DECARBONISATION IN THE INDIAN CEMENT INDUSTRY

Technical Report on Pathways, Technologies, and Policy Enablers for Low-Carbon Cement

Table of Contents

1 Introduction 9
2 Emissions Reduction Pathways for the Indian Cement Sector 12
2.1 Alternative Fuels and Raw Material Substitution 13
2.2 Clinker Factor Reduction and SCM Use 15
2.3 Energy Efficiency Improvements 16
2.4 Decarbonisation of Electricity Usage 18
2.5 Carbon Capture, Utilization and Storage 19
3 Global Policy Initiatives 21
4 Emerging Low-Carbon Cement 23
4.1 LC3 Cement 23
4.2 Composite Cement 25
4.3 Geopolymer Cement and Concrete 26
5 Emerging Technologies and Processes in Cement Production 27
6 Conclusion 29
7 Annexure: Stakeholder Consultation Output 31
7.1 Supply-Side Stakeholder Views 31
7.1.1 Sector Expert 1, Chief General Manager, Holtech Consulting Private Ltd., Gurugram (Haryana) 31
7.1.2 Sector Expert 2, Birla White Cement, Jodhpur (Rajasthan) 33
7.2 Demand-Side Stakeholder Views 35
8 Annexure: Global Policies for Cement Decarbonisation 39
8.1 Overview 39
8.2 United States of America 48
8.3 Asia – Vietnam, Indonesia, Malaysia, and Thailand 42
8.4 Brazil 46
8.5 European Union 47
8.6 Concluding Remarks 52

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This report has been developed through a collaborative effort between Alliance for an Energy Efficient Economy (AEEE) and the American Council for an Energy-Efficient Economy (ACEEE). It provides a strategic roadmap for decarbonising India's cement industry by identifying key pathways to reduce greenhouse gas emissions across the sector. The roadmap is structured around six critical pillars: alternative fuel substitution, increased use of supplementary cementitious materials (SCMs), energy efficiency improvements, decarbonisation of electricity consumption, deployment of carbon capture, utilization and storage (CCUS) technologies, and other enabling measures to accelerate the transition towards low-carbon cement production.

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The report cover photograph shows the JK Lakshmi Cement integrated Jaykaypuram plant in Sirohi, Rajasthan. This facility manufactures Limestone Calcined Clay Cement (LC3), a sustainable cement which combines clinker, calcined clay, limestone, and gypsum, and reduces CO_2 emissions by up to 40% compared to traditional Portland cement.

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Executive Summary

This report identifies pathways for India's cement industry to decarbonise at a pace compatible with the national climate goal of net-zero emissions by 2070.

Cement production is responsible for approximately 6–7% of India's greenhouse gas emissions, and these are primarily from three sources: limestone calcination, fuel combustion, and electricity use. Limestone calcination releases carbon dioxide (CO_2) as a by-product of chemically transforming limestone into clinker, and the process accounts for approximately 56% of cement sector emissions. Fuel combustion for kilns contributes 32% and electricity use for grinding and auxiliary operations accounts for the remaining 12%. Over the last decade, the adoption of vertical roller mills and advanced process controls have optimized specific electrical energy consumption and stabilized thermal energy intensity. These advances demonstrate that Indian cement manufacturing is already among the most efficient globally.

Thus, reducing emissions from the cement industry in line with India's climate goals will require structural interventions. The pathways detailed in this report focus on supply-side interventions in cement decarbonisation. They also take into account supply chain and cost considerations, enabling factors, and complementary strategies that may take longer to implement.

Five Strategic Levers to Reduce Emissions in Cement Manufacturing

- **Increasing the use of alternative fuels.** Today, only 6% of the energy used to heat cement kilns in India comes from alternative fuels such as biomass and refuse-derived fuel (RDF). Increasing the thermal substitution rate (TSR) from 6% to 20% by 2030 will require a reliable supply of these fuels. Establishing a streamlined system for the interstate movement of agricultural residues, biomass, and municipal waste suitable for cement co-processing would strengthen supply chains, simplify approvals, and accelerate the adoption of alternative fuels.
- **Increasing the use of clinker substitutes.** Reducing the share of clinker in cement through the increased use of supplementary cementitious materials (SCMs) can address 7–15% of cement-sector emissions.[1] Because clinker accounts for 85–90% of cement CO_2, emissions, every percentage-point reduction translates directly into lower embodied emissions. India already leads globally, with one of the lowest clinker-to-cement ratios (~0.73), but sustaining this edge will require scaling next-generation SCMs such as limestone calcined clay cement (LC3) as conventional fly ash and slag

[1] NITI Aayog, *Roadmap for Cement Sector Decarbonisation* (2026), niti.gov.in/sites/default/files/2026-01/Roadmap_for_Cement_Sector_Decarbonaisation.pdf.

supplies tighten. Continued evolution of standards, performance-based specifications, and adoption across the construction industry will be critical to unlock deeper reductions.

- **Increasing energy efficiency.** Energy efficiency is the foundational lever, though no longer the primary source of future gains. Two decades of modernisation have made cement made in India among the most energy efficient globally, with thermal consumption of ~731 kcal/kg of clinker and electrical consumption of ~73 kWh/tonne, well below global averages of 838 kcal/kg and ~104 kWh/tonne. Because most plants now operate near the thermodynamic limits of clinkerisation, further gains will be incremental. Efficiency thus remains essential for cost competitiveness and enables the other levers but is no longer a standalone route to deep decarbonisation.
- **Decarbonising electricity.** Cement plants use a lot of electricity, mostly for grinding and material handling, and this accounts for about 12% of the sector's CO_2 emissions. Cutting these emissions could deliver 20–30% of the abatement the sector needs. There are three ways to do it. The first is to switch to cleaner power: leading companies have already installed over 1,800 MW of renewables, mostly solar and wind, wheeled through the grid. The second is to capture waste heat from kilns, where India can scale from 538 MW today to around 1,100 MW, though this potential will shrink over time as kilns become more efficient. The third is simply to use less electricity, through equipment like variable frequency drives and vertical roller mills. Together, these steps cut emissions and reduce dependence on coal-based power.
- **Scaling carbon capture, utilization, and storage (CCUS) technologies.** CCUS is the long-term backstop for emissions that no other lever can eliminate. Because around 56% of cement's CO_2 comes from limestone calcination, a reaction independent of fuel or efficiency, even fully optimised plants emit substantial process CO_2 that only capture can address. India has moved CCUS from ambition to a funded priority, with ₹20,000 crore committed in the 2026–27 Union Budget. Viability hinges on utilisation (converting CO_2 into products such as green urea and building materials) and a hub-and-cluster model for shared transport and storage. With capture costs at USD40–120 per tonne, CCUS is a post-2040 lever as technology and infrastructure mature.

Global Policy Landscape

A survey of selected other countries and regions (Vietnam, Indonesia, Malaysia, Thailand, Brazil, the European Union, Germany, and the United States) show common approaches to reducing emissions in the cement sector. The suite of policies includes those that promote decarbonisation through alternate fuels, clinker reduction with alternate cements and SCMs like limestone calcined clays, waste heat recovery, renewable energy deployment, CCUS, and demand-side optimization. Supportive elements used to advance technology adoption and market transformation include regulatory infrastructure, standards for low-carbon products to support their mainstreaming, green public procurement to promote market demand, pilots and demonstrations to build market confidence, market-wide stakeholder engagement to build acceptance, innovative financing models to cover the green premium, and carbon pricing through emissions trading schemes or cap and invest mechanisms. These strategies align with ones currently pursued and recommended for the Indian market. India exports cement to other countries in Asia, Africa and the European Union. Decarbonisation of the Indian cement sector is in alignment with evolving global policy developments, including the European Union’s Carbon Border Adjustment Mechanism, and is important to maintain competitiveness in export markets.

Low-Carbon Cements for Construction Industry Adoption

The construction industry will need to adopt cements made from processes that are less reliant on clinker. The most promising of these are limestone calcined clay cement, composite cements, and geopolymer cements. Noida International Airport (Jewar), India’s first large-scale deployment of limestone calcined clay cement, marks a major step in low-carbon construction.

Emerging Process Technologies to Further Lower Emissions

Other emerging technologies at mid-to-high technology readiness levels with the potential to drive deeper decarbonisation in the near and medium term include use of mineralizers to reduce energy consumption, fluidized beds for calcination to facilitate energy efficiency and CCUS, low-pressure-drop cyclones to reduce electricity consumption, and high-efficiency classifiers that reduce electricity use by optimizing grinding.

Three Phases of Decarbonisation

Decarbonising the Indian cement sector can be organized into three phases:

- **Phase 1 (2025–2030):** Address the low-hanging fruit. Scale composite cements and operationalise limestone calcined clay cement. Aim for 100% coverage of waste heat recovery systems across integrated units and increase the renewable energy share to over 50%. Achieve a thermal substitution rate (or TSR, this is use of alternative fuels instead of conventional fossil fuels) of 15–20%.
- **Phase 2 (2030–2040):** Deploy technologies maturing today and transition from fossil fuel dependence to circular economy principles. Achieve a TSR of 30% or higher,

widespread deployment of electric fleets for logistics, and the integration of oxyfuel kilns that improve the efficiency of CCUS.

- **Phase 3 (2040–2070):** Address unavoidable process emissions by deploying CCUS and potentially adopting green hydrogen for thermal energy.

By implementing the decarbonisation levers described in this report, the Indian cement sector can successfully decouple growth from emissions and provide a blueprint for emerging economies and others in the Global South.

1 Introduction

The building construction sector has emerged as one of the largest contributors to global carbon dioxide (CO_2) emissions. This reflects the scale and pace of urbanisation and infrastructure development in recent decades. As populations grow and living standards improve, construction activity is expanding rapidly around the world. This growth has brought significant environmental impact and the buildings sector, including the construction and operation of buildings, was responsible for approximately 34%[2] of global energy related CO_2 emissions in 2023.

A closer examination of these emissions reveals a critical distinction between the energy used to run buildings and the carbon embodied in their materials and construction. Operational emissions arising from heating, cooling, and powering the existing building stock reached a record 9.8 gigatonnes (Gt) of CO_2 in 2023. That same year, embodied carbon from the production of building materials such as cement, steel, and glass and from construction activities contributed approximately 2.9 Gt of CO_2. While these emissions have historically been linked to economic development, the continued growth in emissions highlights how the carbon intensity of the material supply chain remains a distinct and growing challenge for meeting global climate goals.

Cement occupies a critical position within this landscape. Globally, the cement industry accounts for about 7–8%[3] of anthropogenic CO_2 emissions, and it is one of the most carbon-intensive industrial sectors. Adding to the challenge is the fact that cement emissions comprise direct process emissions and energy-related emissions that stem not only from fuel combustion but also from the inherent chemistry of limestone calcination. When limestone ($CaCO_3$) is heated to high temperatures to produce clinker, it chemically breaks down into lime (CaO) and CO_2 is released as a byproduct. This chemical reaction alone accounts for approximately 56%[4] of the sector's total emissions; the remaining 44% comes from the energy used to heat the kiln and other auxiliary loads. Thus, calcination presents a unique chemical challenge distinct from energy use and this chemical reality limits the scope for mitigation through energy efficiency alone.

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[2] UN Environment Programme and the Global Alliance for Building and Construction, *Global Status Report for Buildings and Construction 2024-25* (2025), https://globalabc.org/sites/default/files/2025-03/Global-Status-Report-2024_2025.pdf.

