The Business Case for LC3

A Global Solution for Low-Carbon, Low-Cost Cement

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Executive Summary

The moment is now for limestone calcined clay cement (LC3). As the cement industry seeks to cut costs and decarbonize, LC3 offers a scalable, cost-effective solution that is primed and ready. This report analyzes LC3's financial and environmental benefits, ultimately showing that LC3 is a transformative opportunity for cement producers worldwide.

The analysis compares the costs of LC3, normalized to US dollars per ton (US$/t), with local cement benchmarks across four regions: North America, Europe, Latin America, and Africa. Modeling results of LC3 and conventional cement investments show capital and operating expenses across each step, including kiln retrofits, energy use, grinding, mixing, and more. Key financial metrics — payback period, internal rate of return (IRR), and CO_2 emissions avoided — provide a clear view of LC3's economic potential. Model scenarios built using the LC3 tool from Universidad Central de las Villas, Cuba, explore options for production through integrated plants and grinding stations, offering a realistic path to industry-wide adoption.

Key Study Results

LC3 demonstrates a compelling route to decarbonization with strong financial performance and significant emissions reductions:

- **Operational Cost Savings:** LC3 production can reduce operating expenses by up to 33%. Lower calcination temperatures for clay, reduced fuel use, and the absence of limestone mass loss in the process contribute to these savings, especially in regions where fuel costs are high.
- **Rapid Payback and High Returns:** LC3's lower production costs and emissions create financial advantages, with payback periods as short as a few months in favorable regions. On the higher end, payback periods can extend up to 10 years, depending on regional factors and capital requirements. IRRs are especially high in areas with low clay costs and high clinker import costs, although lower returns can occur in markets with higher retrofit and transportation expenses.
- **Resilience to Transportation Costs:** Even with clay sources located up to 200 km from the plant, LC3 remains more profitable than ordinary portland cement (OPC) because calcined clays are far cheaper than clinker. This geographic flexibility supports widespread adoption in varied markets.
- **CO_2 Emissions Avoided:** LC3 avoids emissions up to 32% compared with traditional cement blends, and over 40% compared with OPC. This avoidance is achieved through high clinker replacement (up to 50%) and calcined clay, which emits significantly less carbon than clinker production.

Key Strategic Insights

LC3 unlocks opportunities for new technologies and business models, supporting a shift toward more adaptable, efficient, and sustainable cement production:

- **Converting Clinker Kilns:** As the market adapts to lower clinker ratios with blends like LC3, reduced clinker demand may accelerate the closure of inefficient clinker plants; however, companies can proactively plan to convert these kilns for clay calcination.
- **Electrifying Clay Calcination Kilns:** Calcining clay requires lower temperatures than clinker production, potentially enabling the use of electric calciners powered by renewable energy.
- **New Business Opportunities:** Calcined clays can promote new business models to emerge such as modular kilns colocated on clay mines, potentially opening the low-carbon cement market to new, smaller-scale producers.

Introduction

LC3 is a low-carbon cement blend that combines calcined clay (kaolinite clay heated at lower temperatures) and limestone to significantly reduce the need for traditional clinker, the most carbon-intensive component of cement. By replacing up to 50% of clinker with these materials, LC3 dramatically lowers the energy consumption and CO_2 emissions associated with cement production. The emissions reduction potential of LC3 is substantial, with estimates suggesting a 30%–40% reduction in greenhouse gas (GHG) emissions compared with ordinary portland cement (OPC) can be achieved and deployed today.[1]

This reduction is vital because the cement industry is responsible for approximately 8% of global GHG emissions, making decarbonization efforts in this sector crucial for meeting global climate targets.[2] Cement is the primary ingredient in concrete, which is the world's most widely used construction material due to its strength, durability, and cost-effectiveness. As the world continues to urbanize — particularly in rapidly developing regions such as Asia, Africa, and Latin America — the demand for cement is expected to grow significantly. According to estimates, by 2050, more than 70% of the global population will live in cities, and developing nations will need to build vast amounts of infrastructure to accommodate this shift.[3]

The environmental impact of this construction boom could be enormous if traditional cement continues to dominate the market because its production is highly energy intensive and emits large amounts of CO_2 emissions due to the calcination of limestone. This makes the decarbonization of cement production a critical climate action that is essential to meeting the growing infrastructure needs of an urbanizing world without exacerbating climate change.

The findings show that replacing OPC with LC3 in concrete can reduce CO_2 emissions over 40% while maintaining or improving performance. The plant analysis also reveals up to 30% reduction in operational costs on average compared with OPC for the modeled scenarios.

LC3 offers a scalable, profitable alternative to OPC that can meet increasing cement demand while reducing the sector's contribution to global emissions, thus playing a pivotal role in building a more sustainable, resilient future for both developing and developed regions. The ability to reduce emissions without major changes to existing production infrastructure makes LC3 an ideal solution for widespread adoption, particularly in regions with high growth potential.

New RMI analysis, showcased in this report, explores the potential of LC3 to decarbonize the cement industry, drawing on case studies and interviews with early adopters to assess the financial viability and emissions reductions across seven cement plant scenarios in North America, Europe, Latin America, and Africa. The findings show that replacing OPC with LC3 in concrete can reduce CO_2 emissions over 40% while maintaining or improving performance. The plant analysis also reveals up to 30% reduction in operational costs on average compared with OPC for the modeled scenarios, with payback periods ranging from less than 1 year to 10 years without a carbon price, and from less than 1 year to 4 years with a carbon price.

The report also begins to examine LC3's broader potential impact on the industry and its future trajectory. With compelling evidence of significant cost savings, swift payback periods, and substantial emissions reductions, this report makes a clear business case for LC3 as a critical solution for the cement industry. To remain competitive and lead in the transition to sustainable construction, now is the time for stakeholders to invest in and scale LC3.

Cement and Concrete Production

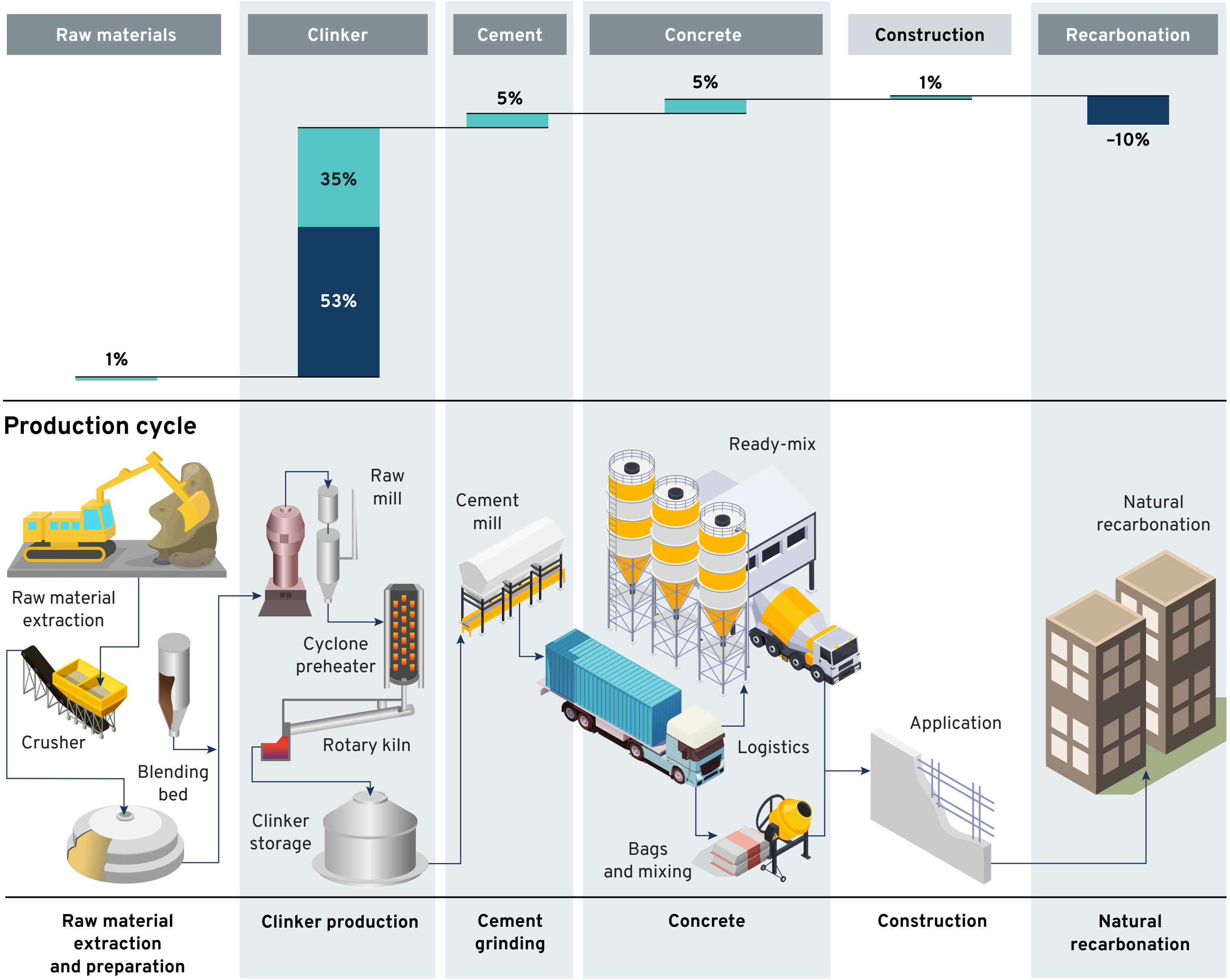
The industry standard for cement is OPC, which is made from two inputs: clinker and gypsum. At the heart of this process is the production of clinker, the key ingredient in OPC, which is formed by heating limestone (calcium carbonate) to high temperatures in a kiln. This heating, or calcination, causes the limestone to break down into lime (calcium oxide) and releases significant amounts of CO_2 in the process. The clinker is then cooled, ground, and mixed with gypsum to produce cement.

