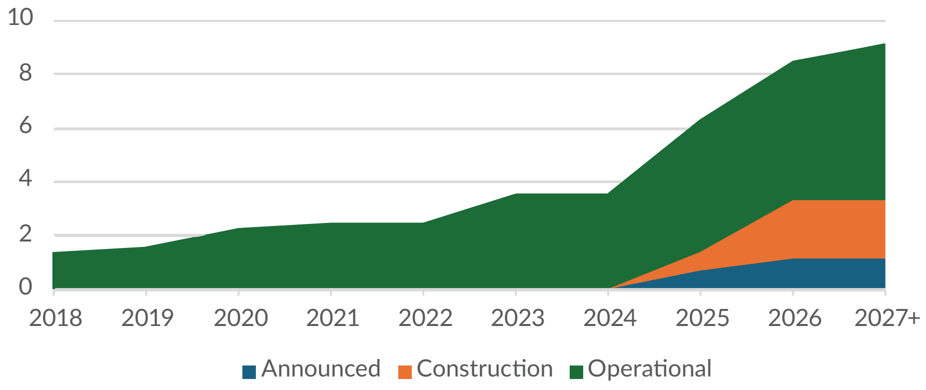
- CIMPOR has a planned brownfield conversion of the mothballed Line 2 kiln at CIMPOR's Souselas plant near Coimbra, Portugal, into a 1500-ton-per-day calcined clay production line; total investment is approximately EUR 40.6 million, within a broader EUR-360-million decarbonization programme. Described by CIMPOR in November 2025 as the largest calcined clay production line within the EU, it is planned to be commissioned in 2026.

Apart from the projects mentioned above, there are five projects that have either been delayed or their operational status cannot be confirmed using publicly available information and another five that do not have an announced planned commissioning date. More information on these projects is available in the Green Cement Technology Tracker dataset.

The commissioning of these large-scale projects should further inspire confidence in calcined clay kilns, particularly in the relatively new LC3 mix that is being deployed across many of the plants. However, it is difficult to project future commissioning, due to the drop in new announcements in 2025 and 2026.

Continued investments and ambition will be critical to achieve decarbonization of the cement industry. Given the 9.2 million tons per year of calcined clay production capacity that are currently operational and publicly announced and assuming an optimistic cement blend containing 35% calcined clay and 65% clinker, 9.2 million tons would provide sufficient calcined clay for approximately 26 million tons per year of cement production capacity with reduced clinker content. This cement production capacity is less than 1% of current global cement production, which stands at 4000 million tons per year (US Geological Survey, 2025). When including the CCUS-linked cement production capacity from our earlier report in May, we arrive at only 84 million tons per year of cement production where the carbon emissions have been reduced through the application of either of these two technologies, which is just over 2% of global cement production capacity.

Figure 3: Cumulative production capacity of calcined clay by planned commissioning year and project status



As shown in Figure 3, total planned and operational production capacity has increased notably since 2024. However, more ambition is clearly needed to keep the current pace of decarbonization in the cement industry.

Only one major commercial scale project has been cancelled, according to the Green Cement Technology Tracker: the National Cement Lebec Plant in California, US, after termination of the funding agreement with the US Department of Energy. However, the remaining major projects tracked continuing to progress through development.

Cost-effective pathway, to a degree

Several studies have concluded that the emissions reduction from blending calcined clay with clinker can range from 20% to 40%, with recent research mostly focused on various LC3 blends and the factors that can determine emissions reductions (Hosen & Chen, 2025; Sanchez et al., 2025). Some of these factors include the choice of fuel used in the calciners (Haverkamp et al., 2025), the kaolinitic content of the clay, the distance of the raw material from the kilns, and most importantly the blend of clinker to calcined clay in the final mix.

However, in almost all scenarios considered, the return on investment from the retrofitting of existing kilns with calciners is quite positive. CCUS can be added to LC3 to achieve deeper levels of decarbonization, but economic viability requires supportive measures such as carbon pricing or public procurement. Sanchez et al. (2025) show that carbon taxes can improve the financial attractiveness of LC3–CCUS configurations. While the objective of this report is not to do an extensive technoeconomic analysis and return on invested capital (ROIC) calculation for individual projects, as a general trend it can be observed that brownfield conversions are generally much cheaper compared to greenfield plants, as they only require the addition of a clay calciner to an existing plant as a retrofit, while greenfield projects include all the costs for building a new cement plant.

The decision to use calcined clay in the final mix is driven not just by economic and environmental considerations but the required strength, porosity and other physical properties of the final concrete. Compared to traditional OPC, there are some trade-offs that need to be made with calcined clay cement. For example, OPC gains its target strength at a faster setting time than calcined clay–blended cement.

However, quite often the properties of LC3 can be comparable or even better than OPC, even with this trade-off (Hosen & Chen, 2025). Organizations that set the standards for cement mixes need to take these factors into consideration. Standards such as the European CEM VI standard and the LC3-35 standard allow for clinker content to be as low as 35%. However, most commercially available calcined clay cements currently contain higher clinker shares, typically around 55–65%, reflecting the fact that lower-clinker formulations have only recently been adopted and are not yet widespread.