[3] Michael Purton. "Cement is a big problem for the environment. Here's how to make it more sustainable," World Economic Forum, Sep 13, 2024. https://www.weforum.org/stories/2024/09/cement-production-sustainable-concrete-co2-emissions/.

[4] Cement Manufacturers Association, *Cement, Energy and Environment, January to June 2025, Vol XXIV-I* (2025), https://www.cmaindia.org/public/e-book/Cement%2C-Energy-and-Environment2025/40/.

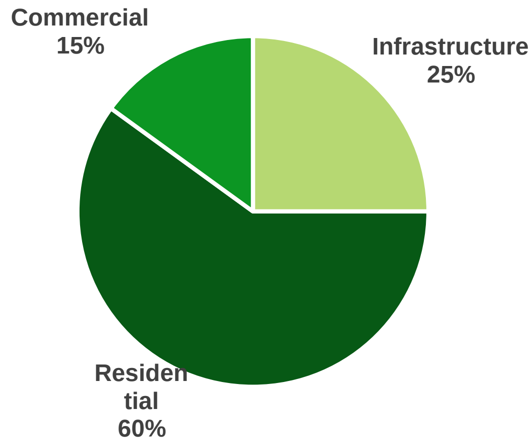

Figure 1: Cement consumption by sector

India is the world's second-largest cement producer, with around 8%[5] of total global installed cement capacity. Cement is a cornerstone of India's development and has fuelled growth in commercial and residential buildings and industrial projects. Unlike bulk-dominated Western markets, India's cement sector is uniquely driven by bagged retail sales, which account for approximately 75–80% of total consumption.[6] Despite the scale of its production and capacity, India's per-capita cement consumption is only 257 kilograms (kg), far below the global average of 540 kg.[7] This difference highlights significant scope for expansion as urbanisation and infrastructure investment accelerate. The cement consumption across different sectors in India is provided in Figure 1.[8]

In FY2024–25, India's cement industry recorded an estimated annual production of 427 million metric tonnes (MMT), and domestic cement consumption reached 435 MMT.[9] The sector's total thermal energy consumption was about 312.1 petacalories (Pcal)[10] and it used 31.2 terawatt-hours (TWh) of electricity, which is equivalent to 26.8 Pcal. Together, these activities resulted in approximately 290 MMT of CO_2 emissions.[11] To evaluate decarbonisation pathways effectively, this report categorises emissions into two primary scopes. Scope 1 emissions or direct emissions encompass process emissions from the calcination of limestone and emissions from fuel combustion in kilns. They are larger than the Scope 2 emissions, which cover emissions from purchased electricity used for grinding, material handling, and auxiliary plant operations. The analysis here is conducted to align with India's broader climate goals.

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[5] Cement Manufacturers, *Cement, Energy and Environment*.
[6] Yvonne Leung, Andrew Minson, and Vikram Janakiraman, "Here's How India Can Reduce its Cement-Related Emissions", World Economic Forum, December 12, 2022, https://www.weforum.org/stories/2022/12/here-s-how-india-cement-net-zero/.
[7] Global Cement and Concrete Association (GCCA), India and The Energy and Resources Institute (TERI), *Decarbonisation Roadmap for the Indian Cement Sector Net-Zero CO2 by 2070* (2025), https://teriin.org/policy-brief/decarbonization-roadmap-indian-cement-sector-net-zero-co2-2070.
[8] Dr S B Hegde, "India in Focus -- A Comprehensive Analysis of the Indian Cement industry," World Cement, February 12, 2025, https://www.worldcement.com/special-reports/12022025/india-in-focus/.
[9] "Growth of Cement Industry in India – Infographic," India Brand Equity Foundation, last updated February 2026, https://www.ibef.org/industry/cement-india/infographic.
[10] AEEE analysis.
[11] AEEE analysis.

As part of the country's climate efforts, India's cement sector has made tangible progress over the past decade. Still, the average emissions intensity of cement production remains close to 0.68 metric tonnes of CO_2 (tCO_2) per tonne of cement production,[12] largely because Scope 1 process emissions from calcination continue to dominate the carbon footprint. Achieving India's climate commitments will therefore require a shift beyond incremental efficiency improvements towards deeper, structural decarbonisation levers that address the chemical reality of clinker production. Additionally, India's revised Nationally Determined Contribution which in March 2026 raised the target to a 47% reduction in greenhouse gas emissions intensity of its GDP by 2035 compared with 2005 levels, serves as further impetus to reduce emissions in the cement sector.

The rest of this report is organised as follows. Section 2 discusses the five main levers to reduce emissions, and Section 3 provides a brief overview of global policy initiatives aimed at decarbonising the cement sector in other countries, many of which align with the NITI Aayog 2026 Cement Sector Decarbonisation Roadmap. Subsequently, in Section 4, we present three types of new low-carbon cement and concrete that are of the greatest relevance for the Indian market, and Section 5 discusses other emerging process technologies to improve energy efficiency and decarbonise cement production in India. The report concludes in Section 6, which proposes a high-level strategic roadmap for decarbonising the sector in three phases.

The annexures provide further detail to support the findings presented: Annexure 7 includes feedback from consultations with supply- and demand-side stakeholders, and Annexure 8 describes the details of global policies for cement decarbonisation.

This report focuses on supply-side interventions in cement decarbonisation with an overview of a phased implementation strategy till 2070. While we assessed demand-side market considerations for background understanding of the marketplace, demand side interventions are not within the scope of this report.

The next stage of research will formulate a comprehensive decarbonisation roadmap that quantifies the impact of key levers to accelerate the Indian cement sector's transition to Net Zero.

[12] Cement Manufacturers, *Cement, Energy and Environment*.

2 Emissions Reduction Pathways for the Indian Cement Sector

Cement production emissions are primarily from three sources: calcination, fuel combustion, and electricity use. Calcination is the dominant contributor, and accounts for approximately 56%[13] of the sector's total emissions (Figure 2). This process involves the chemical transformation of limestone into clinker, and CO_2 is released as an inherent byproduct. Fuel combustion for thermal energy in kilns that typically use coal and petcoke contributes another 32%. Electricity use for grinding and auxiliary operations accounts for the remaining 12%, though this share varies depending on the plant's specific power mix (grid vs. captive thermal).

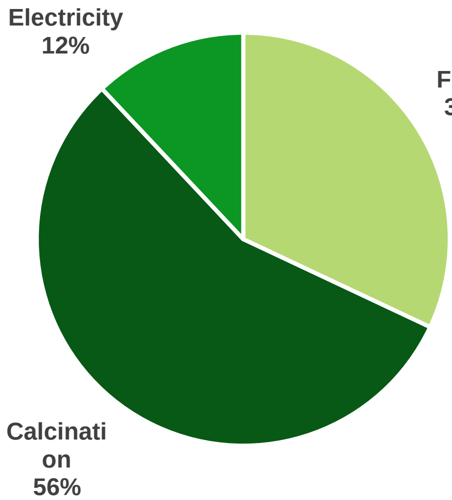

Figure 2: Cement-sector emissions

To align with national decarbonisation goals, the industry must transition from only incremental efficiency improvements to deep structural interventions while continuing to leverage advances in energy efficiency. Achieving significant abatement requires a mitigation hierarchy that prioritises high-impact sources.

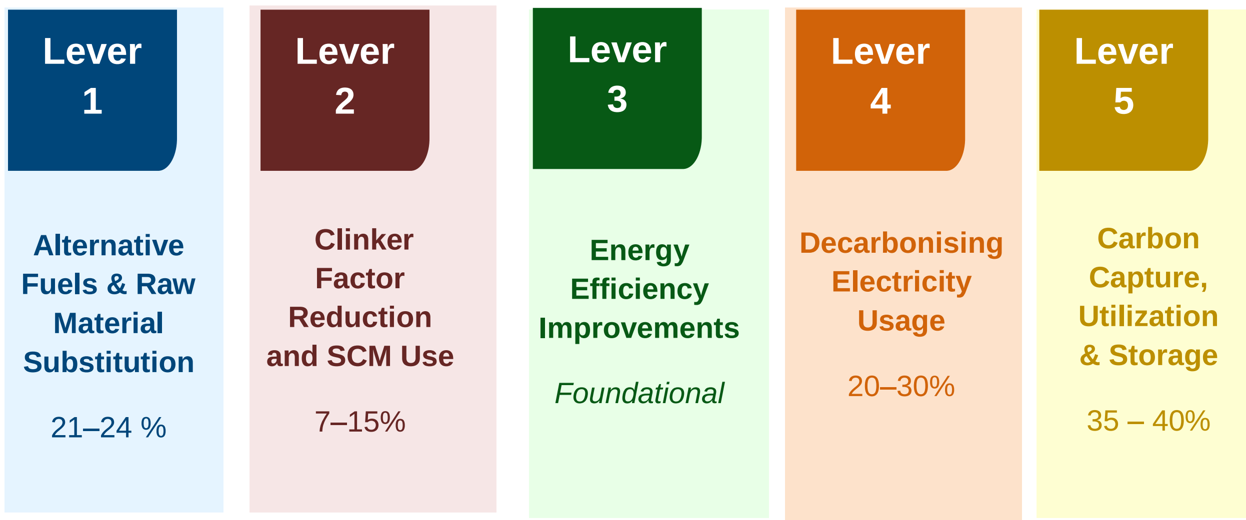

Figure 3: Key decarbonisation levers, in order of importance with contribution to emissions reduction

[13] Kartheek Nitturu, Pratheek Sripathy, Deepak Yadav, Rishabh Patidar, and Hemant Mallya, *Evaluating Net zero for the Indian Cement Industry: Marginal Abatement Cost Curves of Carbon Mitigation Technologies* (New Delhi: Council on Energy, Environment and Water, 2025), https://www.ceew.in/sites/default/files/How-Can-India-Decarbonise-For-Net-Zero-Sustainable-Cement-Production-Industry.pdf.

Figure 3 outlines five strategic levers that address emissions at key sources in the production process. We take into account market supply chain and cost considerations, enabling factors, and complementary strategies that may take longer to implement. The first lever that can be immediately implemented is alternative fuels to lower thermal carbon intensity. The second lever is clinker factor[14] reduction, to tackle the dominant process emissions. These are complemented by the third or central lever of energy efficiency improvements; as new efficiency technologies are adopted, they reduce overall energy demand and enable more efficient fuel substitution (first lever) and the decarbonisation of electricity usage via renewables and waste heat recovery systems (WHRS) (fourth lever). However, there is an inherent “efficiency paradox" between the third and fourth levers: As thermal efficiency improves and kilns are optimised to consume less heat, the temperature and volume of available exhaust gases decline, and this technically decreases the potential for power generation through WHRS. The fifth lever, carbon capture, utilization, and storage (CCUS), serves as the ultimate backstop to manage unavoidable residual emissions.

2.1 Alternative Fuels and Raw Material Substitution

The use of alternative fuels and raw materials (AFR) allows cement plants to practically and immediately partially replace virgin fossil fuels (e.g., coal and petcoke) with waste-derived and biomass-based energy sources. To effectively assess the mitigation potential, it is critical to distinguish between the two primary categories of alternative fuels based on their carbon-accounting implications. Biomass-based fuels such as agricultural residues (e.g., rice husk, mustard husk, and bamboo) are typically treated as carbon-neutral in emission inventories and thus offer the highest direct abatement potential. Fossil-based wastes, including refuse-derived fuel (RDF), discarded tyres, and plastics, still emit CO_2, upon combustion, but at a lower level because they possess a lower carbon intensity than coal. While not carbon neutral, utilising these materials prevents methane emissions from landfills and supports the circular economy approach by recovering energy from waste that would otherwise be discarded.