As shown in Exhibit 1, the clinker production phase is responsible for around 85%–90% of cement's total CO_2 equivalent (CO_2e) emissions.[4] Depending on plant age and efficiency, roughly 35%–40% of clinker production emissions come from the energy required to heat the kilns, traditionally sourced from fossil fuels such as coal and petroleum coke (petcoke), and the remaining 60%, known as process emissions, derive from the conversion of limestone into lime.[5] The remaining 10%–15% of cement's total CO_2e emissions come from the energy required to heat the kilns, traditionally sourced from fossil fuels like coal and petcoke, for phases after clinker production.[6]

Exhibit 1 Emissions from the full concrete and cement value chain

Percentage of total CO_2 emissions of the concrete and cement sector

■ Value chain included in analysis (Scope 1 and 2) ■ Process emissions ■ Energy emissions



Note: This illustration covers Scope 1 and 2 emissions and includes total raw material extraction. Other construction materials are not considered in this analysis.

RMI Graphic. Source: Mission Possible Partnership, *Cement and Concrete Sector Transition Strategy*

Decarbonization Pathways

To tackle these emissions, several key decarbonization pathways have been identified: reducing the clinker factor, improving fuel efficiency, developing alternative binders, and implementing carbon capture, utilization, and storage (CCUS). While each of these strategies offers unique opportunities to cut emissions at different stages of the cement-making process, this report focuses on high-impact pathways to reduce clinker in cement.

Strategies for Reducing Clinker in Cement

Clinker production is the most carbon-intensive step in cement manufacturing; thus, reducing the ratio of clinker in cement can have a major impact on overall emissions. One of the most effective strategies for reducing CO_2 emissions in cement production is lowering the clinker factor by using blended cements. Lowering the clinker content in cement production can also be implemented in the near term, whereas decarbonization strategies such as CCUS or alternative binders will become available in the medium-to-long term.

Blended cements are produced by partially substituting clinker with supplementary cementitious materials (SCMs), which contribute to the cement's final properties while significantly reducing the emissions associated with clinker production. SCMs can replace a substantial portion of clinker, offering a critical pathway for emissions reductions by leveraging materials with lower carbon footprints. Moreover, most SCMs can offer significant cost savings compared with clinker, making their use an attractive option for reducing both emissions and production costs.[7]

Traditional SCMs

Several traditional SCMs have been used for decades to create blended cements:

- **Fly Ash:** A by-product of coal combustion in power plants, fly ash has been widely used as an SCM due to its pozzolanic properties, which help improve the strength and durability of concrete. Fly ash can replace up to 30%–35% of clinker in cement.[8] However, its availability is declining due to the global phaseout of coal power plants and concerns exist about its sustainability as a fossil-derived material.

- **Ground Granulated Blast Furnace Slag (GGBFS):** Another common SCM is GGBFS, a by-product of the steelmaking process. It has the potential to replace 45%–95% of clinker, making it one of the most effective clinker substitutes in terms of emissions reduction.[9] However, the supply of GGBFS is linked to traditional steel manufacturing, leading to concerns about the availability and stability of GGBFS as a long-term solution as the steel sector decarbonizes. Additionally, it can be more expensive than other SCMs due to its processing requirements and limited availability.

- **Limestone:** Limestone, when finely ground, can be used as an SCM in small quantities (5%–15%) to reduce the clinker content.[10] Although it does not have the same pozzolanic properties as fly ash or slag, its abundance and relatively low processing costs make it an attractive option. However, the substitution range for limestone is relatively low.

Emerging SCMs

As the supply of traditional SCMs faces constraints, the industry is increasingly looking to emerging SCMs such as calcined clays and natural pozzolans.

- **Calcined Clays:** Calcined clays, especially when combined with limestone, offer a highly scalable and impactful solution. LC3 can replace 30%–40% of clinker, making it a significant contributor to emissions reductions.[11] LC3 is particularly attractive because both limestone and clay are abundant raw materials, which means this technology has the potential to be widely adopted across diverse geographies.[12] Calcining clays requires lower temperatures than clinker, reducing the overall energy demand and associated production emissions.[13]

- **Natural Pozzolans:** Natural pozzolans, such as volcanic ash and other siliceous materials, can replace 30%–40% of clinker.[14] Like calcined clays, they have been used historically in concrete production and are increasingly being explored as a sustainable SCM. However, the availability of quality pozzolans is limited in many geographies.

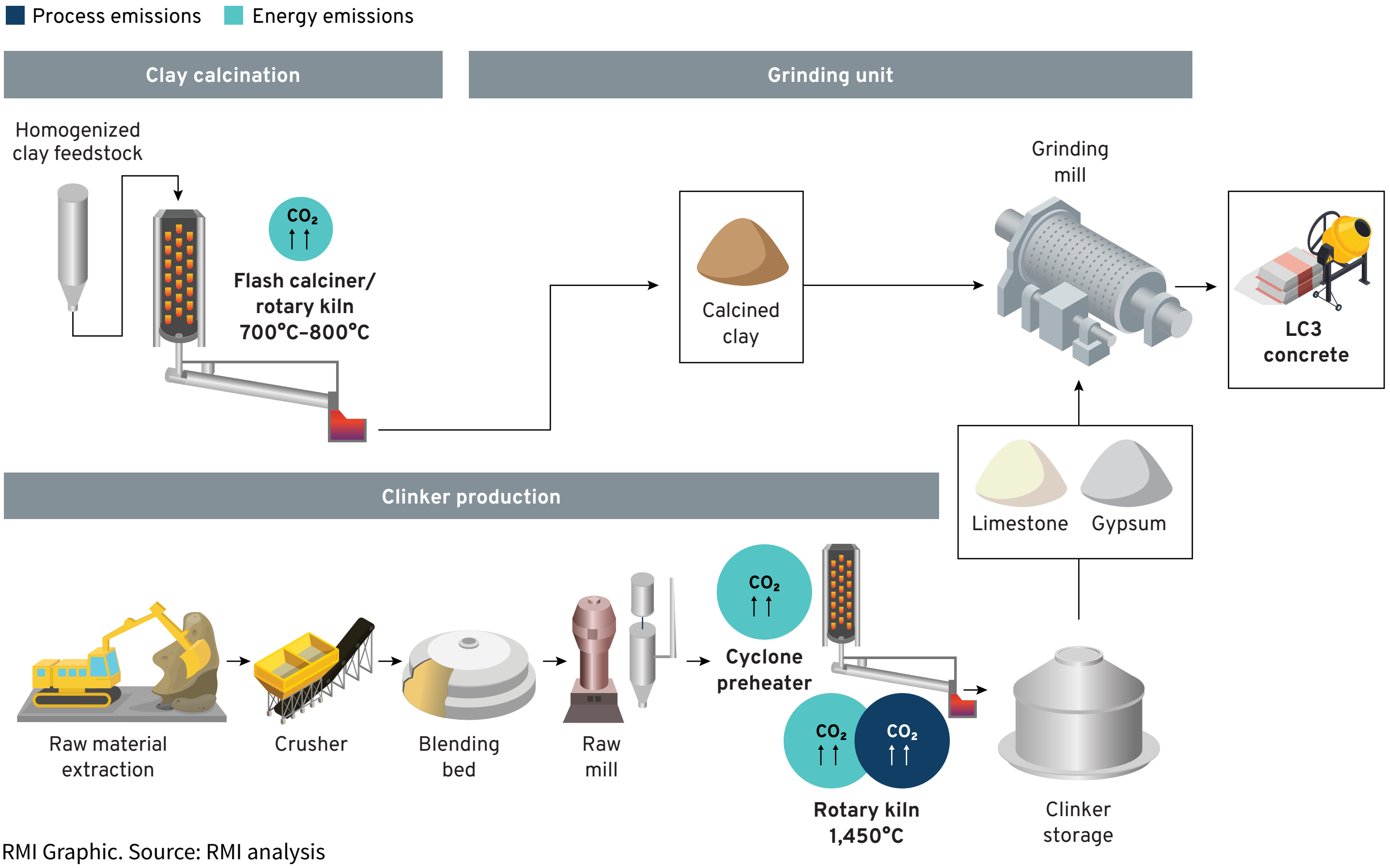
Other SCMs

Many innovators are exploring synthetic and engineered SCMs to further reduce the clinker factor, and even using SCMs as a mechanism to store carbon.[15] Although they hold significant potential to further reduce clinker usage and emissions, these SCMs face challenges related to technology readiness, cost, market adoption and scalability, and limited real-world application. Their future role in decarbonizing cement will depend on overcoming these barriers and proving their effectiveness in large-scale use.

Clay Calcination

Two primary equipment options exist for the calcination of clay: the flash calciner and the rotary kiln (see Exhibit 2). These systems, already available in today's market, cater to different production contexts. The flash calciner option requires smaller granulated clay, whereas the rotary kiln approach, a technology already used at cement plants for the clinkerization process, can accommodate a larger grain size and offers the potential to repurpose existing clinker kilns. Ultimately, the necessary adjustments and additions for incorporating calcined clay depend on a plant's unique infrastructure and equipment.

Exhibit 2 **Depiction of LC3 production process**



RMI Graphic. Source: RMI analysis

The Business Case for LC3 in Different Markets

As the cement industry explores various decarbonization pathways, LC3 stands out as a key solution that aligns with the industry's immediate and long-term goals. Among the strategies aimed at reducing clinker content, LC3 offers significant advantages in terms of scalability and ease of integration. Unlike other SCMs, which face supply constraints, LC3 relies on abundant raw materials — limestone and clay. This scalability and accessibility give LC3 a clear business advantage for broad implementation, particularly in regions where limited limestone deposits drive up clinker import costs, such as Africa.[16] By adopting LC3, these regions could significantly reduce costs while also achieving substantial environmental benefits, making it a financially and environmentally sound investment.

LC3 is rapidly becoming market ready globally, with Colombia showcasing the most extensive use due to its adoption by Colombian cement producer Argos Cementos. LC3 has been applied in high-rise buildings, highways, and tunnels, demonstrating its viability in large-scale infrastructure. Full-scale production is underway in a handful of cement plants (see Exhibit 3), with additional projects recently announced in the United States, supported by Department of Energy (DOE) funding.