Even with optimistic assumptions about calcined clay deployment, significant emissions reductions will still need to be achieved in cement production. Assuming that existing calcined clay facilities achieve an average emissions reduction of 30% and that calcined clay accounts for 40% of the final cement blend, a substantial share of emissions associated with clinker production remains.

CCUS technologies provide much higher levels of emissions abatement, nearly eliminating all emissions in best case scenarios. But at significantly higher costs, they are cost prohibitive in price sensitive markets and difficult to achieve in the absence of strong financial de-risking and the presence of stable and high carbon pricing.

One benefit that is not captured in the Green Cement Technology Tracker but is worth mentioning is that unlike CCUS, calcined clay kilns offer a decreased operational expense (OPEX) while manufacturing the cement. Researchers from the Rocky Mountain Institute reported lower operating expenses of up to a third and lower carbon prices in regions with carbon taxes for LC3 as compared to OPC, driven by decreased energy and material costs (Randol et al., 2024). This makes it an inherently viable commercial decision for companies to make and is bolstered in regions that have carbon markets that reward emissions reductions associated with the replacement of clinker with calcined clay.

Further emissions reductions in calcined clay can be achieved by development of electrified calcination technologies. Examples include electric arc calciner technology or electrified linear calcination conveyers, which replace fossil fuels with electrified alternatives that, when paired with clean, renewable electricity, can reduce emissions even further.

Key success factors for a calcined clay kiln project

From the projects assessed in the Green Cement Technology Tracker, we observe a set of success factors that have led to successful project development and commercialization.

Government-funded de-risking of capital expenditures (CAPEX) was critical for the progress of many projects. While the amount of funding in most cases was relatively small compared to CCUS projects, we see that for major projects in the tracker that if the public funding was terminated, the project stalled and was eventually cancelled. In other cases, public and development finance has helped de-risk projects. CIMPOR's Souselas received partial funding from the EU Recovery and Resilience Fund. The Heidelberg Ghana Tema facility received partial funding from Norfund and Impact Fund Denmark (previously known as Investment Fund for Developing Countries, IFU). As for many emerging technologies, the LC3 project was supported by government agencies, such as the Swiss Agency for Development and Cooperation through its Global Programme in Climate Change.

Standards that allow for higher SCM or calcined clay material are critical public policy signals to greenlight calcined clay projects, as they indicate government confidence in the technology. These include the LC3-35, LC3-50, CEM II/C-M (EU), IS 18189:2023 (India), GS 1118 (Ghana) standards and others. Some standards allow clinker percentages as low as 35% and upwards of 50% for calcined clay. Without these standards, it is unlikely that companies would be willing to risk adoption of calcined clays that have inherently different properties from OPC.

Proximity to kaolin deposits clearly is a critical success factor. It should come as no surprise that most of the commercial calcined clay projects in the tracker are present in tropical countries where kaolin is present in large quantities in topsoils, making it a cheap and easy-to-access resource that requires no imports.

Green public procurement is a key demand-side driver of green cement adoption, as governments are often major customers of the construction materials industry. Many governments already have green public procurement policies in place for services, materials and products with low-carbon emissions. For example, Ireland's public procurement guidance specifies, "Concrete products procured by public bodies, or used in publicly produced construction projects … should in general specify a minimum of 30% clinker replacement". The guidance also discourages highly polluting standard cement (CEM I) and requires Environmental Product Declarations for all public concrete usage (Government of Ireland, 2024).

Conclusion

Calcined clay has earned its place as one of the most viable near-term pathways for cement decarbonization by being technically mature, commercially proven across multiple continents, significantly cheaper than CCUS, and increasingly supported by the standards frameworks needed to translate laboratory promise into market reality. Yet the scale gap remains stark, with the total operational and announced calcined clay projects in the Green Cement Technology Tracker amounting to less than 1% of global cement manufacturing capacity. Even when combined with the CCUS-linked capacity tracked in our companion report, the figure reaches only around 2% of global production.

Calcined clay is also, by nature, a partial solution, as it delivers emissions reductions in the 20–40% range rather than the deep abatement a net-zero trajectory ultimately demands, which means it must work in parallel with CCUS and other solutions, rather than as a substitute for them. The slowdown in new project announcements observed in 2025 and 2026 adds a further note of caution. Pipelines require replenishment, and if the deceleration reflects something structural rather than a data lag, the commissioning curve will flatten precisely when it needs to steepen.

The evidence from the Green Cement Technology Tracker makes clear that continued scale-up depends less on further technical validation, which the sector has largely achieved, and more on the deliberate alignment of four enabling conditions. These are: proximity and availability of high quality kaolin deposits; standards that permit higher clinker substitution rates and are actively used rather than merely adopted; green public procurement mandates that harness governments' substantial purchasing power to drive demand for lower-carbon cement; and sustained financing support for the project pipeline, particularly in emerging markets, where kaolinite is abundant and the costs of the final cement product are most sensitive and a key determinant in adoption by end users.

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