Despite the theoretical potential, the Indian cement sector currently lags global best practices in thermal substitution rate (TSR).[15] While the global average industry TSR is in the range of 15% to 20%,[16] and the European Union averages a TSR of approximately 50%, with some

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[14] Clinker factor reduction is partially replacing energy-intensive Portland clinker with alternative materials without compromising concrete strength or durability.

[15] Thermal substitution rate (TSR) measures the percentage of total heat input in a cement kiln derived from alternative fuels rather than conventional fossil fuels like coal, petcoke, and natural gas.

[16] Prateek Sharma, Pratik Sheth, Bhabasia Mohapatra, “Recent Progress in Refuse Derived Fuel (RDF) Co-processing in Cement Production: Direct Firing in Kiln/Calciner vs Process Integration of RDF Gasification,” *Waste and Biomass*

individual plants exceeding 90%,[17] the national average in India remains around 6%.[18] This gap is largely driven by structural constraints rather than kiln technology. Unlike mature markets where waste sorting is mandated, Indian plants often receive unsegregated municipal waste with high moisture content and varying calorific value. This inconsistency poses operational risks because volatile impurities like chlorides can cause kiln blockages and corrosion that necessitate expensive investments in chlorine bypass systems once substitution rates exceed 15–20%. Furthermore, regulatory barriers such as complex permitting processes for interstate waste transport create supply chain uncertainty and discourage spending the capital required for pre-processing platforms. To address this bottleneck, establishing a "National Single-Window System" for the interstate movement of hazardous and municipal waste that is specifically tailored for cement co-processing is highly recommended. This would streamline approvals and secure supply chains.

Some Indian plants have successfully achieved high substitution rates through targeted infrastructure investments, and these demonstrate how these technical barriers can be overcome. For instance, the Reddipalayam Cement Works[19] in Tamil Nadu reported a TSR exceeding 25% for sustained periods—significantly higher than the national average. To mitigate the volatility of external waste markets, the plant established a dedicated pre-processing facility to handle and standardise diverse waste streams, including RDF, industrial plastics, and hazardous waste. This implementation serves as a technical proof-of-concept

Valorization 13, no. 6 (2022): 1-28, https://www.researchgate.net/figure/Status-of-TSR-of-the-cement-industry-for-different-nations_fig1_361498383.

[17] New Climate Institute, *Decarbonisation Pathways for the EU Cement Sector: Technology Routes and Potential Ways Forward* (2020), https://newclimate.org/sites/default/files/2020/12/SGCCC-EU-Cement-paper-NewClimate_Nov2020.pdf.

[18] Global Cement, "India's Cement Sector Embraces Decarbonisation Amidst Robust Outlook," November 20, 2025, https://www.globalcement.com/news/20131-india-s-cement-sector-embraces-decarbonisation-amidst-robust-outlook.

[19] "Case Studies, UltraTech Unit Reddipalayam Cement Works Helps Reduce Pollution in Ariyalur & Perambalur Districts," Ultratech Cement, June 2021, https://www.ultratechcement.com/corporate/sustainability/case-studies/ultratech-unit-reddipalayam-cement-works-helps-reduce-pollution-in-ariyalur-and-perambalur-districts.

and validates that Indian kilns can achieve global-standard substitution rates when supported by robust internal pre-processing infrastructure and consistent waste-sourcing strategies.

Figure 4: The Reddipalayam Plant in Tamil Nadu utilises AFR. *Source*: Ultratech Cement.

From a quantitative perspective, scaling up the RDF from municipal solid waste (MSW)[20] to achieve 20% thermal substitution rate by 2030 could result in a cumulative emissions reduction of approximately 80 MMT of CO_2.[21] To provide sector-wide context, maximising the TSR through alternative fuels accounts for 21–24%[22] of the total abatement potential required to decarbonise the Indian cement sector against business-as-usual projections.

2.2 Clinker Factor Reduction and SCM Use

Reducing the clinker factor through the increased use of supplementary cementitious materials (SCMs) is one of the most effective and immediately deployable decarbonisation levers available to the cement industry. Owing to both limestone calcination and its associated high thermal energy demand, clinker production is responsible for 85–90% of the total CO_2 emissions associated with cement manufacturing. Consequently, every percentage point reduction in clinker content translates directly into a proportional reduction in the embodied CO_2 emissions of cement.

India has historically been a global leader in blended cement production, and this is driven by both resource availability and supportive standards. The widespread adoption of Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC) has enabled the Indian cement industry to achieve one of the lowest average clinker factors globally. As of recent estimates, the average clinker-to-cement ratio in India stands at approximately 0.73,[23] and the global average is around 0.77. This structural advantage has already delivered significant emissions avoidance relative to other markets dominated by Ordinary Portland Cement (OPC).

Fly ash and granulated blast furnace slag remain the dominant SCMs in India. Fly ash availability is closely linked to coal-based thermal power generation and slag supply depends on crude steel production. As of 2025, the cement sector consumed over 27%[24] of total fly ash generated in the country and nearly all of the available granulated slag suitable for cement manufacturing. These materials not only reduce clinker demand but also improve the durability and long-term performance of concrete. This makes them particularly suitable for

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[20] Municipal solid waste (MSW) is everyday waste discarded by households, commercial businesses, and institutions.
[21] NITI Aayog, *Roadmap for Cement Sector Decarbonisation*.
[22] Holtec Consulting Private Ltd., *Roadmap for Decarbonisation Indian Cement Industry* (2025), https://holtecnet.com/holtecdocs/TechnicalPapers/p_2025_6.pdf.
[23] Indian Cement Review, "Cut Cement Carbon," November 20, 2025, https://indiancementreview.com/2025/11/20/cut-cement-carbon/.
[24] Global Cement, "India Utilises 333Mt of Fly Ash in the 2025 Financial Year," August 28, 2025, https://www.globalcement.com/news/19802-india-utilises-333mt-of-fly-ash-in-the-2025-financial-year.

infrastructure applications, but future SCM availability presents a growing challenge. India's planned transition away from coal-based power generation is expected to constrain fly ash supply over the long term, and slag availability is limited by steel production routes and competing uses. Recognising this, the industry is actively exploring next generation SCMs such as calcined clay, limestone fillers, and industrial by-products, including through the development of limestone calcined clay cement (LC3; this is discussed in greater detail later in this report). Pilot projects and early commercial trials of LC3 in India have demonstrated clinker reductions of 30–40% with comparable performance to OPC; these position it as a promising solution for scaling low-carbon cement in the medium term. It is estimated that clinker substitutes can address 7–15% of cement sector emissions by 2070.[25]

The Bureau of Indian Standards (BIS) expanded acceptance of blended cements with the Composite Cement (IS 16415) standard, which allows multiple SCM combinations. Further evolution of standards, performance-based specifications, and greater acceptance by construction stakeholders will be critical for unlocking deeper clinker reduction across all segments of the market.

2.3 Energy Efficiency Improvements

Cement manufacturing is a highly energy-intensive process that requires significant thermal and electrical inputs at various stages of production. Over the past two decades, the Indian cement industry has demonstrated a strong downward trend in specific energy requirements and established itself as one of the most energy-efficient cement industries globally. To benchmark this intensity, the average specific thermal energy consumption of 731 kcal/kg of clinker and specific electrical energy consumption of 73 kWh/tonne of cement production[26] are much lower than the global average thermal energy consumption of 838 kcal/kg of clinker and average electrical consumption of roughly 104 kWh/tonne of cement.[27] The improvements in thermal and electrical consumption were driven by widespread adoption of modern production technologies, including dry-process kilns equipped with multi-stage preheaters and precalciners, vertical roller mills for raw material and cement grinding, and advanced process control and automation systems. Together, these technologies enhance heat recovery, reduce specific energy consumption, and improve kiln stability and operational reliability.

[25] NITI Aayog, *Roadmap for Cement Sector Decarbonisation*.
[26] NITI Aayog, *Roadmap for Cement Sector Decarbonisation*.
[27] Chandra Bhushan and Srestha Bannerjee, *Just Transition in Maharashtra: An Opportunity for Green Growth and Green Jobs* (International Forum for Environment, Sustainability and Technology [iFOREST], New Delhi, 2024), https://chandrabhushan.net/wp-content/uploads/2025/07/Just-Energy-Transition-in-Maharashtra-An-Opportunity-for-Green-Growth-and-Green-Jobs.pdf.

Historically, energy efficiency has been a primary driver of sector-wide decarbonisation. However, unlike other emerging levers such as alternative fuels and CCUS, pure thermal efficiency improvements now face the law of diminishing returns. As a significant majority of Indian plants are already operating near the theoretical thermodynamic limits of the clinkerization process, further efficiency gains are projected to be incremental rather than transformational. Hence, the energy efficiency lever is expected to contribute a relatively smaller share to future emission reductions. Efficiency is thus a foundational requirement for performance improvement and cost competitiveness, rather than a standalone solution for deep decarbonisation.

Policy support has played a critical role in accelerating these efficiency gains. The Perform, Achieve and Trade (PAT) scheme launched by the Bureau of Energy Efficiency under the National Mission for Enhanced Energy Efficiency has been particularly effective for the cement sector. From 2015 to June 2024, the scheme enabled Indian industrial units to cumulatively avoid more than 106 MMT of CO_2 emissions. Under PAT Cycle V, 12 designated consumers (DCs)[28] from the cement sector were assigned an energy-saving target of 0.087 MMT of oil equivalent (Mtoe). Actual achieved thermal energy savings reached 0.153 Mtoe and electrical energy savings were 1.78 million units, for an associated emissions reduction of approximately 0.61 MMT of CO_2 per year. PAT Cycle V achievements are provided in Table 1.

Table 1: PAT Cycle V achievement

No. of DCs covered	Energy savings target (Mtoe)	Thermal energy savings (Mtoe)	Electrical energy savings (MU)	Emissions reduction (MMT CO_2/year)
12	0.087	0.153	1.78	0.61

In parallel, to support India's NDC commitment, a National Framework for the Indian Carbon Market is being developed; it covers 186 DCs[29] from the cement sector, including 131 integrated plants and 55 grinding units. The average emissions intensity is approximately 0.627 tCO_2 per tonne of cement for integrated units and 0.02965 tCO_2 per tonne for grinding units. A cumulative emissions reduction target of 7.179 MMT of CO_2 per year has been allocated to these units to be achieved by the end of FY2026–27.

[28] Bureau of Energy Efficiency, *Impact of Energy Efficiency Measures for the Year 2022*-2023 (Ministry of Power, 2023), https://beeindia.gov.in/WriteReadData/L45218/6482394116468231.pdf.

[29] The Gazette of India, "Announcement of National Framework for the Indian Carbon Market," No. 655, New Delhi, October 8, 2025, https://egazette.gov.in/WriteReadData/2025/266804.pdf.

2.4 Decarbonisation of Electricity Usage

There are three main ways to reduce Scope 2 electricity emissions: use carbon-free sources for grid-based electricity, capture more energy from WHRS, and increase the efficiency of electrical use onsite. Presently in the cement industry, about 12% of CO_2 emissions are from electricity consumption during the manufacturing process. The electricity for cement plants is sourced from coal-based captive power plants (CPP) located at integrated clinker units, the national grid, WHRS installed on the cooler and pre-heater exhaust sides, and other renewable sources like solar plants or windmills via wheeling through the grid. Decarbonising electricity in cement manufacturing requires comprehensive approaches that include both supply-side decarbonisation and demand-side improvements in energy efficiency to reduce electricity consumption.