Exhibit 3 Features of four cement companies currently producing or planning to produce LC3 and calcined clay blends

Plant	Location	Start of Operation/ Production	LC3 or Other CCB*	Key Features
CBI Ghana	Tema, Ghana	2025	LC3	• Expansion of an existing OPC plant • Cement blends with 60%–70% clinker content • 30%–40% CO_2 emissions reduction per ton
Holcim	Macuspana – Tabasco, Mexico	2023	LC3	• Cement blend with 50% clinker content • 50% CO_2 emissions reduction in combination with alternative fuels and waste heat recovery
	Saint-Pierre-la-Cour, France	2023	CCB	• 50% CO_2 emissions reduction in combination with alternative fuels and waste heat recovery
	La Malle, France	2021	CCB	• First calcined clay cement line in France • 30% CO_2 emissions reduction in combination with alternative fuels and waste heat recovery
Fortera	Redding, CA, US	2023	CCB	• Reactive calcium carbonate (vaterite) can be used to form CCB: 45% clinker, 5% gypsum, 25% vaterite, 25% calcined clay • 36% CO_2 emissions reduction • Improved workability versus comparable CCB using interground limestone
Vicat	Sobradinho, Brazil	2009	CCB	• Rotary kiln used for calcination • Durability features such as resistance to chloride ingress and alkali silica reaction • Improved early-age strength • 16% CO_2 emissions intensity reduction
	Xeuilley, France	2024	LC3	• Flash calcination technology • Supported by grants from ADEME, the French national agency for the environment, and the EU because of its environmental benefits

*Note: CCB is calcined clay blend.

RMI Graphic. Source: RMI interviews

An overview of the regulatory environments for each region is provided below, setting the stage for a more detailed case study analysis of North America, Europe, Latin America, and Africa, which follows later in the report.

North America

Prescriptive standards are dominant in North America, but recent DOE funding is boosting momentum for LC3 in the United States.

North America operates under highly prescriptive standards that pose challenges to the adoption of innovative materials like LC3. The American Concrete Institute (ACI), which sets key concrete design and construction standards, the International Code Council's (ICC) International Building Code, which governs construction safety regulations, and ASTM International, which develops and publishes widely recognized consensus-based standards for materials, products, systems, and services, play crucial roles in shaping the cement and concrete markets. While these standards ensure quality and safety, they also create barriers to commercialization of more sustainable technologies like LC3.

One major specification governing blended cement is ASTM C595, which defines requirements for various types of blended hydraulic cement and limits clinker replacement. In contrast, ASTM C1157 represents a shift toward performance-based standards, offering more flexibility for materials and chemical additions to clinker. For instance, ASTM C1157 allows cement producers to target specific needs, such as high early strength or high sulfate resistance, without mandating materials or mix proportions. ASTM C1157, around since 1992, is starting to see more adoption in the US construction industry with sophisticated purchasers such as technology companies building out data centers. However, adoption could be more widespread as many engineers, contractors, and regulators continue to rely on traditional prescriptive standards.

Despite these limitations, LC3 is gaining traction in the United States. In March 2024, the DOE's Industrial Demonstrations Program signaled strong support for LC3 when awarding $1.5 billion to six cement decarbonization projects, three of which focus on producing calcined clays, a key component of LC3.[17] Driven by federal and state "buy clean" policies and growing corporate commitments, end-users are increasingly seeking lower-carbon options that can be specified and implemented today, positioning LC3 as a timely solution.[18]

Fortera produces a reactive form of calcium carbonate called vaterite, which can be blended with calcined clay in lieu of limestone, achieving a mixture that replaces 50%–70% of clinker. The company's ReAct™ (45% clinker, 5% gypsum, 25% vaterite, and 25% calcined clay) reduces emissions by 36% compared with OPC. Fortera uses its ReCarb® process to produce vaterite by recombining CO_2 emissions from the kiln with calcium oxide, resulting in a highly reactive, spherical mineral that can reduce water demand, increase early strength, and improve workability compared with calcined clay blends made using ground limestone. The company recently launched a small commercial-scale plant to produce vaterite within an existing cement plant in Redding, California. As with many new cement technologies, some of the potential benefits of this material, and the economics and practicalities of producing it at scale, are not fully proven in real-world applications.

In Mexico, standards such as NMX-C-414 set strict requirements for cement composition, with limitations on clinker replacement that similarly restrict LC3's adoption. However, some Mexican cement producers are actively exploring performance-based approaches to demonstrate LC3's compliance with structural and durability requirements within the current regulatory framework, aiming to accelerate LC3 acceptance.

Holcim has identified LC3 and CCB as a solution in line with its industry-first 2050 net-zero targets, validated by the Science Based Targets initiative. One of the ways Holcim is decarbonizing cement is by increasing the use of low-emissions raw materials, such as calcined clay, in its ECOPlanet line of low-carbon cement.

At its Macuspana plant in Tabasco, Mexico, Holcim introduced ECOPlanet Fuerte Más, Latin America's first calcined clay ECOPlanet cement. This LC3 blend reduces CO_2 emissions by 50% compared with OPC, achieved through clinker reduction, alternative fuels, and waste heat recovery. Key differentiators of ECOPlanet Fuerte Más include a red color (due to iron in the clay), higher yield, and enhanced strength. Holcim's testing shows that LC3 requires specific plasticizers at higher dosages for optimal workability, and that clay heterogeneity can be managed by homogenizing it based on application needs.

Europe

Europe's progressive standards and the EU's Green Deal are accelerating LC3 adoption across the region.

Europe presents a significant opportunity for the adoption of LC3, driven by the EU's Green Deal and aggressive carbon reduction targets. One of the key developments in the region is the introduction of EN 197-5, a revision to European cement standards that permits the use of LC3-50 (up to 50% clinker replacement) under the classification CEM II/C-M(Q-LL). This new standard is crucial for accelerating the use of calcined clay and limestone in cement blends, positioning LC3 as a viable, low-carbon alternative to traditional cement across Europe. Updating prescriptive standards such as EN 197-1 (cement composition and clinker substitutes) and EN 206 (concrete mix and performance requirements) to include LC3-50 will be essential to enabling broader adoption of LC3.

In France, regulatory drivers such as the RE2020 building emissions standard and rising EU carbon costs (around €90/ton as of early 2024) influenced Holcim's decision to expand calcined clay cement production. Since 2021, Holcim's La Malle plant has produced calcined clay cement using a clinker kiln, creating a ternary blend with clay and slag to meet the local market's CO_2 reduction and durability requirements. In 2023, Holcim commissioned a new calciner at its Saint-Pierre-la-Cour plant, supported by national grants, using patented technology to produce calcined clay with a nearly zero net CO_2 footprint. By leveraging 100% alternative fuels and waste heat recovery, this facility will produce an LC3 blend and other calcined clay cements tailored for various market segments in the Paris region.

Building on recent regulatory advancements, the industry is now making significant strides toward low-carbon cement production. Lafarge France, a subsidiary of Holcim, launched Europe's first calcined clay cement line at its Saint-Pierre-la-Cour plant, which is expected to produce up to 500,000 tons of LC3 annually. In February 2024, NeoCem announced another 200,000-ton calcined clay plant in France.[19] These plants exemplify how updated standards like EN 197-5 are facilitating the production and commercialization of LC3 cement.

With the UK's construction sector under increasing pressure to meet sustainability targets, LC3 is emerging as a prime candidate for integration into future building codes. The UK's more flexible approach to material standards compared with some other European countries makes it a promising market for early adoption of LC3, particularly as it seeks alternatives to traditional cement that align with its net-zero goals.[20]

Vicat is currently constructing an LC3 plant in Xeuilley, France, with operation anticipated to begin by the end of 2024. This plant uses flash calcination technology. This project was supported by a grant from ADEME, the French national agency for the environment, and the EU, on the basis that the production of calcined clay cement provides environmental benefits. Some challenges to producing LC3 at this plant have been the required administrative authorization to produce calcined clay, the need to update cement and concrete standards to apply to calcined clay blends, and the lack of French market receptivity to a new cement blend.

Latin America

Latin America's growing emphasis on sustainability is creating opportunities for LC3 adoption, though outdated standards in some countries still present challenges.

Latin America is becoming a favorable market for LC3 adoption, driven by a mix of local and international standards that govern cement production and an increasing focus on sustainability. Brazil, as one of the largest cement markets in Latin America, holds significant potential for LC3 due to its use of performance-based standards. These standards, particularly those that regulate concrete performance, allow for greater flexibility in the use of blended cements, positioning Brazil as a leader in low-carbon cement innovation within the region.

Vicat's calcined clay plant at the Sobradinho, Brazil, plant has been in operation since 2009, producing a calcined clay binary mix. This plant uses a rotary kiln for calcined clay production. Vicat's calcined clay blends show the typical durability features, such as resistance to chloride ingress and alkali silica reaction, and strength properties as other cements employing SCMs. The blend also has a higher Blaine value, which measures the specific surface area of the cement particles to determine fineness and air permeability.

Other Latin American countries, including Argentina, Chile, and Peru, are beginning to implement sustainability-focused policies aimed at reducing CO_2 emissions in the construction sector. These countries are exploring alternative cementitious materials as part of broader national strategies to decarbonize their economies. The momentum generated by these sustainability policies is opening the door for LC3 to be integrated into their cement markets.

However, in many parts of Latin America, outdated prescriptive standards remain a challenge. These older regulations, which mandate specific material compositions and proportions, limit the adoption of innovative technologies like LC3. Countries with such prescriptive frameworks may face delays in LC3 adoption until regulatory revisions or new performance-based standards are implemented. The modernization of these standards, along with advocacy and industry engagement, will be essential for the broader acceptance of LC3 across the region.

Africa

Africa's push to modernize standards could enable broader LC3 adoption, with early promise in South Africa and Kenya.

Africa faces unique challenges and opportunities when it comes to adopting LC3. Many countries on the continent still rely on older prescriptive standards based on OPC, which could slow the introduction of innovative materials like LC3. These standards often mandate specific material compositions, leaving little room for alternative cement blends critical to reducing CO_2 emissions in the construction sector. However, there is growing momentum toward modernization and harmonization of standards across the region.

The African Organization for Standardization is actively working to harmonize standards across the continent. This initiative aims to create a unified framework that could pave the way for the introduction of alternative materials like LC3, allowing countries to leapfrog older technologies and adopt more sustainable solutions. Once harmonization efforts advance, LC3 could gain broader acceptance across Africa, particularly as part of efforts to align with global climate goals.

Leading markets such as South Africa and Kenya show promise for early LC3 adoption. South Africa, with its more advanced performance-based standards, is well positioned to integrate LC3 into its construction sector. The flexibility offered by performance-based standards provides a conducive environment for the introduction of new technologies, including LC3, which could play a key role in South Africa's ongoing efforts to decarbonize its cement industry.