Supply-side options to decarbonise electricity include increasing the share of electricity from green sources like WHRS and renewables like solar and wind. According to the Cement Manufacturing Association, the total installed capacity of WHRS in Indian cement plants is 538 MW and there is potential for 1,100 MW.[30] If utilized at full scale, WHRS has the potential to replace about 8.6 MMT of coal and reduce 12.8 MMT of CO_2 emissions. The 1,100 MW potential is based on present clinker production volumes and the conventional pyroprocessing route, and it is not static. As Indian kilns approach world-class thermal efficiency, the temperature and volume of available exhaust gases decline, leaving the most advanced lines with lower-grade waste heat. More fundamentally, the deeper decarbonisation pathways discussed in Sections 4 and 5, reduced clinker factor through low-carbon cements and alternative process routes, directly shrink and reshape the exhaust gas waste heat resource on which WHRS depends. WHRS is therefore best understood as a high-value near- and medium-term lever; its absolute contribution is expected to plateau and then decline in 2050 deep decarbonisation scenarios, even as the CO_2 benefit per unit of generation also falls with a greening grid.

As of 2024, leading cement companies have installed more than 1,800 MW of total renewable energy capacity, and about 58% of this is solar and wind. While integrated plants rely heavily on thermal CPPs, most standalone cement grinding units are consuming power from the grid, and that results in Scope 2 CO_2 emissions; these units rely on the grid because the massive capital, land, and coal-linkage requirements of thermal CPPs are not feasible options for them.

[30] Cement Manufacturers Association, "Enhancing Energy Efficiency Through Waste Heat Recovery Systems (WHRS)," September 30, 2021, https://www.cmaindia.org/enhancing-energy-efficiency-through-waste-heat-recovery-system.

However, many in the industry have already started using renewable energy either through open-access or group captive plants. Cement plants including Shree Cement[31] and Ambuja Cement[32] are installing solar plants and windmills and then utilising the power through wheeling via the grid; some of these installations are near the plant and others are farther away. This approach offers the added benefit of making the grid greener while significantly reducing plant Scope 2 emissions.

Demand-side decarbonisation involves reducing electricity consumption by improving the efficiency of equipment and optimising its utilisation. Key areas of focus include use of variable frequency drives (VFDs) in centrifugal fans and screw compressors, replacement of low-performing fans with high-efficiency fans, and replacement of low-performing compressors with highly efficient centrifugal compressors. Other options include replacement of old grinding mills with vertical roller mills and replacement of old separators with high-efficiency separators to lower grinding energy consumption. Transitioning from ball mills to vertical roller mills for raw material and cement grinding offers the highest impact, with typical savings of 10–15 kWh/tonne[33] compared with legacy systems. Furthermore, installing VFDs on large process fans allows for dynamic load management that reduces motor energy consumption by 20–30% during variable operation ranges.

2.5 Carbon Capture, Utilization and Storage

Carbon capture, utilization and storage (CCUS) is increasingly recognized as an essential lever in the long-term net-zero pathway for the sector because it addresses emissions that cannot be avoided through conventional measures. Recall that about 56% of cement plant CO_2 emissions arise from the calcination of limestone, a chemical process intrinsic to clinker production that releases CO_2 irrespective of fuel choice or energy-efficiency improvements. As a result, even the most energy-efficient, fuel-optimized cement plants continue to emit substantial volumes of process-related CO_2.

In the Indian context, the government has decisively shifted CCUS from a “theoretical ambition” to a “funded priority.” In the Union Budget 2026–27,[34] a dedicated outlay of ₹20,000

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[31] Shree Cement, “Shree Cement joins RE100 Commits to transition 100% to Renewable Electricity by 2050,” news release, April 25, 2024, https://www.shreecement.com/uploads/cleanupload/pressrelease25april.pdf.
Adani Group, “Ambuja Becomes the World’s First Cement Company to Join the Alliance for Industry Decarbonisation,” news release, September 26, 2024, https://www.adani.com/newsroom/media-releases/ambuja-becomes-the-worlds-first-cement-company-to-join-the-alliance-for-industry-decarbonization.
[33] Confederation of Indian Industry, *Energy Benchmarking for the Indian Cement Sector. Version 7.0* (2025), https://energy.greenbusinesscentre.com/mv/greencementech/pub24/CementBenchmarking14_May_25.pdf.
[34] Government of India, *Key Features of Budget 2026-2027*.

crore was announced to scale up CCUS technologies over the next 5 years. This funding specifically targets hard-to-abate sectors like cement and steel and aims to bridge the gap between pilot success and commercial deployment. It directly supports the roadmap produced by NITI Aayog and the Department of Science and Technology (DST), which prioritizes the development of indigenous capture solvents and mineralization technologies currently being tested in five active DST testbeds (e.g., UltraTech, Dalmia, and JSW[35]).

The captured CO_2 can be converted into value-added products such as green urea, chemicals, and building materials such as concrete and aggregates.[36] Because India is still in the early stages of mapping large-scale geological storage sinks, creating a circular "carbon economy" through utilization provides the fastest pathway to commercializing capture technologies and offsetting high operational costs.

While policy support has arrived, infrastructure remains a bottleneck. Standalone "point-to-point" CCUS projects are economically unviable for inland plants. The sector is therefore moving towards a "hub and cluster" strategy that connects high-density cement clusters like Satna and Gulbarga to shared transport pipelines and geological storage sinks.[37] The new budgetary allocation is expected to fund the feasibility studies and initial infrastructure for these shared hubs. To maximize the impact of this funding and de-risk private investment, there is a strategic opportunity to deploy a "carbon-as-a-service" model. Under this framework, the government would build and own the core CO_2 pipeline and storage networks, and individual cement plants would pay a usage-based "tolling fee" for the carbon they transport and store. This approach would drastically reduce the upfront capital expenditure for individual plants and make commercial deployment far more viable.

The economic challenge associated with CCUS remains significant. Global assessments suggest that CO_2 capture costs in the cement sector typically range from USD40 to 120 per tonne of CO_2,[38] depending on the capture technology, energy source, and scale of deployment. Indian cement producers are operating in a highly competitive, price-sensitive market and such costs are currently prohibitive without strong policy support. Achieving net-zero emissions by 2070 in the Indian cement sector is expected to require cumulative

[35] "India Launches First Cluster of CCU Testbeds in Academia-Industry Collaboration for Cement Industry," Government of India, Ministry of Science and Technology, last updated July 17, 2025, https://dst.gov.in/india-launches-first-cluster-ccu-testbeds-academia-industry-collaboration-cement-industry.
[36] Press Information Bureau, "NITI Aayog Releases Study Report on 'Carbon Capture, Utilisation, and Storage (CCUS) Policy Framework and its Deployment Mechanism in India," news release, November 29, 2022, https://www.pib.gov.in/Pressreleaseshare.aspx?PRID=1879865&reg=48&lang=2.
[37] NITI Aayog, *Carbon Capture, Utilisation, and Storage (CCUS): Policy Framework and its Deployment Mechanism in India* (2022), https://www.niti.gov.in/sites/default/files/2022-11/CCUS-Report.pdf.
[38] Adam Baylin-Stern and Niels Berghout, "Is Carbon Capture Too Expensive?" Internal Energy Agency, February 17, 2021, https://www.iea.org/commentaries/is-carbon-capture-too-expensive.

investments running into hundreds of billions of dollars, with a substantial share of this going to CCUS.

Beyond capture, the sector will also need access to reliable CO_2 transport networks, certified geological storage sites, and additional low-carbon electricity to meet the energy demands of capture systems. India's first experimental CO_2 storage drilling initiatives, led by public-sector enterprises and academic institutions, represent an important early step, but large-scale storage readiness is still several years away.

Given these realities, CCUS should be viewed as a long-term, strategic intervention for the Indian cement industry rather than an immediate decarbonisation solution. Most sectoral roadmaps anticipate limited CCUS deployment before 2035 and then gradual scaling after 2040 as technology costs decline, infrastructure develops, and policy frameworks mature.

3 Global Policy Initiatives

This overview of cement decarbonisation policies from other regions describes the range of options being considered in Vietnam, Indonesia, Malaysia, Thailand, Brazil, the European Union, Germany, and the United States. Some of these countries share common market characteristics with India and others have made policy choices worth exploring on the path to deep decarbonisation, even if their market characteristics differ from those in India. A detailed discussion of these initiatives is provided in Annexure 8 for readers seeking further information.

The policies fall into five main categories: (1) pilots and demonstrations for alternative cements and CCUS; (2) standards for low-carbon products; (3) green public procurement; (4) energy efficiency, alternative fuels, and waste heat recovery; and (5) demand reduction. Policies around categories 1 and 4 align with the key decarbonisation levers described in Figure 3 of this report and with the strategies described in the NITI Aayog Cement Sector Decarbonisation Roadmap. Standards for low-carbon products, green public procurement, and demand reduction are all essential elements that work in concert with the supply side to drive market transformation.

All the countries surveyed, Vietnam, Malaysia, Thailand, Indonesia, Brazil, the European Union, and the United States are using a common set of strategies to decarbonise their cement sectors. The policies promote the use of alternative cements (including LC3 and blended cements), alternative fuels, waste heat recovery and energy efficiency, the reduction in clinker content through SCMs, renewable energy like solar and wind, and CCUS. All the countries except for Malaysia, Indonesia, and Brazil are also pursuing demand reduction through performance code development and lean design considerations.

Alternative fuel substitution has been one of the most successfully implemented approaches; the European Union is the global leader with an average TSR of 56% and in Asia, Vietnam has achieved a TSR of 40% in some plants. Brazil has been successful in leveraging renewable energy through hydropower to decarbonise its grid and reduce cement sector emissions. The European Union has a history of implementing CCUS over the past 20 years and may offer lessons learned as India considers this approach in its decarbonisation suite. Thailand is conducting pilots and demonstrations of CCS in Asia. The European Union has seen success in clinker reduction with a clinker-to-cement ratio of 74-77% using fly ash and slag.

All countries surveyed include the following elements in their roadmaps and implementation plans to facilitate technology adoption and transform the market: a regulatory infrastructure to establish rules, standards, and enforcement mechanisms for the market, standards for low-carbon products to support mainstreaming their use, green public procurement to send market demand signals, pilots and demonstrations of new technologies to build market confidence, market-wide stakeholder engagement to build market acceptance, and innovative financing models to cover the green premium associated with new, lower-carbon options and mitigate risk. All countries are also pursuing some form of carbon pricing through emissions-trading schemes, cap-and-trade or cap-and-invest mechanisms either at the national or state or regional levels. Germany is pursuing an innovative financial model to incentivize decarbonisation of hard-to-abate sectors like cement through its contracts for differences (CfD) programme.

Some highlights among these supporting elements and tools include how the European Union has successfully leveraged regulatory approaches like its Emissions Trading Scheme (ETS) and Carbon Border Adjustment mechanism to drive a price on carbon in its market and reduce emissions. The United States has used green public procurement through state Buy Clean policies and pilots and demonstrations in public and private sector projects to also promote lower-emission cement and concrete products. Lastly, Vietnam has successfully used regulatory mandates to drive the use of waste heat recovery, establish a cap-and-trade system to price carbon in its market, and conduct pilots and demonstrations of alternate fuels that resulted in a TSR of 40%. Brazil has implemented innovative financial models through innovation hubs to fund low carbon cements.