In Kenya, growing interest in sustainable construction and government efforts to encourage low-carbon building materials could drive demand for LC3. Kenya's construction sector, which is expanding rapidly, is increasingly focused on sustainability, and LC3 offers a cost-effective solution in a region where expensive clinker imports are common due to limited limestone availability. The ability to use locally available clays to partially displace clinker consumption makes LC3 an economically attractive option for Kenya and other African nations where infrastructure growth is coupled with high material costs.

Despite challenges, including outdated standards and the need for regulatory modernization, Africa's focus on economic development, infrastructure growth, and sustainability presents a compelling case for LC3.

CBI Ghana upgraded a plant to include LC3 equipment in an expansion project in Tema, Ghana, roughly 30 km (~19 miles) from the industrial city of Accra. The plant, which will be commissioned in 2025, will have a large calciner with a capacity of 400,000 tons per year. This project will yield cement blends with 60%–70% clinker, yielding a 30%–40% reduction in CO_2 emissions per ton of cement compared with OPC. Both clay and limestone for this plant are available around 90 km (~56 miles) from the plant. The clay used in this plant has a low kaolinite content of 35% on average. The plant uses natural gas as a fuel source for calcination. On the regulatory level, the company is working with policymakers on policies that promote sustainability, but no financial incentives were available for equipment installation for this project. CBI Ghana identified a few differences in the physical properties of LC3 at this plant, such as a relatively high water demand, with an expected water consistency of approximately 36%–37% compared with the typical 28%–33% for cement in the Ghanaian market.

The adoption of LC3 across the globe will depend heavily on the ability to align performance-based standards with the material's capabilities, while also advocating for updates to prescriptive standards where they exist. Regions with more flexible performance-oriented frameworks are likely to see earlier adoption of LC3, whereas areas with stricter prescriptive codes may require more time and effort to overcome regulatory barriers. Nonetheless, the global push for decarbonization and LC3's economic and environmental benefits present a strong case for its integration into the cement industry's future.

Study Approach

Methodology

Although multiple cement companies have begun producing LC3 at scale, little information is available about their production processes. To address this problem and to provide some insight into the production numbers, this report first compares the cost (normalized to US$/t) of LC3 versus locally representative OPC benchmarks. The business case analysis considers investments that go into an OPC plant versus an LC3 plant in four geographies. The financial model was developed by splitting the LC3 production process into clinker, calcined clay, and limestone, and accounting for the capital expenditures (CAPEX) and operating expenses associated with each material, as well as the steps in the process after mixing in the grinding unit. Additionally, the payback period, IRR, and CO_2 emissions avoided are estimated and compared for the different scenarios. The case studies were conducted with the goal of exploring the challenges and opportunities that companies have encountered while developing LC3 systems, technical aspects of production, market analysis, environmental impact analysis, and drivers toward LC3 use.

LC3 Cement Plant Case Studies and Model Scenarios

Exhibit 4 summarizes the seven LC3 cement plant case studies and includes each plant's region, weighted average cost of capital, type of calciner, a technology description, and the nomenclature.

Exhibit 4 **Summary of LC3 cement plant case studies**

	Region	Weighted Average Cost of Capital (WACC)	Calciner	Technology Description	Nomenclature
Plant 1	Africa	14%	Rotary	New rotary kiln installed at a grinding station *(grinding-new)*	AF-GU-N(R)
Plant 2	Africa	14%	Rotary	Retrofit of an existing rotary kiln at an integrated plant *(integrated-retrofit)*	AF-INT-R(R)
Plant 3	Africa	14%	Flash	New flash calciner installed at a grinding station *(grinding-new)*	AF-GU-N(F)
Plant 4	Latin America	12%	Rotary	New rotary kiln installed at an integrated plant *(integrated-new)*	LA-INT-N(R)
Plant 5	Latin America	12%	Rotary	New rotary kiln installed at an integrated plant *(integrated-new)*	LA-INT-N(R)
Plant 6	Europe	8%	Flash	New flash calciner installed at an integrated plant *(integrated-new)*	EU-INT-N(F)
Plant 7	North America	6%	Rotary	Retrofit of an existing kiln at an integrated plant, installing a new grinding unit and a storage unit *(integrated-retrofit kiln-new grinding and silo)*	NA-INT-GU-SU-N(R)

Note: The nomenclature is structured "Region-Plant Type-New/Retrofit(Kiln Type)" with the following definitions: Region: AF = Africa, LA = Latin America, EU = Europe, NA = North America; Plant Type: GU = grinding unit, SU = storage unit, INT = integrated; New/Retrofit: N = new, R = retrofit; and Kiln Type: F = flash calciner, R = rotary kiln.

RMI Graphic. Source: RMI analysis

Assumptions

For modeling the scenarios for the plants in Exhibit 4, the remaining life span of each plant is assumed to be 20 years, with maintenance costs at the plant's half-life estimated to be 15% of the original capital expenditure. The scenarios are analyzed using the LC3 tool developed by researchers at Central University of Las Villas, Cuba. To ensure that the scenarios mirror the real world, they are modeled around the details of existing cement plants at these locations and encompass possible ways to produce LC3 at an integrated plant or a grinding station. The cement plants are presumed to have relatively modern dry-kiln processes. The need for drying and other clay preprocessing (based on local/mine differences) is not detailed here.

Plant-Specific Considerations

Integrated Cement Plants and Grinding Stations

The technical requirements for an LC3 retrofit vary depending on the type of plant. Integrated cement production plants can typically use their existing solid fuel preparation systems for calcined clay production. However, grinding stations that add a calciner, often located far from the main cement plant, may need to rely on natural gas or liquid and heavy fuel oil rather than coal, petcoke, or alternative waste and biomass fuels. This reliance on different fuel sources can affect the economics and emissions profile of the plant.[21]

Flash Calciners

Flash calciners are efficient but come with specific limitations. They cannot process uncrushed or undried materials, so if a plant lacks crushing and drying equipment, a rotary kiln may be a better fit. Flash calciners also operate at lower temperatures, which restricts their use of alternative fuels in regions with environmental regulations designed to prevent the formation of dioxins and furans. However, biomass fuels that do not produce toxic intermediate combustion products may offer a viable alternative fuel option for flash calciners in some regions.[22]

Rotary Kiln Systems

Rotary kilns are more flexible in terms of material processing but have their own challenges. Maintaining consistent temperature and homogeneity is difficult, and these kilns generate harmful nitrogen oxides (NO_x) during production. To reduce NO_x emissions, transitioning to biomass fuels with low nitrogen content is effective and, in some cases, necessary. For example, replacing coal with biomass containing 0.1% nitrogen can lead to a 90% reduction in NO_x emissions. Additionally, for mothballed cement kiln systems being repurposed for metakaolin production, important factors to consider include raw material handling, raw mill type, kiln dimensions, cooling systems, and final material handling.[23]

Grinding Systems

The grinding process for LC3 presents unique technical challenges. Since clay and clinker have different hardness levels, grinding them together can lead to overgrinding the clay, which increases surface area and requires more water and superplasticizers in the final blend compared with OPC. To prevent this, clinker should be ground separately before blending with calcined clay and limestone, although this typically requires additional grinding capacity. If separate grinding is not possible, the materials can be fed into the grinder at different times to minimize differences in fineness.[24]

Equipment and Fuel Considerations

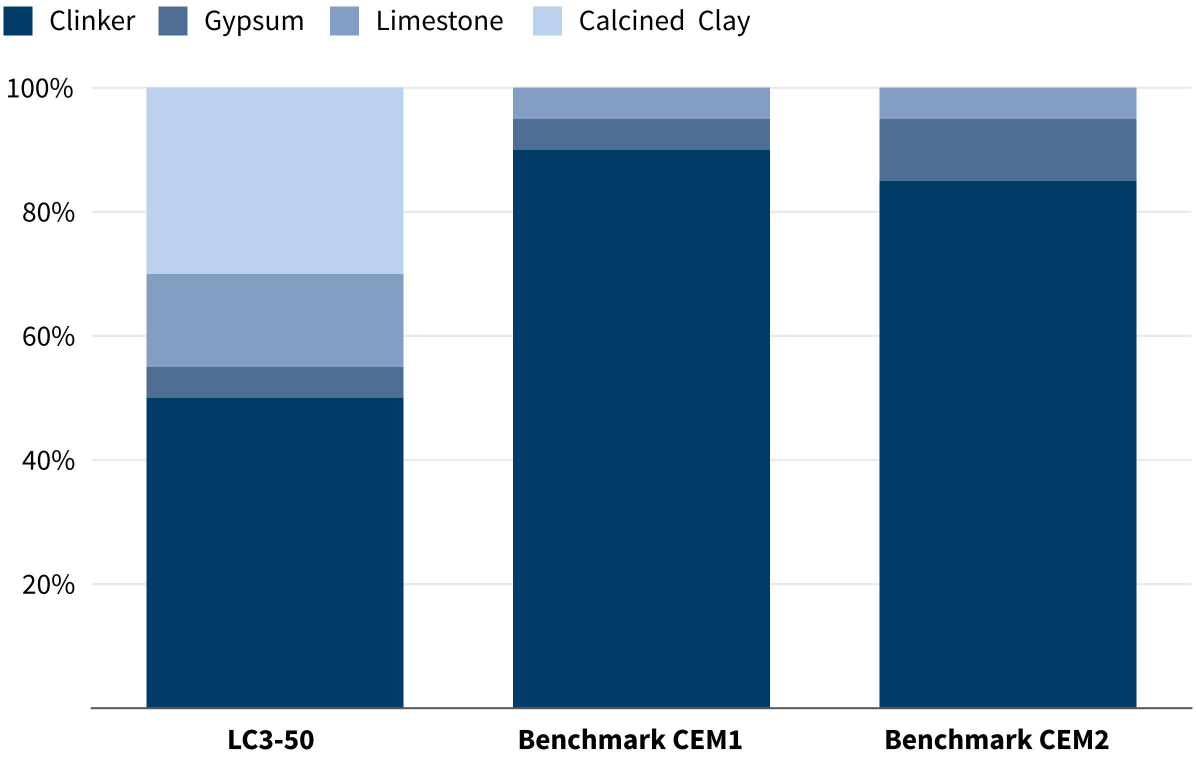
The choice of equipment and fuel varies by plant. Flash calciners and rotary kilns have different operational needs and emissions profiles. Smaller calcination systems, regardless of technology, tend to be less energy efficient and have higher engineering costs per ton of output. Operations and maintenance costs also differ by equipment type and must be factored into planning.[25]

Comparative Analysis of LC3 and Benchmark Cements

Exhibit 5 schematically represents the composition of LC3 compared with the most widely adopted Type 1L cement counterparts used in North America and Europe. Exhibit 6 compares contributions of different factors with overall emissions produced by different blends of cement, including one blend of LC3. LC3 has a reduced emissions intensity compared with OPC and a comparable if not lower emissions intensity than cement blends, including the common SCMs GGBS and fly ash.

Exhibit 5

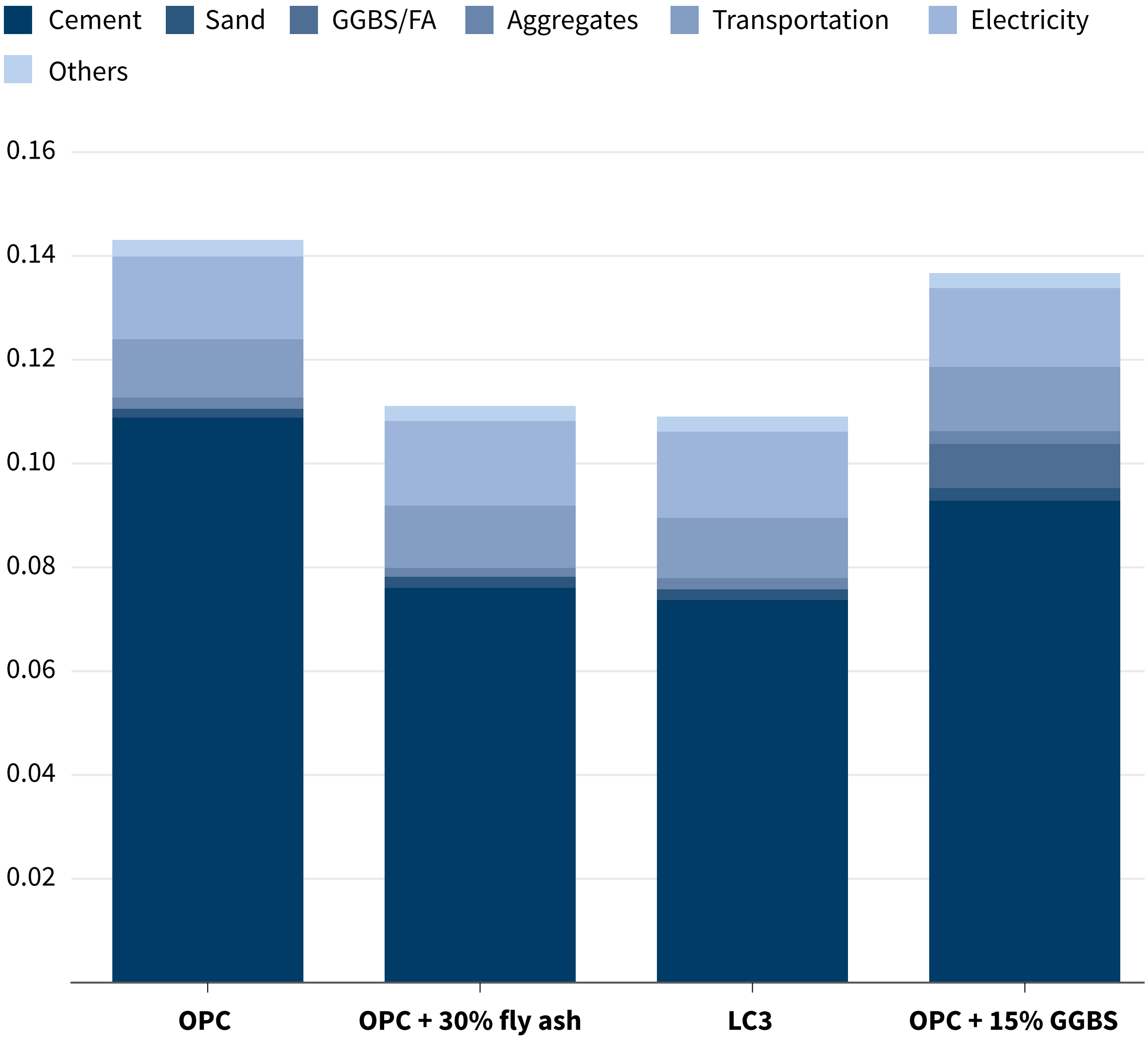
Composition of LC3-50 vs. Benchmark Cements



RMI Graphic. Source: RMI interviews with stakeholders conducted in 2023

Exhibit 6

Contributions of different factors to overall emissions produced by different types of cement (kg CO_2e/kg)



RMI Graphic. Source: Scrivener et al.

Although its environmental advantages are clear, the economics of LC3 production can vary considerably based on geographical nuances and production method. This study undertakes a high-level financial analysis of LC3 production examples across four geographies: Africa, Latin America, Europe, and North America.

Results of the Seven Case Studies

The production capacity, fuel mix,[i] and rate of replacement of clinker are taken from academic literature and outlined in Exhibit 7.[26] Capital expenditures are also shown in Exhibit 7 and are extrapolated from industrial research of the cement plants in the region, considering parameters such as cost of equipment and technology, land acquisition, installation labor, and regulatory compliances, among others.[27] Each location, with its unique economic climate, raw material availability, labor costs, and regulatory landscape, offers a differentiated perspective on the financial dynamics of LC3, among other factors. To compare aspects such as CO_2 emissions reductions and cost per ton, LC3 is measured against typical cement mixes (Benchmark CEM1) in the African and Latin American regions and against typical 1L mixes (Benchmark CEM2) in the European and North American regions. This approach is used because the comparison is targeted to reflect the most commonly used cements in specific geographical locations, which is delineated in Exhibit 7.

Exhibit 7 **Summary of aspects of LC3 vs. Benchmark CEMs at seven model cement plants**

	Region	Cement Type	Clinker (%)	Limestone (%)	Calcined Clay (%)	Gypsum (%)	Fuel Type	Strength Category (MPa)	CAPEX (US$ Million)
Plant 1	Africa	Benchmark CEM1	90	5	0	5	Mix	42.5	12
		LC3	65	10	20	5			
Plant 2	Africa	Benchmark CEM1	90	5	0	5	Coal	42.5	5
		LC3	65	10	20	5			
Plant 3	Africa	Benchmark CEM2	85	10	0	5	Gas	42.5	24
		LC3	50	15	30	5			
Plant 4	Latin America	Benchmark CEM1	90	5	0	5	Coal	42.5	78
		LC3	65	10	20	5			
Plant 5	Latin America	Benchmark CEM1	90	5	0	5	Coal	42.5	12
		LC3	65	10	20	5			
Plant 6	Europe	Benchmark CEM2	85	10	0	5	Mix	52.5	23
		LC3	50	15	30	5			
Plant 7	North America	Benchmark CEM2	85	10	0	5	Mix	42.5	110
		LC3	50	15	30	5			

Note: MPa is megapascals.
RMI Graphic. Source: RMI analysis

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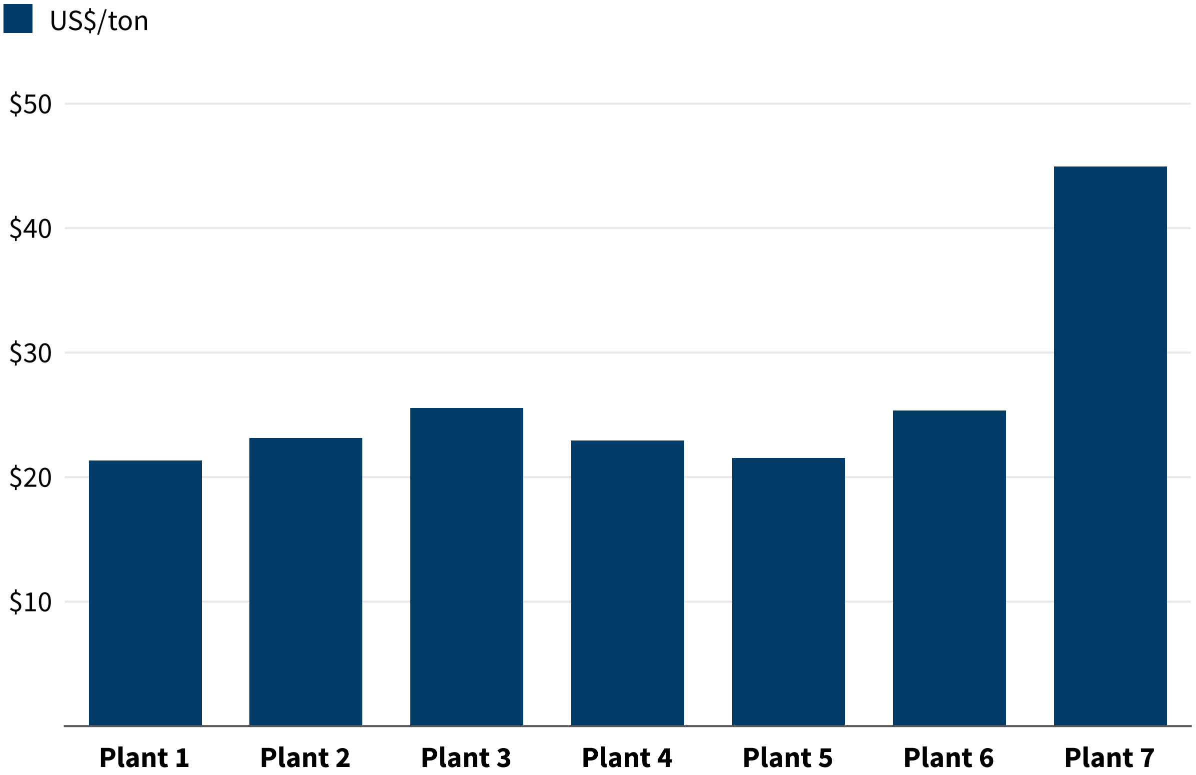
[i] The analysis includes scenarios in which the kiln is fueled via coal, natural gas, a mix of the two, or a mix of coal and an alternative fuels and raw materials source.