These strategies align with regulatory frameworks, mechanisms and policies that India has either adopted (like Perform, Achieve and Trade and the Carbon Credit Trading Scheme), is developing (like CCUS) or is expanding (like green public procurement).

Additionally, since India exports cement to countries in Asia, Africa and the European Union, this review underscores that the Indian cement sector is making progress on decarbonisation in alignment with evolving global policy developments, including the European Union's Carbon Border Adjustment Mechanism and the increasingly ambitious climate commitments in key export markets. The approaches, strategies and development phases proposed in this report are intended to reinforce the strategic importance of decarbonisation for maintaining India's export competitiveness.

4 Emerging Low-Carbon Cement

Supply-side levers are key elements required to optimise cement manufacturing and decarbonise the production process. However, a net-zero transformation requires these supply-side levers to work in concert with a fundamental shift in market consumption. The sector's absolute emissions can be aggressively scaled down by directly reducing the demand for conventional, high-emission cement categories. This is achieved by pivoting the construction industry towards alternative choices and strategic substitution of low-carbon cement varieties. This section describes some of the most promising low-carbon cements that are poised to accelerate this vital demand-side transition.

4.1 LC3 Cement

Limestone calcined clay cement (LC3) is a low-clinker blended cement designed to substantially reduce the carbon footprint of cement while maintaining performance suitable for general construction. A typical LC3 composition consists of approximately 50% clinker, 30% calcined clay, and 15–20% low-grade limestone, with gypsum[39] added for setting control. The reduced clinker content directly lowers process-related CO_2 emissions, and the remaining clinker fraction ensures adequate early and long-term strength development.

Despite its lower clinker content, LC3 exhibits compressive strength comparable with OPC 33-grade cement,[40] and this makes it suitable for structural and non-structural applications. This performance is achieved through a synergistic hydration mechanism. The calcined clay provides reactive alumina and silica, while the limestone has two roles: it acts as a filler to improve particle packing and early strength and also participates in chemical reactions during hydration that form stable carboaluminate phases that enhance microstructural density and durability.

[39] "Uniqueness of LC3," LC3 Technology Resource Center Asia, accessed June 2026, https://lc3trcasia.com/uniqueness-of-lc3/.

[40] Paolo Vargas et al., "Optimisation of Using Low-Grade Kaolinitic Clays in Limestone Calcined Clay Cement Production (LC3)," *Materials* 18, no. 2 (2025): 285. https://doi.org/10.3390/ma18020285.

India is particularly well positioned for LC3 deployment due to the abundant availability of suitable clay (kaolinitic clays) resources across several regions. When calcined at optimal temperatures, typically 700–850°C, these clays develop high pozzolanic reactivity, depending primarily on their content of reactive silica and alumina. In addition, low-grade limestone, which is often rejected from clinker production due to higher magnesium oxide content[41] and lower calcium oxide content,[42] can be effectively utilised in LC3; doing so improves overall resource efficiency and reduces limestone waste. Recognizing this potential, the BIS formally adopted the technology in 2023 under IS 18189,[43] and it paved the way for commercial production and public procurement.

Advantages of using LC3

- CO_2 emissions reduction of up to 35–40% compared with OPC, driven mainly by clinker reduction and lower thermal energy demand
- Lower production cost, with studies reporting potential cost savings of up to 20–25%, owing to reduced fuel consumption and use of locally available materials[44,45]
- Improved durability, including better resistance to sulphate and chloride attack than OPC, due to refined pore structure and stable hydration products
- Compatibility with existing cement plants, as LC3 can be produced using current grinding and blending infrastructure without major process modifications

LC3 case study

Noida International Airport (Jewar) in Uttar Pradesh is the first large-scale infrastructure project in India to deploy LC3. In adopting LC3 for multiple structural and non-structural concrete applications, the project has demonstrated that reduced clinker cements can be successfully used in demanding infrastructure works. LC3 used at the site offers up to ~40% lower CO_2

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[41] LC3 Technology Resource Center, "Uniqueness of LC3."
[42] IIT-Delhi, *Project Summary: LC3*, accessed June 2026, https://web.iitd.ac.in/~bishnoi/lcc/LCCProjectSummary.pdf.
[43] Bureau of Indian Standards, *IS 18189 2023: Portland Calcined Clay Limestone Cement-Specification* (2023), https://archive.org/details/gov.in.is.18189.2023/page/n19/mode/2up.
[44] "Why LC3," The LC3 Project, 2026, https://lc3.ch/why-lc3/.
[45] Sofia Sanchez et al., "Unlocking the Potential of LC3: Economic, Environmental, and Financial Impacts with a Novel Assessment Tool," 2025 IOP Conference Series: Earth and Environmental Science, 1554 012113, https://iopscience.iop.org/article/10.1088/1755-1315/1554/1/012113/pdf.

emissions[46] than conventional OPC while delivering compressive strength comparable to OPC-33 grade cement.

The LC3 technology applied at Jewar is the outcome of a long-term research collaboration involving the Indian Institute of Technology (IIT) Delhi, IIT Madras, EPFL (the Swiss Federal Institute of Technology in Lausanne, Switzerland), and industry partners, and it was supported by the Swiss Development Cooperation. Besides emissions reduction, LC3 provides cost savings of up to ~25%,[47] owing to lower clinker content and the use of abundant local clays and low-grade limestone. The Jewar Airport project is widely seen as a reference case that could accelerate large-scale adoption of LC3 across India's infrastructure sector.

4.2 Composite Cement

Composite cement plays a key role in reducing the carbon footprint of cement production by replacing a portion of clinker with industrial by-products such as fly ash and ground granulated blast furnace slag (GGBS). As mentioned above, the BIS has formally permitted the manufacture of composite cement under IS 16415; this standard allows blends in which 15–35% fly ash and 20–50% GGBS are used alongside Portland cement clinker and gypsum. This flexibility maximises the use of SCMs, lowers clinker content by ~41%, and reduces CO_2 emissions intensity by approximately 56%[48] when compared with OPC, all without compromising structural performance.

Portland Pozzolana Cement (PPC), governed by IS 1489 Part 1[49] and IS 1489 Part 2,[50] incorporates 15–35% pozzolanic material such as fly ash or calcined clay, and the rest is clinker and gypsum. The pozzolanic material reacts slowly with calcium hydroxide (a hydration product of cement) to form additional cementitious phases like calcium silicate hydrate (C–S–H) that strengthen the matrix over time. While early-age strength such as at 3 or 7 days may be slightly lower than OPC, the 28-day strength of PPC is comparable with OPC-33 grade, and the longer-term strength at 56–90 days often surpasses it due to ongoing pozzolanic

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[46] Infrastructure Today, "Noida International Airport Pioneers India's Green Construction Shift with LC3 Cement," September 26, 2025, https://infrastructuretoday.co.in/noida-international-airport-pioneers-indias-green-construction-shift-with-lc3-cement/.
[47] Infrastructure Today, "Noida International Airport Pioneers."
[48] Confederation of Indian Industry, *Discussion Paper on Composite Cement* (Hyderabad: 2017), https://energy.greenbusinesscentre.com/mv/greencementech/pub24/10.%20Discussion%20paper%20on%20Composite%20Cement.pdf.
[49] Bureau of Indian Standards, *IS 1489 Part 1: 2015: Portland Pozzolana Cement - Specification Part 1 Fly Ash Based (Fourth Revision)* (2019), https://archive.org/details/gov.in.is.1489.1.2015/IS1489%3APart1%3A2015/.
[50] Bureau of Indian Standards, *IS 1489–2 (1991): Portland-Pozzolana Cement — Specification Part 2 Calcined Clay Based (Third Revision)* (2004), https://law.resource.org/pub/in/bis/S03/is.1489.2.1991.pdf.

reactions. PPC aids in reducing CO_2 emissions intensity by approximately 27%[51] when compared with OPC.

Portland Slag Cement (PSC), defined in IS 455,[52] is produced by grinding Portland clinker with GGBS, a by-product of steel production. Slag is a latent hydraulic material which, when activated in the presence of calcium hydroxide and water, forms an additional C–S–H gel that contributes to strength development at all ages. Compared with OPC, PSC generally exhibits lower heat of hydration, enhanced long-term strength, and better resistance in aggressive environments like marine coastlines, industrial facilities, and saline soils, which lead to sulphate and chloride attack. Additionally, PSC contributes significantly to decarbonisation and reduces CO_2 emissions intensity by approximately 39%[53] compared with OPC.

4.3 Geopolymer Cement and Concrete

Geopolymer cements are a class of binders composed of two main components: a reactive solid aluminosilicate source[54] such as fly ash, GGBS, metakaolin, or rice-husk ash, and an alkali activator, which is commonly sodium or potassium hydroxide and silicate solutions. When these ingredients react in a highly alkaline medium, they form a three-dimensional inorganic aluminosilicate polymer network. This geopolymeric network is responsible for the material's high compressive strength and durability once hardened.

Unlike OPC, manufacturing geopolymer cements does not rely on high-temperature clinker production or limestone calcination, the principal sources of CO_2 emissions in the traditional cement process. By using industrial by-products as raw materials and avoiding carbonate decomposition, geopolymer cements can achieve dramatically lower carbon footprints. Some studies and industry reports indicate that geopolymer binders have the potential to reduce CO_2 emissions by up to ~80% compared with OPC,[55] depending on feedstock selection and activator formulation. However, the high embodied carbon of producing alkali activators[56] (silicates) must be carefully managed to ensure these life-cycle benefits are realized.

Geopolymer concrete also leverages circular economy principles by utilising industrial wastes such as fly ash and slag that would otherwise be stockpiled or landfilled.

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[51] Confederation of Indian Industry, *Discussion Paper on Composite Cement*.
[52] Bureau of Indian Standards, IS 455: 2015: Portland Slag Cement - Specification (Fifth Revision) (2018), https://archive.org/details/gov.in.is.455.2015.
[53] Confederation of Indian Industry, *Discussion Paper on Composite Cement*.
[54] Government of India, Ministry of Commerce and Industry, *Good Practices Manual: Green House Gases Emission Reduction – Cement Sector* (National Productivity Council and Department of Industrial Policy and Promotion, 2017), https://www.npcindia.gov.in/NPC/Files/delhiOFC/GHG-Manual-Cement-sector.pdf.
[55] Geopolymer Institute, "Geopolymer Cement for Mitigation of Global Warming," April 7, 2006, https://www.geopolymer.org/applications/global-warming/.
[56] Guillaume Habert et al., "An Environmental Evaluation of Geopolymer Based Concrete Production: Reviewing Current Research Trends," *Journal of Cleaner Production* 19, no. 11 (2011): 1229-1238, https://doi.org/10.1016/j.jclepro.2011.03.012.

Advantages of Using Geopolymer Binders

- Geopolymer binders often display enhanced resistance to chemical attack such as sulphate, acid, and salt exposure.
- Geopolymer cement and concrete offer good long-term performance that makes them suitable for a range of construction applications.