Economic Benefits of LC3 for Cement Producers

Cost Savings

Exhibit 8

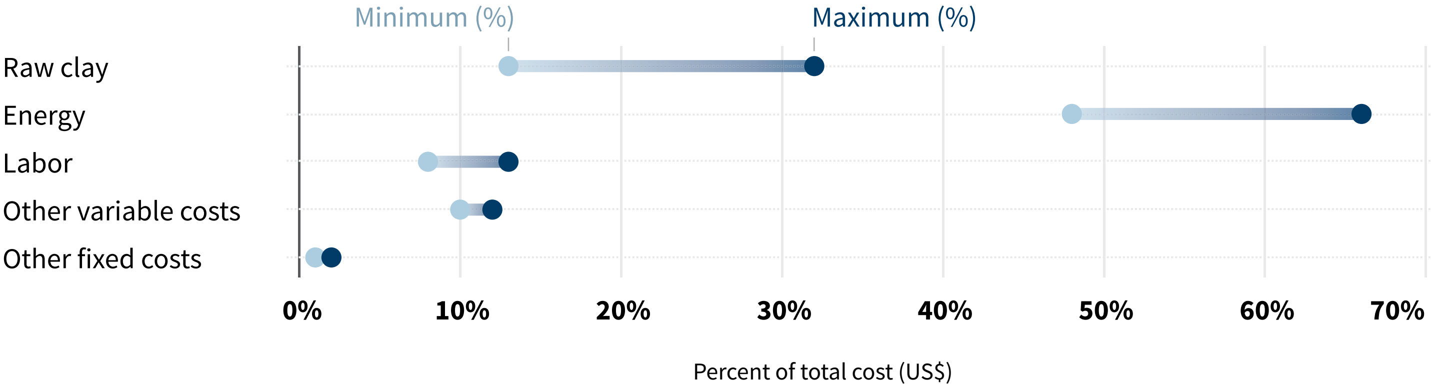
Cost of calcined clay at cement plants



RMI Graphic. Source: RMI analysis

Exhibit 8 illustrates that the cost for producing calcined clay varies from $21 to $25 per ton in most instances. Plant 7 is an outlier, with costs escalating to $44 per ton. This higher cost is attributed to the elevated price of suitable raw clay in North America, which ranges from $15 to $25 per ton due to relatively limited current production of clays despite their abundance. Analysis of this data reveals that the predominant cost factors are the energy requirements for the calcination process and the raw materials, which constitute approximately 70%–80% of the total calcination costs, with labor only accounting for about 10% of the cost. Examples of other variable costs and other fixed costs include mining royalties and concessions, wear parts, and scheduled maintenance.

Exhibit 9 **Breakdown of clay calcination costs**

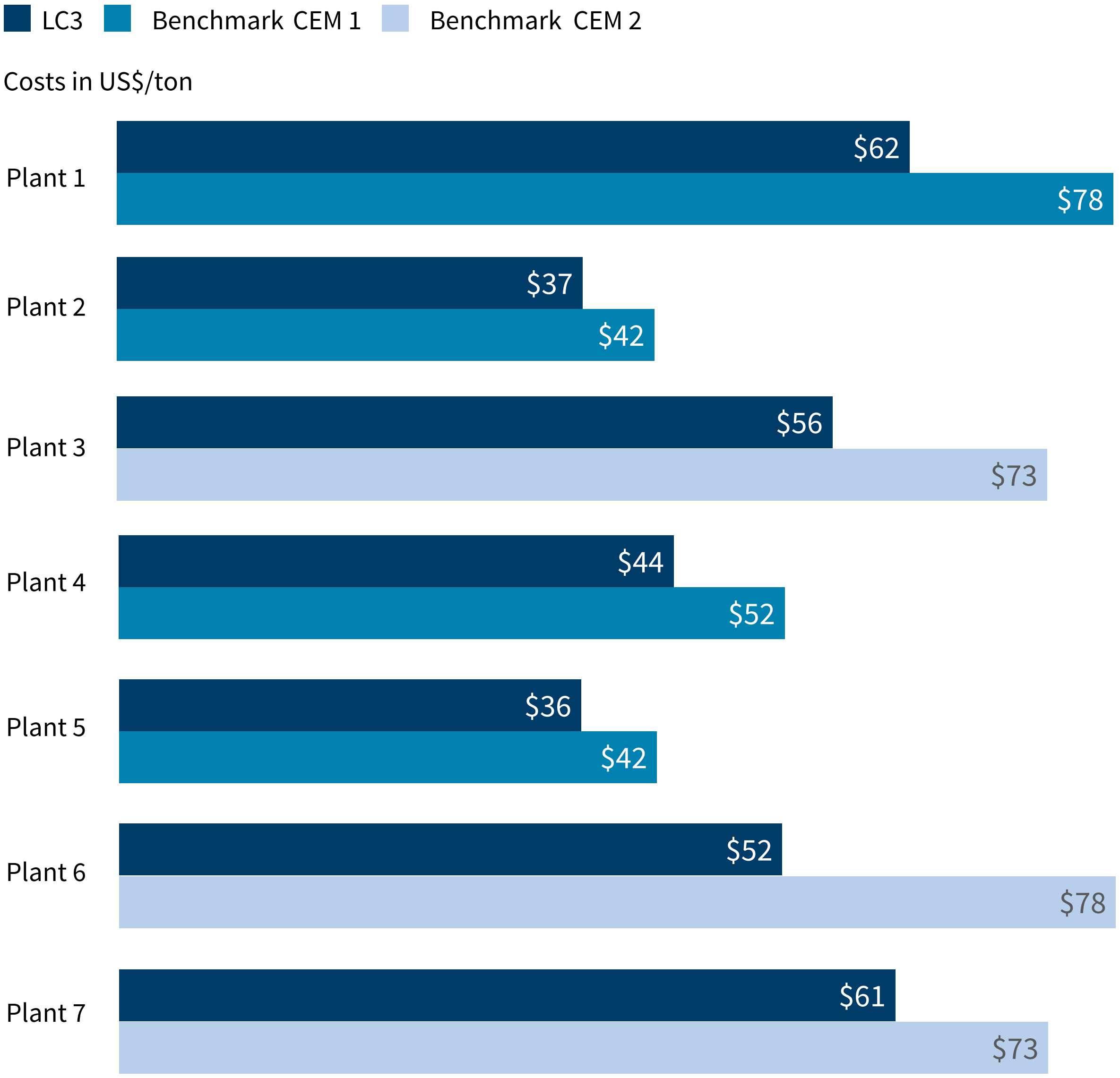


RMI Graphic. Source: RMI analysis

A comparison of LC3 with the respective Benchmark CEMs in Exhibit 10 shows the overall operating expenses of LC3 can offer a cost reduction of up to 33%. This cost efficiency stems from the reduced calcination temperature for clay, which is approximately 50% lower than that required for clinker production. The extent of this cost benefit depends on the technological approach employed, with the maximum savings observed in scenarios where a new flash calciner is installed within an integrated plant, as exemplified by plant 6. Additionally, the calcination of clays does not involve a loss of mass, whereas limestone loses meaningful mass in the form of process emissions during clinker production.

Exhibit 10

Comparison of operating expenses at LC3 plants versus benchmark cement plants



RMI Graphic. Source: RMI analysis

Investment Opportunities

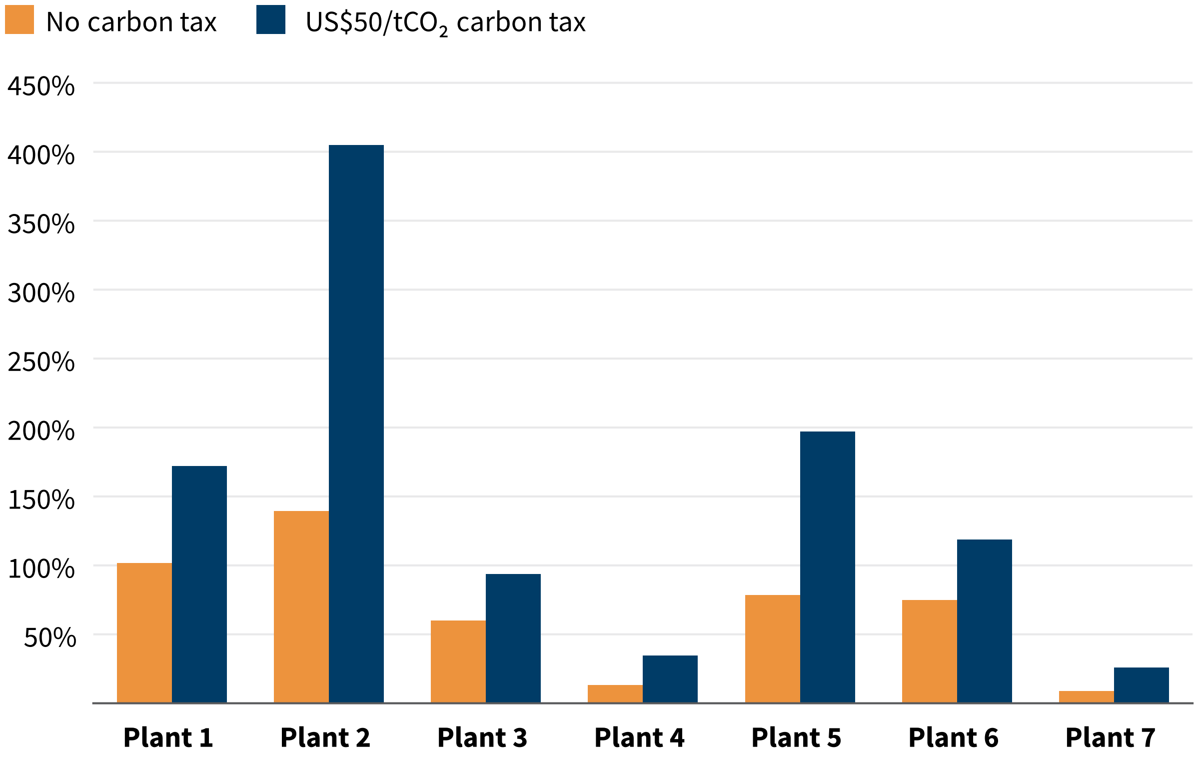
In a best-case scenario, capital expenditure investments for LC3 can be recovered in a span of a few months. As the analysis demonstrates, higher IRRs and shorter payback periods, as seen in plants 1 and 2, are especially pronounced in Africa. The key influencing factors are experienced by geography but driven by low clay costs, high imported clinker costs, and the type of technology employed for LC3 adoption (integration of new flash calciners or retrofitting of existing kilns). LC3 plants gain an additional economic advantage in geographies where carbon tax, tax credits, incentives, or grants are offered for low-carbon cement production, such as the United States, the UK, the Netherlands, Sweden, Germany, and France.