Geopolymer Case Studies

Australia's Toowoomba (formerly Brisbane West Wellcamp) Airport[57] used approximately 40,000 m³ of geopolymer concrete for aprons, taxiways, and pavements, making it one of the largest single-site monolithic pavement applications of geopolymer concrete in the world. The binder combined fly ash and GGBS, activated with alkaline solutions, to form a high-strength, durable, three-dimensional aluminosilicate network. By eliminating Portland cement clinker, the project reduced CO_2 emissions by 6,600 tonnes[58] compared with conventional concrete while utilising industrial by-products and supporting circular economy principles. The airport demonstrates the practical feasibility of geopolymer concrete in large-scale infrastructure and combines structural performance with substantial decarbonisation benefits.

Another case study from India shows that geopolymer concrete is actively demonstrating massive decarbonisation and economic potential across diverse infrastructure sectors. The Delhi Metro Rail Corporation utilised geopolymer concrete for precast track beds on its Violet line and Pink line and achieved a 40% reduction in CO_2 emissions[59] and faster construction times.

5 Emerging Technologies and Processes in Cement Production

Here we discuss several new and emerging technologies that can support decarbonisation of other processes in cement production. These are at various stages of technological readiness, with some approaching commercial application and others at earlier stages of development on the standardised 1–9 scale used to measure the maturity of a technology from early laboratory development stages (Levels 1–3) to pilots and demonstrations (Levels 4–6) to being fully operational in a commercial system (Level 9).

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[57] Geopolymer Institute, *#23 Technical Paper on Geopolymer Aircraft Pavement*, (October 2015), https://www.geopolymer.org/library/technical-papers/technical-paper-on-geopolymer-aircraft-pavement/.
[58] Geopolymer Institute, "70,000 Tonnes Geopolymer Concrete for Airport," October 1, 2014, https://www.geopolymer.org/news/70000-tonnes-geopolymer-concrete-airport/.
[59] Meera Raghavan and Ashutosh Nair, "Geopolymer Concrete for Sustainable Construction: A Green Revolution in Civil Engineering," *International Journal of Advance Civil Engineering and Technology* 5, no. 1 (January-June 2020) https://admin.mantechpublications.com/index.php/IJoACET/issue/download/9339/10584.

- **Use of mineralizers.** These are used to improve the chemical reactivity of the cement raw mix and promote formation of crucial early strength minerals at lower temperature. Mineralizers allow clinker formation to take place at temperatures 50°C lower than usual without any adverse effect on clinker quality. This reduces fuel consumption, improves clinker mineralogy, and improves compressive strength. Mineralizers are currently at the higher technology readiness levels (TRL) 7–9 and nearing regular commercial use.
- **Fluidized bed technology.** Already used in other industries, this is promising for sintering (or burning) cement clinker. During the fluidization process, energy savings are achieved because heat transfer during clinkerization takes place via conduction; this is more energy efficient than the radiative heat transfer that is common in rotary kilns. Sintering within a fluidized bed has been validated in laboratory tests and pilots and is currently in the TRL 4–5 range. Limestone and clay calcination using fluidized beds is more developed and in the TRL 6–7 range, meaning it is moving from a validated prototype to a commercially deployed, field-proven product. Additionally, the use of oxyfuels with fluidized bed technologies in cement kilns creates a purer stream of CO_2 that improves the efficiency of CCUS.
- **Low-pressure-drop cyclones.** These are installed in pre-heater systems and will reduce the power consumption of the kiln exhaust gas fan system. Depending upon the efficiency of the fan, for every 50 mm water column (WC) reduction in pressure drop, specific power consumption typically decreases by 0.6–0.8 kWh/t clinker. Installation of low-pressure-drop cyclones involves costs that are site specific, but electrical energy consumption can be reduced. This is in the TRL 6–9 range.
- **High-efficiency classifiers.** In the latest grinding systems, classifiers separate the finer particles from coarser particles, and only the coarser particles are recycled back into the mill for additional grinding. Standard classifiers might have low separation efficiency, which leads to over-grinding of finer particles and increased grinding energy. Because high-efficiency classifiers offer better classification efficiency and do not allow over-grinding, the electrical energy consumption is reduced. This is at TRL 9, full commercial application.
- **High-efficiency motors and drives.** Several operations in cement plants are carried out by motors, including kiln rotation, transportation of material, and size-reduction operations. A cement plant may have as many as 700 electrical motors in operation. Power usage in the rotary kiln is approximately 50 kWh per ton clinker. Transitioning from fixed-speed AC motors to IE4/IE5 high-efficiency motors and installing VFDs on process fans can reduce electrical energy waste by 3–8%. Furthermore, minimizing

throttling losses in airflow systems is a critical zero-cost maintenance lever. This is at TRL 9, full commercial application.

6 Conclusion

The Indian cement sector stands at a pivotal juncture. The more than 400 MMT of cement produced annually contributes to approximately 6–7% of India's national GHG emissions. To support national climate goals, these emissions need to be reduced. At the same time, the sector has demonstrated remarkable resilience and technical leadership. Over the last decade, specific electrical energy consumption has been optimized to 73 kWh/tonne cement, and thermal energy intensity has stabilized at approximately 731 kcal/kg of clinker. These advances were driven by the adoption of vertical roller mills and advanced process controls, which demonstrate that Indian manufacturing is already among the most efficient globally.

Because efficiency has reached a thermodynamic plateau, the next phase of decarbonisation requires a structural shift from optimisation to transformation. To put the sector on a path to contribute to the goal of Net Zero by 2070, our recommended next steps are divided into three phases.

Phase 1 (2025 to 2030). The immediate priority for Phase 1 activities is to take full advantage of low-hanging fruit to reduce peak emissions intensity. This entails reducing the national average clinker-to-cement ratio from 0.72 to 0.65 by scaling composite cements like PPC and PSC while simultaneously operationalizing LC3 to leverage India’s clay reserves against future fly ash shortages. On the energy front, the sector should aim for 100% coverage of WHRS across integrated units and increase the renewable energy share to over 50% via Group Captive and Open Access models. Furthermore, thermal decarbonisation needs to be accelerated by boosting the TSR from the current low single digits to 15–20%; this will require unlocking supply chains for municipal solid waste and agricultural biomass. Phase 1 should also develop the key technologies and infrastructure required for Phases 2 and 3.

Phase 2 (2030 to 2040). In Phase 2 activities, the focus shifts to technologies that are currently maturing. This decade will define the transition from fossil-fuel dependence to circularity. Key levers include achieving TSR levels of greater than 30% and the integration of fluidized bed technologies leveraging oxyfuel kilns that produce a pure CO_2 stream and significantly lower the cost of capture. Other strategies that are not covered in this report but are relevant to whole-of-plant emissions include the widespread deployment of electric fleets for logistics. Phase 2 should also include the development of key technologies and infrastructure required for Phase 3.

Phase 3 (2040 to 2070). In Phase 3, focus shifts to addressing the unavoidable process emissions (~60% of the total). This phase relies on the commercial deployment of CCUS hubs and the potential switch to green hydrogen for thermal energy. Success here depends on the infrastructure laid down in the previous phases and the establishment of a viable CO_2 transportation network.

Achieving this roadmap requires explicit policy interventions to bridge the economic viability gap. On the supply side, the ₹20,000 crore CCUS budget allocation and the transition to the Indian Carbon Market provide the critical capital signals to de-risk high-capex technologies. On the demand side, the sector must overcome the “green premium,” which is currently estimated at 5–21% for early-stage alternative binders like LC3. To neutralize this cost barrier, implementing a robust Green Public Procurement (GPP) framework is essential. By mandating low-carbon cement use in large-scale government infrastructure projects such as airports and highways, GPP guarantees initial offtake. This strategic demand-side intervention absorbs early market risks, drives down costs through economies of scale, and catalyses broader decarbonisation. By aligning the supply, demand, and finance levers, the Indian cement sector can successfully decouple growth from emissions and serve as a blueprint for emerging economies and others in the Global South.

To translate this strategic framework into execution, the upcoming stage of this effort will formulate a comprehensive decarbonisation roadmap that quantifies the impact of key levers to accelerate the Indian cement sector’s transition to Net Zero.

7 Annexure: Stakeholder Consultation Output

We consulted with stakeholders on both the supply and demand sides of the value chain. On the supply side, these were cement manufacturers and industry experts, and on the demand side, developers, architects, and institutional buyers. The consultations revealed both a strong complementarity and a critical disconnect between the production and adoption of low-carbon cement.

On the supply side, cement manufacturers and sector experts outlined a clear and technically robust pathway for decarbonising cement production. Key strategies include increasing the use of alternative fuels, reducing clinker content through SCMs, deploying innovative low-carbon binders such as LC3 and geopolymers, improving energy efficiency through waste heat recovery, and piloting carbon capture technologies. Their collective view was that many of the technological solutions required to produce lower-carbon cement are already available and are progressively being integrated into Indian manufacturing facilities.

On the demand side, developers, architects, and institutional buyers expressed a strong willingness to adopt low-carbon cement products. However, they highlighted several barriers that constrain market uptake, including fragmented supply chains, the absence of clear standards and regulatory mandates, concerns regarding long-term performance, higher transition costs, and limited awareness among end users and project stakeholders.

Taken together, these perspectives present a coherent narrative: While the technological and manufacturing pathways for low-carbon cement are advancing rapidly, the market ecosystem, regulatory framework, and confidence-building mechanisms necessary to support large-scale adoption have yet to evolve at the same pace. Bridging this gap will be essential for accelerating the transition towards a low-carbon cement sector in India.

7.1 Supply-Side Stakeholder Views

7.1.1 Sector Expert 1, Chief General Manager, Holtech Consulting Private Ltd., Gurugram (Haryana)

Why are Alternative Fuels Needed?

- Fossil fuel scarcity
- Reduction of greenhouse gas emissions
- Energy security and reduced dependence on imports
- Waste-to-energy utilisation
- Better waste management and reduced landfill requirements
- Significant reduction in energy costs

Indian Cement Industry – What Is the Past and Future of Alternative Fuels?

- 2011: Limited co-processing, mainly industrial waste
- 2016 onward: Shift towards municipal solid waste (MSW), biomass, processing investments
- 2021: Policy support for alternative fuels emissions exemption
- 2030 target: 30–40% thermal substitution rate (TSR) to meet 2070 Net Zero ambitions

What Is the Waste Supply Potential in India?

- Generated MSW: ~160,000+ tonnes/day (TPD)
- Treatable RDF for cement: ~30,000+ TPD
- MSW is the key source for achieving 30% TSR

How Can Technology Gaps Be Bridged for Higher TSR?

- Need for advanced pre-processing plants
- Alternative fuels storage and automated feeding systems
- Bypass systems for handling chlorine
- Requirement of multi-fuel burners and pyro-section upgrades
- Install De-NO_x and De-SO_x environmental control equipment to remove nitrogen and sulphur oxides

What Types of Alternative Fuels Exist in India?

- Agricultural Biomass: Rice husk, wheat straw, bagasse
- Non-Agricultural Biomass: Sewage sludge, paper sludge
- Hazardous/Industrial Waste: Solvents, paint residues, tyres
- Municipal Waste Streams: RDF, plastics, textiles

What Is the Impact of Alternate Fuel Usage?

- Increased moisture may increase heat consumption
- Production limitation from preheater fan/calciner residence time
- Heavy metals mostly incorporated into clinker
- Potential reduction in WHR power recovery
- Chlorine could require bypass installation

Case Studies

- Europe plant: TSR improved to 45%, capacity increased, calciner and cooler upgraded
- India plant: Achieved 30% TSR after modifications like preheater fan and bypass additions

Key Takeaways and Goals That Will Be Met by the Use of Alternate Fuels

- Cost reduction and lower fossil fuel dependency
- Reduced landfill and environmental footprint
- Supports circular economy and national sustainability goals

What Is Holtec's Role in Decarbonisation?