In contrast, a longer payback period can range up to 10 years due to savings in operating expenses. Lower IRRs and longer payback periods are influenced by higher retrofitting costs and additional capital expenditures such as a storage silo, as seen in plants 4 and 7. However, even with the longest payback period of 9.9 years in plant 7, the investment remains relatively attractive because clinker costs are significantly lower in integrated plants, which may offset higher clay costs. The choice of technology and proximity to clay sources are crucial factors influencing the overall cost efficiency of LC3 production.

Exhibits 11 and 12 demonstrate the impact of a carbon tax on LC3 production. While the economic case for LC3 is strong absent a carbon tax, the analysis shows that with a carbon tax of $50 per ton of carbon, the IRR boost ranges from 17% to 266% (see Exhibit 11), and the payback period is shortened by five months to nearly six years (see Exhibit 12). The range in the scenarios is wide, driven by variations in clinker replacement levels, capital expenditure requirements, and costs of calcined clay and clinker.

Exhibit 11

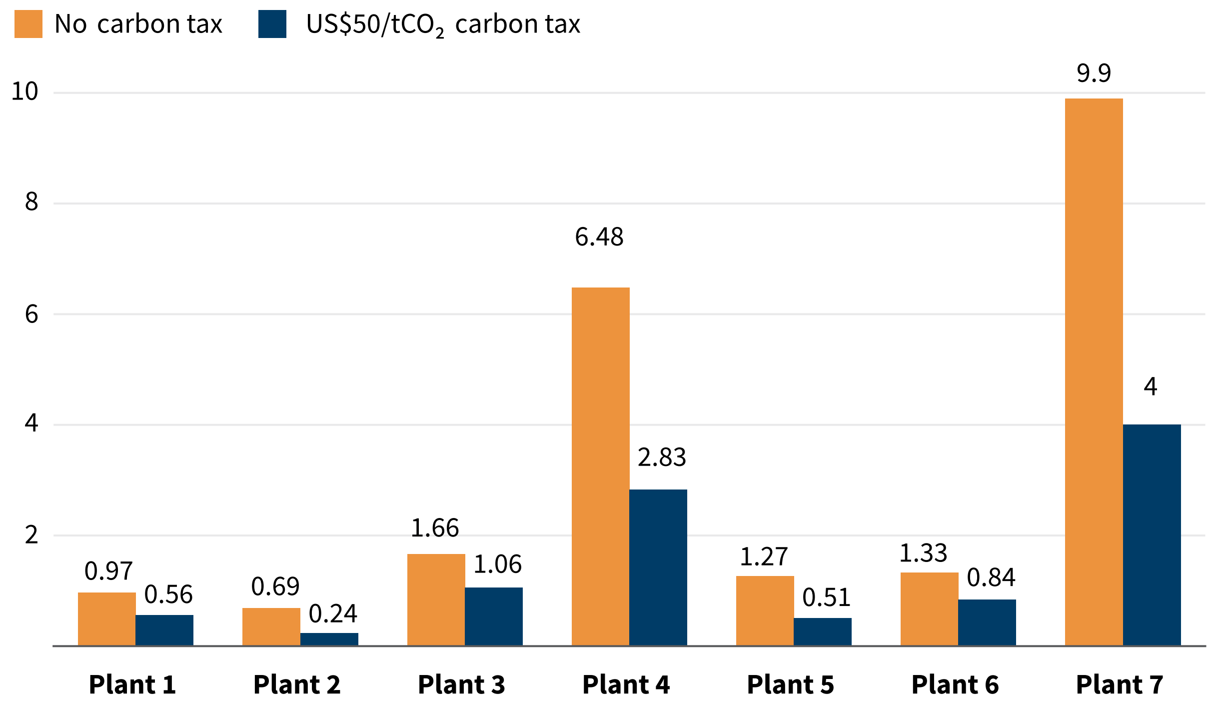
Estimated IRR for LC3 production in different carbon tax scenarios



RMI Graphic. Source: RMI analysis

Exhibit 12

Estimated payback period for LC3 production in years



RMI Graphic. Source: RMI analysis

Proximity of Clay Deposits and Transportation: Impacts on Profitability

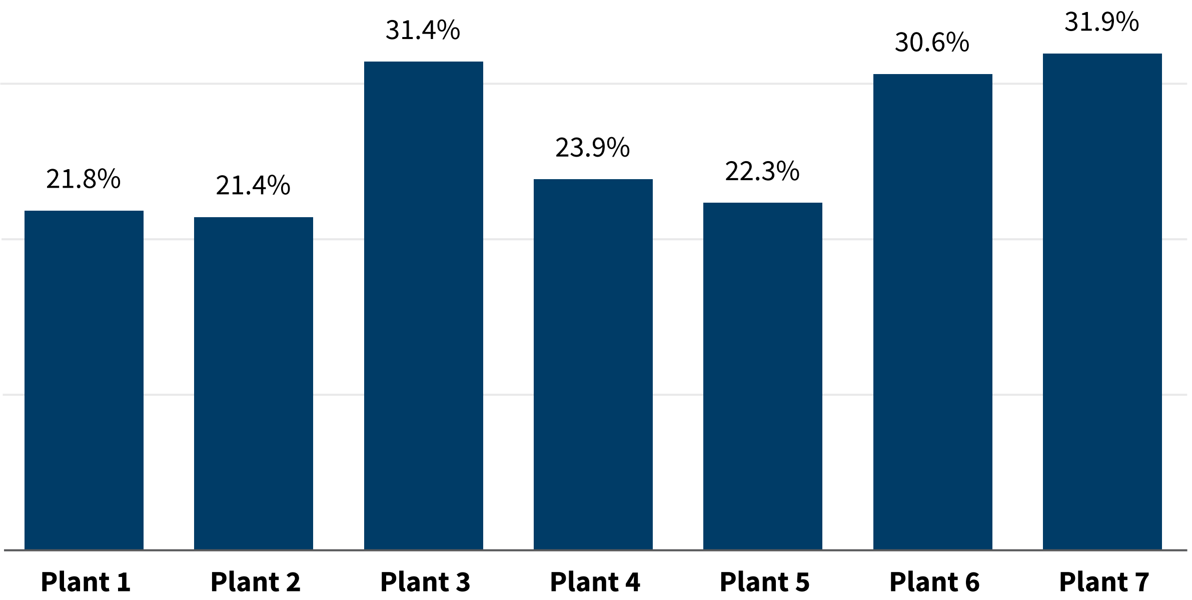
In the analysis, it is presumed that proximity of clay deposits to the cement plants minimally affects LC3 production costs. However, to assess the influence of clay transportation distances on LC3 costs, scenarios with clay sourced from 50 and 200 km away were examined. This involved comparing the operational costs of clay calcination with clinker costs. The analysis reveals that, in most instances, LC3 production retains its profitability even with clay sourced up to 200 km away. Notably, the cost difference is most substantial in units that only grind without local clinker production. This is due to the significantly higher clinker costs, which are inflated by importation or transportation. This finding underscores the importance of considering logistical factors such as distance from raw material supply, particularly in scenarios where materials are not locally sourced.

Climate Impact of LC3

Exhibit 13 demonstrates that the reduction in CO_2 emissions during the production of LC3 reached up to 32% compared with the Benchmark CEMs in the scenarios considered. This substantial decrease in emissions is particularly notable in plants 3, 6, and 7, where the clinker replacement level is 50%, in contrast to other scenarios, where the replacement level stands at 35%. It is important to note that the 30% reduction in emissions in these plants is in comparison to portland limestone cement production, type 1L, which already has a lower clinker factor and emissions reduction compared with OPC. When LC3 is compared with standard OPC, the literature suggests the CO_2 emissions avoided could be as high as 40%.[28] If every cement plant worldwide adopted LC3 and achieved even just a 30% reduction, global CO_2 emissions could be reduced by approximately 500 million tons annually — equivalent to the total CO_2 emissions produced by Mexico each year.

Exhibit 13

CO_2 emissions avoided from LC3 production at cement plants



RMI Graphic. Source: RMI analysis

Barriers and Challenges

1. Materials Sourcing

One key challenge identified across the case studies was colocation of raw materials sourcing. The distance between the production facility and suitable clay and limestone sources is a key determinant of whether a project will be economically viable, although the threshold of reasonable distance depends on the region. Additionally, there is usually a lack of infrastructure for producing and distributing LC3.[29] A number of factors affect the viable distance for materials sourcing, including the cost of slag, fly ash, and other competing SCMs; regional environmental priorities; carbon price and other supporting regulations; means of transport available between quarry and production plant; and clay quality. In some regions, such as parts of Western Africa, limestone is difficult to access but clay is more readily available, so the adoption of LC3 and other clay-based mixes can reduce raw material costs. In general, a cost for carbon and more stringent emissions standards for cement producers improves the relative financial viability of LC3 and other calcined clay blends.

2. Adherence to Standards

Many global prescriptive standards pose barriers to LC3 adoption, despite its low-carbon benefits. In Europe, EN 197-5 limits clinker replacement to 50% and restricts pozzolan options, reducing the environmental impact potential of LC3. Similarly, EN 206 further constrains LC3 adoption by excluding LC3-50 as a concrete component and setting minimum cement content and SCM substitution limits. In the United States, ASTM C618 restricts water demand, making it difficult to use LC3, which generally requires

higher water content for workability. Additionally, ACI 301 mandates specific concrete mix parameters, such as minimum binder content, and only allows calcined natural pozzolans that comply with ASTM C618, limiting the scope for innovative binders like LC3.

Performance-based standards offer a more flexible approach by focusing on physical performance rather than specific mix compositions. India's IS 18189 is a pioneering example, providing comprehensive guidelines for LC3 use in concrete, setting a standard for low-carbon innovation.[30] In the United States, ASTM C1157 allows for greater flexibility by determining cement's acceptability based on targeted characteristics, such as early strength and sulfate resistance, rather than strict composition limits. Similarly, ASTM C1679-17 and Eurocode 1992-1-1 are performance-based, using tests like isothermal calorimetry to validate performance, which enables the broader adoption of LC3.[31] To pave the way for performance standards, Karen Scrivener is heading a technical committee of RILEM (The International Union of Laboratories and Experts in Construction Materials, Systems and Structures) to develop the testing approaches needed.

Exhibit 14 **Codes that support global LC3 production**

Code	Region	Cement or Concrete?	Description	Source
IS 18189:2023	India	Both	Comprehensive guidelines for production, testing, and usage of LC3-based concrete in India	Bureau of Indian Standards
NC 120:2014	Cuba	Concrete	Allows for replacement of clinker by LC3 up to 50% and different doses/mixes (H1, H2, H3, H4) depending on "levels of atmospheric aggressiveness"	Cuban National Bureau of Standards, Alemán et al., 2019
ASTM C618	US	Both	Allows for natural or calcined pozzolans with physical and chemical standards (e.g., limited water demand)	ASTM 618
ASTM C1157	US	Cement	A move toward performance-based standards that does not put a limit on the number, type, or chemical additions to clinker	ASTM C1157
ASTM C1679-17	US	Cement	Allows for testing the reactivity of a blended cement through isothermal calorimetry, which is a quick and reliable method	ASTM C1679-17
ASTM C595	US	Cement	Allows clinker factor down to 40% and the ternary blend of calcined clay and limestone	ASTM C595
ACI 301	US	Concrete	Contains prescriptive limits on the mix design of concrete (minimum binder content, maximum aggregates size, etc.) and only allows replacing OPC with calcined natural pozzolans complying with ASTM C618	ACI 301
EN-197-5	Europe	Cement	LC3-50 allowed with up to 50% clinker replacement [CEM II/C-M category]	GlobalSpec
EN206	Europe	Concrete	Does not recognize CEM II/C (incl. LC3-50) within potential constituents in concrete mixes	Basheer et al., 2017
Eurocode 1992-1-1:2021	Europe	Concrete	A performance-based approach for the assurance of the durability of concrete structures by demanding a certain concrete cover	Eurocode

RMI Graphic.

3. Physical Properties

The difference in physical properties between LC3 and OPC is also a common challenge. LC3 has similar performance to OPC, and in some cases, LC3 may outperform OPC. For instance, LC3 may exceed the durability (e.g., chloride resistance, alkali silica reaction resistance, and resistance to marine environments) of OPC; in longer time frames (e.g., 7–28 days), the strength of LC3 may exceed that of OPC due to chemical reactions that occur during hydration.[32]

However, a few properties differ, including early strength. Although early strength is not important for some applications, it increases the speed of construction, allows for early use of concrete in load-bearing applications and early removal of formwork, and affects the temperature range in which cement can be deployed.[33] It is therefore necessary to consider construction conditions on a project-by-project basis to determine the viability of LC3 for a particular application. The early strength development is tied to the kaolinite content of the calcined clay.[34] Research has shown that using clays with higher kaolinite content can help with this, and a minimum of 40% calcined kaolinite content is sufficient to have comparable compressive strength to OPC beyond seven days.[35] As analyzed, there is little to no additional benefit to compressive strength beyond 60% kaolin content. The mixes show comparable strength, performance, and durability characteristics better than their OPC counterparts.

LC3 can also affect workability and increase water demand, although the extent depends on mix designs.[36] The additional water demand required for LC3 workability affects the design strength of concrete, but this can be overcome by using polycarboxylate ether–based admixtures, superplasticizers, and high-range water reducers. These chemical admixtures are added at the rate of <2% by weight of binder content, which in turn increases the cost of concrete by 1%–3%. Studies have achieved design strengths of 45 megapascals and above with the use of ultra-high-volume LC3, in which 50%–80% clinker was replaced, and exhibited better durability performance.[37]

Another physical difference between LC3 and other cements is its color. Depending on the iron oxide content of the clay, some LC3 blends are reddish in color, which can make customers hesitant to use it in projects. Holcim has addressed this challenge in the markets served by its Mexico plant by recommending it to buyers as a way to avoid the cost of painting regular cement.[38] A technique to regulate color was also explored and effectively tested on a pilot kiln in India. This involved introducing liquid fuel into the kiln's carcass as the calcined material leaves, ensuring it burns and uses up available oxygen during cooling. By managing the calcination environment, black calcined clay was produced instead of the typical red material. Other graying techniques have been developed as well.

4. Capital Expenses

LC3 presents a cost-effective solution for reducing CO_2 emissions, with capital expenditures ranging from $5 to $110 million and operating expense decreases ranging from 21% to 32%, depending on the region and plant-specific details. Although the capital expenditures can be significant, LC3 is especially favorable on a cost per ton of CO_2 abated. Several companies noted that a carbon price, like in Europe, further offsets the necessary capital expenditure investments, facilitating quicker deployment. Although managing CO_2emissions is not always a priority for producers, the introduction of a carbon price typically shifts this focus. Government grants have accelerated investments, but one-time funding opportunities limit long-term impact on business models. In regions with carbon taxes, such as Europe, adopting low-carbon technologies like LC3 can enhance cost-effectiveness. For instance, with an average carbon price of $90 per ton of CO_2, the additional cost per ton of OPC rises, but LC3 can reduce these costs by roughly 25%.

Furthermore, policies such as France's RE2020, which sets embodied carbon limits for buildings instead of cement tonnage, may encourage customers to reduce emissions and increase their willingness to pay a green premium.

Key Analytical Findings

- **Operational Cost Savings:** LC3 production can reduce operating expenses by up to 33%. Lower calcination temperatures for clay, reduced fuel use, and the absence of limestone mass loss in the process contribute to these savings, especially in regions where fuel costs are high.

- **Rapid Payback and High Returns:** LC3's lower production costs and emissions create financial advantages, with payback periods as short as a few months in favorable regions. On the higher end, payback periods can extend up to 10 years, depending on regional factors and capital requirements. IRRs are especially high in areas with low clay costs and high clinker import costs, although lower returns can occur in markets with higher retrofit and transportation expenses.

- **Resilience to Transportation Costs:** Even with clay sources located up to 200 km from the plant, LC3 remains more profitable than OPC because calcined clays are far cheaper than clinker. This geographic flexibility supports widespread adoption in varied markets.

- **CO_2 Emissions Avoided:** LC3 avoids emissions up to 32% compared with traditional cement blends, and over 40% compared with OPC. This avoidance is achieved through high clinker replacement (up to 50%) and calcined clay, which emits significantly less carbon than clinker production.

Implications of LC3 on the Cement Market, Actions Needed, and What Comes Next

LC3 presents a compelling business case for reducing costs and emissions while transforming the cement industry. Its ability to significantly lower production costs and CO_2 emissions without requiring substantial changes to existing production infrastructure could reshape the cement production landscape. Early adopters of LC3 will gain a competitive edge through cost savings, and they will benefit from government incentives and global carbon pricing mechanisms. They will also see an increased market share due to growing demand for sustainable construction materials.

The next steps for LC3 involve navigating key market dynamics, overcoming operational challenges, and seizing emerging opportunities. This section outlines the future implications of LC3 adoption, the actions needed to drive its widespread implementation, and what comes next.

Impact on Clinker Kilns

- **Reduced Clinker Demand:** LC3's low clinker requirements decrease reliance on the most carbon-intensive component in cement production.

- **Pressure on Inefficient Kilns:** Declining clinker demand, rising energy costs, and stricter carbon regulations will make it harder for older inefficient kilns to remain profitable, especially in regions with high fuel costs or carbon pricing.

- **Shift to Efficient Kilns:** This trend will likely accelerate the consolidation of clinker production into fewer but larger modern, high-efficiency kilns.

Strategic Decisions for Cement Producers

- **Timing of Adoption:** Cement producers must decide when and how aggressively to adopt LC3:

    - **Early Adoption:** Early adoption of LC3 provides advantages such as securing raw materials, establishing sales contracts, and reducing reliance on limited SCMs, with first-mover benefits for companies ready to meet rising demand.

    - **Challenges of Transition:** Shifting to LC3 involves new supply chains, equipment investment, and readiness to meet customer demand, which may not be fully established.

- **Investment Considerations:** Cement producers investing in LC3 should account for regional factors — including demand projections, production costs, raw material access, and local policies — to maximize the economic benefits of LC3.

Opportunities for New Technologies and Business Models

- **Electric Kilns:** Due to the lower temperatures needed for clay calcination, electric calciners powered by renewable energy are a viable option, further reducing emissions and costs.

- **Modular Kilns and Localized Production:** Modular kilns located near clay deposits can minimize transportation costs and create local production hubs, decentralizing cement production and even enabling smaller producers to enter the low-carbon cement market.

Actions Needed for Scaling LC3 Adoption

- **Infrastructure Investment:** Investments in kiln retrofits, new clay calciners, electric kilns, and production line optimization will be critical in scaling LC3 production.

- **Advocacy for Performance-Based Standards:** Supporting the shift toward performance-based standards will enable greater flexibility for LC3's use in construction.

- **Strong Demand Signals:** Strong demand signals from the public and private sectors can drive investment to LC3 projects. Initiatives such as green public procurement, demand aggregation, alternative chains of custody, and corporate commitments to low-carbon materials can help establish a market for LC3 and make these projects more attractive to investors.

Conclusion

LC3 is a scalable, profitable, and immediate low-carbon solution available for industry-wide adoption now. It represents a transformative opportunity for the cement industry, addressing both financial and environmental goals by cutting operational costs by as much as 33% and reducing CO_2 emissions by up to 40%. Embracing it will position early adopters to thrive in a rapidly evolving market and significantly reduce global CO_2 emissions.

LC3 can become a cornerstone of the cement industry's decarbonization efforts — a critical solution for sustainable construction worldwide — by addressing the challenges and seizing the opportunities outlined above, such as converting inefficient clinker kilns, leveraging new technologies like electric kilns, and adopting innovative business models.

The time to invest in LC3 is now. With the support of policies including grants, carbon pricing, and public procurement, as well as industry actions such as advanced standards, strong demand signals, and sustainable building certifications, LC3 can drive the cement industry's transformation toward a sustainable, climate-resilient future.

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