- Energy audits, process optimization, clinker reduction
- Waste heat recovery systems (WHRS) and alternative fuels and raw materials (AFR) integration consulting
- Greenfield and brownfield engineering for low-carbon projects
- Execution: procurement, inspection, and site supervision

7.1.2 Sector Expert 2, Birla White Cement, Jodhpur (Rajasthan)

Why Decarbonise the Cement Sector?

- Protect public health through reduced air pollution
- Combat climate change by reducing greenhouse gases
- Ensure energy security by reducing fossil fuel dependence
- Enable green economic growth through clean-tech investments

What Are the Drivers for Indian Cement-Sector Decarbonisation, i.e., India's Net Zero Commitment?

- Net-zero greenhouse gas emissions target by 2070
- Expand non-fossil energy to 500 GW by 2030
- Meet 50% energy requirements via renewables by 2030
- Reduce carbon intensity by 45% by 2030
- Lower emissions by 1 billion tonnes by 2030

What Are the Sources of CO_2 Emissions in the Cement Sector?

- Calcination contributes 55–60% emissions
- Fuel combustion contributes 30–35%
- Electricity and transportation account for the remaining 5–15%

What Are the Main Decarbonisation Levers for the Cement Industry?

- Clinker efficiency (thermal energy improvements)
- Alternative fuels usage (biomass/waste-derived fuels)
- SCMs to reduce clinker factor (fly ash, slag, limestone, calcined clay)
- Decarbonisation of electricity through WHRS and renewables
- New binders (LC3, calcium sulfoaluminate, geopolymer, magnesium-based)

- Cement-use efficiency via ready-mix adoption
- CCUS: Carbon capture, utilization and storage

What Are India's Decarbonisation Targets (Cement)?

- Reduce emissions intensity by ~45% by 2030
- Blended cement share >85% by 2030
- TSR (Thermal Substitution Rate) 30–40% by 2030
- WHRS >50% adoption by 2030
- CCUS pilot development to begin before 2030

What is the Progress on Clinker Efficiency in India?

- India's average specific heat consumption has been achieved at ~715 kcal/kg clinker
- Expected target by 2030 is ~680 kcal/kg clinker
- Energy reduction via biomass fuels and advanced combustion

How Will SCM Adoption Lower Clinker Factor?

- Current clinker ratio ~73%
- Reduction target ~65% by 2030
- Major SCMs: Fly ash, slag, LC3 cement technologies
- CO_2 reduction potential: 15–25%

How Can Decarbonisation of Electricity Be Improved in Cement Plants?

- Electric energy use improvement from 70 to 65 kWh/ton
- WHRS installed ~1,100 MW versus >2,000 MW potential
- Shift to green electricity via renewables for plant operations

What Are Some Emerging New Low-Carbon Binders?

- LC3, which reduces CO_2 footprint by ~40%
- Calcium sulfoaluminate cement offers 25–30% reduction
- Geopolymers: offer up to 80% reduction

What Will Increase Cement Use Efficiency?

- Increased ready mix concrete (RMC) share to ensure optimized cement usage
- Better concrete mix design, use of admixtures, quality control

What Is the Perception of Carbon Capture, Utilization and Storage in the Marketplace?

- CO_2 capture efficiency: 85–95% (amine system)
- India in pilot stages and major barrier is high cost (~$80/ton CO_2)
- CO_2 utilization options include methanol, urea, polymers, sustainable aviation fuel (SAF)

What Is the Perception of SAF as a Utilisation/Circular Economy Option in the Marketplace?

- Up to 80% life cycle GHG reduction versus fossil jet fuel
- Can blend into existing fuel supply chain (“drop-in fuel”)
- Production pathway uses CO_2 + green hydrogen → methanol → SAF

Global Benchmark Comparison of India versus Other Countries/Regions?

- India lags behind EU/China/USA in alternative fuels usage and WHRS integration
- No current carbon pricing mechanism in India

Indian Decarbonisation Initiatives – Examples?

- Large cement groups investing in solar and wind capacity
- CO_2 emissions intensity reduction ~6–10% by industry leaders
- Biomass/industrial waste co-processing continues to expand

How is India developing Green Hydrogen and SAF Initiatives?

- Major partnerships: NTPC Limited (formerly National Thermal Power Corporation), Indian Oil Corporation Limited (IOCL), Bharat Petroleum Corporation Limited (BPCL), Greenko Group, GAIL (India) Limited (formerly known as Gas Authority of India Ltd.), Adani Group
- Focus on developing green hydrogen clusters and SAF pilots

7.2 Demand-Side Stakeholder Views

To better understand the perspectives of demand-side stakeholders, we held stakeholder consultations in Lucknow and Noida that brought together developers, architects, and industry consultants. The developers, architects, design professionals, cement-industry experts, and policy representatives from the Uttar Pradesh New and Renewable Energy Development Agency and the National Real Estate Development Council (NAREDCO) expressed a clear willingness to adopt low-carbon cement and green building materials such as LC3, composite cements, geopolymer concrete, fly ash bricks, and autoclaved aerated concrete (AAC) blocks. Participants acknowledged that these materials have shown promising performance in pilot applications and can be scaled with the right market support and regulatory backing. At the same time, they were candid that intent alone cannot move the market: Adoption is constrained by unreliable supply, the absence of statutory standards, gaps in performance data, higher transitional costs, and limited awareness across the value chain. The themes below capture the consolidated demand-side perspective.

7.2.1 Market and Supply Chain Barriers

Developers consistently identified the lack of a reliable supply chain as the most critical bottleneck in mainstream adoption. While demand for low-carbon alternatives exists, there is an “availability gap” that forces developers to treat these materials as high-risk and slows their market acceptance and use.

- Large-scale production of LC3 and geopolymer materials is limited, inconsistent, fragmented, and not yet at the scale needed for large construction projects.
- Uncertainty around steady availability and the absence of dependable suppliers continue to limit uptake in mainstream projects.
- Significantly, even established low-carbon options like fly ash bricks and AAC blocks face sourcing challenges at the required scale.
- In an illustrative experience, industry leaders Lodha and Mahindra Lifespaces reported that, despite a clear strategic intent to adopt LC3, they were unable to procure it for their projects due to supply shortages.

7.2.2 Regulatory and Standardisation Challenges

Stakeholders pointed to the regulatory and standardisation gaps that hinder market confidence and strongly recommended ways to address these challenges.

- Lack of finalised Bureau of Indian (BIS) standards and guidelines for green building material (GBM) classes remains a key barrier to confidence and procurement.
- Private rating systems such as the Confederation of Indian Industry’s GreenPro and the Green Rating for Integrated Habitat Assessment (GRIHA), India’s official national green building rating system developed by The Energy and Resources Institute (TERI) and backed by the Indian government, currently exist to classify and rate green materials. Because these frameworks lack the statutory backing of BIS, classification is left fragmented.
- BIS should establish a single, universally recognised classification process for green building materials.
- Integrating this standard into public procurement frameworks would de-risk adoption of new materials, signal market demand, and immediately boost developer confidence.

7.2.3 Technical and Performance Concerns

Architects and engineers expressed a strong need for more performance data, and cement experts pointed to the lack of pilot and demonstration projects. Both of these elements hinder market acceptance of new technologies.

- Need more performance data on the long-term durability, workability, and compatibility of low-carbon alternatives across varied climatic and structural conditions.
- Increase the number of pilot-scale and demonstration projects as these are the most direct ways to validate performance and build acceptance.

7.2.4 Cost and Financial Barriers

Developers pointed out that both initial costs and risk perceptions remain higher than for conventional materials and offered strategies to overcome these barriers.

- Higher procurement prices are driven by supply scarcity and higher manpower costs arising from longer settling times.
- Risk perceptions are also linked to unproven technology and supply-chain unreliability.
- Fiscal incentives, concessional finance, and recognition through carbon markets could bridge the financial gap during the transition phase to new technologies.

7.2.5 Awareness and Capacity Building

Participants at the Noida consultation agreed that awareness among builders, contractors, and clients remains limited, and that demand-side education is as important as technical readiness. They offered the following suggestions to address these concerns.

- Integrate low-carbon materials into green rating systems and expand training programmes for professionals.
- Educate youth, who increasingly shape home-buying decisions, through social-media campaigns highlighting how building ratings improve comfort, reduce costs, and enhance safety to build bottom-up demand.
- Train cement manufacturers’ sales teams to articulate the value proposition for low-carbon cement, including its benefits, applications, cost advantages, durability, and certifications.
- Drive mass-level promotion through mass market channels like TV, digital platforms, and real-estate expos to build broad-based demand and normalise low-carbon choices in the consumer marketplace.

7.2.6 Consolidated Key Recommendations

Drawing on both consultations, stakeholders converged on the following priority actions to bridge the information, policy, and market gaps and accelerate the transition to low-carbon cement:

- Accelerate standardisation and certification of low-carbon cement and integrate it into building codes and procurement systems.
- Create demand-pull mechanisms through green public procurement, large institutional buyers, and state-level mandates.
- Introduce financial incentives such as tax benefits, concessional finance, and carbon-credit eligibility.
- Support demonstration and pilot projects that showcase material performance and cost-effectiveness in real construction settings.
- Enhance awareness and capacity building through workshops, technical training (including unskilled workers), and including information in architectural and engineering curricula.

- Train cement sales teams on low-carbon cement and embed green performance indicators in sales pitches and technical materials.
- Launch mass-scale public awareness campaigns via TV, digital platforms, real-estate expos, and on-site “Low Carbon Cement Used Here” displays to build bottom-up demand.
- Raise youth awareness of green building rating systems through targeted social-media campaigns, integration with academic curricula, and developer-led promotion.
- Promote bulk procurement through a cluster-based approach in association with builders/developers’ associations such as NAREDCO and the Confederation of Real Estate Developers' Associations (CREDA) in India.

The demand side is ready to adopt low-carbon cement, but achieving adoption at scale will require addressing availability, standards, performance evidence, affordability, and awareness. Participants concluded that transitioning to low-carbon cement and construction materials is both necessary and achievable through collaborative action. Additionally, they expressed that bridging the current information, policy, and market gaps will be crucial for India’s cement industry to align with national decarbonisation goals and global sustainability commitments.

8 Annexure: Global Policies for Cement Decarbonisation

8.1 Overview

In considering options to further reduce emissions from the Indian cement and concrete sector, we review cement decarbonisation policies from other regions around the world. As seen in Table 8-1, in some instances, we highlight areas that have adopted innovative policy solutions. In other cases, we chose countries or regions that have market characteristics similar to those in India, as their policy choices are potentially relevant for India. The selected countries/regions are Vietnam, Indonesia, Malaysia, Thailand, Brazil, the European Union, Germany, and the United States.

Table 8-1: Comparison of the Market Characteristics of India and Select Regions

REGION	MARKET CHARACTERISTICS					
	Population as of 2026 (millions)[60]	Urbanisation rate as of 2024 (%)[61]	Large-scale infrastructure investment/ spending as of 2026 (USD annually)	Cement production as of 2024–2025 (MMT/year)[62]	Bagged cement market share (%)	Bulk cement market
India	1,400	37–40 (Up to 60 in peri-urban	$133 billion[63]	450–470	65	20-25
Vietnam	102	38–50	$41 billion[64]	100–110	65–70	Unknown
Malaysia	34.5	68	$41 billion	40[65]	Data not available	Majority
Thailand	71.5	62–63	$18 billion (2024)[66]	34[67]	Data not available	Data not available
Indonesia	288	60	$107 billion[68]	64–67	71–75[69]	29

60 "Countries in the World by Population (2026)," Worldometers, accessed June 2026, https://www.worldometers.info/world-population/population-by-country/.
61 "Urban Population, % of Total Population," WorldBank Open Data, 2024, https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS.
62 U.S. Geological Survey, *Cement Production by Country in 2025* (2026), https://pubs.usgs.gov/periodicals/mcs2026/mcs2026-cement.pdf and https://www.globalcement.com/magazine/articles/1390-global-cement-top-100-2026.
63 Ashwin Manikandan and Komal Salecha, "India Raises Infrastructure Spending by 11.4% to Record 12.2 Trillion Rupees for 2026-27," *Reuters*, February 1, 2026, https://www.reuters.com/world/india/india-budget-india-raises-infrastructure-spending-record-122-trillion-rupees-2026-02-01/.
Vietnam+, "Public Investment Disbursement Reaches 21.6% of 2026Ttarget," June 3, 2026, https://en.vietnamplus.vn/public-investment-disbursement-reaches-216-of-2026-target-post343933.vnp.
65 "Production of Cement in Malaysia from 2015 to 2024," Statista, accessed June 2026, https://www.statista.com/statistics/719188/cement-production-malaysia/?srsltid=AfmBOophsLGnNNA44X5pzg5GAKGtcX34VWL1TRx7UrNHdDX041ePXKyq.
66 Price Waterhouse Coopers, "Thailand Infrastructure Investment Projected to Hit THB21 trillion by 2050," news release, June 8, 2026, https://www.pwc.com/th/en/press-room/press-release/2026/press-release-08-06-26-en.html.
67 "Thailand Cement Industry Outlook 2025," January 5, 2026, https://www.thaipr.net/en/manufacturing_en/3681114.
68 "Indonesia Infrastructure Market Size and Share," Mordor Intelligence, last updated January 6, 2026, https://www.mordorintelligence.com/industry-reports/infrastructure-sector-in-indonesia.
69 "Indonesia Cement Industry Statistics," Wifi Talents, last updated June 22, 2026, https://wifitalents.com/indonesia-cement-industry-statistics/.

REGION	MARKET CHARACTERISTICS					
	Population as of 2026 (millions)[60]	Urbanisation rate as of 2024 (%)[61]	Large-scale infrastructure investment/ spending as of 2026 (USD annually)	Cement production as of 2024–2025 (MMT/year)[62]	Bagged cement market share (%)	Bulk cement market
Brazil	214	88	$300 billion	67	66–68[70]	32–34
European Union	453	75	Slowed down	415[71]	9–12	91
United States	349	83	$400 billion[72]	84–86	10–15	60–65

The international policies described in what follows fall into five categories that play key roles in decarbonising this sector: (1) pilots and demonstrations for alternative cements, and CCUS; (2) standards for low carbon products; (3) green public procurement; (4) energy efficiency, alternative fuels, and waste heat recovery; and (5) demand reduction. The findings and recommendations of this report on decarbonisation levers and technologies align with these categories of global policies. The items in 1 and 4 are key decarbonisation levers described in Figure 3. Standards for low-carbon products, green public procurement, and demand reduction are all essential elements that drive market transformation and work in concert with the supply-side recommendations described in the report.

Table 8-2 provides an overview of decarbonisation approaches different regions have identified as focus areas in various policies and roadmaps, and further details are in the sections that follow.

Table 8-2: Comparison of Cement Decarbonisation Approaches in Selected Regions

REGION	POLICY SOURCE(S)	DECARBONISATION APPROACH					
		Alternative cements	Alternative fuels, waste heat recovery	CCUS	Electrification / renewable energy use	Reducing energy, clinker	Reducing demand
ASEAN	AFCM 2035 Cement Decarbonisation Roadmap (Regional)[73]	●	●	●	●	●	Not included

[70] Yury Villagrán-Zaccardi et al., "Overview of Cement and Concrete Production in Latin America and the Caribbean with a Focus on the Goals of Reaching Carbon Neutrality," *RILEM Technical Letters* 7, (2022): 30-46, https://letters.rilem.net/index.php/rilem/article/view/155.

[73] Asian Federation of Cement Manufacturers, *2035 Asian Federation of Cement Manufacturers Decarbonisation Roadmap* (2025), https://www.thaicma.or.th/en/ebook_detail/15/231.

Vietnam	UNIDO Preliminary Roadmap for Industrial Decarbonisation in Vietnam[74]	●	●	●	●	●	●
Malaysia	NIMP 2030,[75] NTER,[76] AFCM Roadmap	●	●	●	●	●	Not currently
Thailand	TCMA 2050 Net Zero Cement & Concrete Roadmap[77]	●	●	●	●	●	●
Indonesia	5-Pillar Decarbonisation Strategy[78]	●	●	●	●	●	Not currently
Brazil	Netzero Roadmap for the Cement Industry[79]	●	●	●	●	●	Not currently
European Union	CEMBREU NetZero 2050 Roadmap,[80] CBAM[81]	●	●	●	●	●	●
United States	IIJA,[82] IRA,[83] Buy Clean	●	●	●	●	●	Private sector

[72] U.S. Geological Survey, *Mineral Commodity Survey: Cement. US Cement Market Statistics* (2026), https://pubs.usgs.gov/periodicals/mcs2026/mcs2026-cement.pdf.
[73] Asian Federation of Cement Manufacturers, *2035 Asian Federation of Cement Manufacturers Decarbonisation Roadmap* (2025), https://www.thaicma.or.th/en/ebook_detail/15/231.
[74] UN International Development Organization, *Preliminary Roadmap for Cement Decarbonization in Vietnam* (2024), https://decarbonization.unido.org/resources/preliminary-roadmap-for-industrial-decarbonisation-in-vietnam/.
[75] Ministry of Investment, Trade, and Industry of Malaysia, *Malaysia New Industrial Master Plan 2030* (2023), https://www.nimp2030.gov.my/.
[76] Ministry of Economy of Malaysia, *Malaysia National Energy Transition Roadmap* (2023), https://ekonomi.gov.my/sites/default/files/2023-08/National%20Energy%20Transition%20Roadmap.pdf.
[77] Thai Cement Manufacturer's Association, *Thailand 2050 Net Zero Cement & Concrete Roadmap* (2024), https://www.thaicma.or.th/en/ebook_detail/3/197.
[78] Kurniawati Hasjanah, "Government Finalizes Industrial Decarbonization Roadmap," Institute for Essential Services Reform, August 21, 2025, https://iesr.or.id/en/government-finalizes-industrial-decarbonization-roadmap/; and Global Cement, "Indonesian Government Backs Cement Industry's 5-Pillar Decarbonsation Strategy," April 17, 2026, https://www.globalcement.com/news/20661-indonesian-government-backs-cement-industry-s-five-pillar-decarbonisation-strategy.
[79] Brazilian Cement Industry Association et al., *Net zero Roadmap for the Brazilian Cement Industry* (2025), https://emaisenergia.org/wp-content/uploads/2025/11/Epg_roadmap-cimento_en.pdf.
[80] The European Cement Association (CEMBREAU), *Cement Europe's Net Zero Roadmap*, accessed June 2026, https://www.cementeurope.eu/about-us/our-net-zero-roadmap/.
[81] European Commission, *Carbon Border Adjustment Mechanism (CBAM) Policy* (2025), https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en.
[82] United States, "Infrastructure Investment and Jobs Act," Public Law No. 117-58, November 15, 2021, https://www.congress.gov/bill/117th-congress/house-bill/3684.
[83] United States, "Inflation Reduction Act," Public Law No. 117-169, August 16, 2022), https://www.govinfo.gov/content/pkg/PLAW-117publ169/pdf/PLAW-117publ169.pdf.

Table 8-3 provides an overview of additional elements being considered or applied by other countries to ensure their chosen decarbonisation approaches have the support needed for uptake. These are also further detailed in the sections that follow.

Table 8-3: Comparison of Supportive Strategies for Cement Decarbonisation in Selected Regions

REGION	DECARBONISATION SUPPORT						
	Regulatory framework support	Standards for low-carbon products	Green public procurement	Pilots/ demos	Market-wide stakeholder engagement	Carbon pricing, emissions trading system (cap & trade, cap & invest	Financing models (grants, credits, PPP, blended)
ASEAN	●	●	—	●	●	●	—
Vietnam	●	●	●	●	●	●	●
Malaysia	●	●	●	●	●	●	●
Thailand	●	●	●	●	●	●	●
Indonesia	●	●	●	●	●	●	●
Brazil	●	●	●	●	●	●	●
European Union	●	●	●	●	●	●	●
United States	●	●	●	●	●	●	●

8.2 Asia – Vietnam, Indonesia, Malaysia, and Thailand

ASEAN Region

In 2025, the ASEAN Federation of Cement Manufacturers (AFCM) published the 2035 Cement Industry Decarbonisation Roadmap, which was developed with support from the Global Cement and Concrete Association (GCCA). AFCM estimates a reduction of 38 MMT of CO_2 emissions across the region by 2035 based on its proposed strategies. The roadmap was endorsed by the industrial members from all eight covered countries in the region (Brunei, Cambodia, Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam), which all use significant quantities of cement for their rapidly growing infrastructure and construction needs.[84]

[84] CemNet, "ASEAN Cement Sector Launches First Regional Decarbonisation Roadmap," news release, December 1, 2025, https://www.cemnet.com/News/story/180359/asean-cement-sector-launches-first-regional-decarbonisation-roadmap.html#:~:text=The%20ASEAN%20Federation%20of%20Cement%20Manufacturers%20(AFCM),the%20Global%20Cement%20and%20Concrete%20Association%20(GCCA).

The roadmap offers regional goals in four focus areas: (1) increasing the use of low-carbon cement in the market, by promoting blended cements and performance-based standards; (2) improving the thermal and electrical efficiency of cement manufacturing processes, by promoting greater adoption of renewable energy; (3) maximising the use of alternative raw materials like SCMs to reduce use of clinker in concrete; and (4) promoting CCUS for deeper emission reductions. A key near-term action proposed by the roadmap is to immediately minimise the use of ordinary Portland cement (OPC) as an emission reduction strategy; this sets the stage for shifting to more blended cements through the use of alternative raw materials. The roadmap only indirectly supports green public procurement through its focus on regulatory infrastructure and standards, and it does not address demand reduction. It also gives each country leeway to tailor strategies and implementation timelines to their own needs, regulations, industrial setup, and energy systems.

All the Asian countries surveyed for this report are pursuing some form of an emissions trading scheme or setting up carbon markets, and they are also setting up financial models to support cement decarbonisation activities by industry.

Vietnam

Vietnam and India share similar market characteristics. Vietnam is the third-largest cement producer in the world (after China and India) and produces about 95 tonnes/year (one-fourth to one-fifth that of India) with installed capacity of 110–120 tonnes. Like other Asian nations, Vietnam is undergoing rapid and large-scale urbanisation and infrastructure development that requires cement. Bagged cement represents a relatively large share of the marketplace (30–40%), but the market is increasingly transitioning to ready-mix concrete for bulk concrete. As a smaller test crucible, Vietnam may potentially offer valuable lessons from the implementation of low-carbon cement and concrete.

In Vietnam, the Ministry of Construction has partnered with the UN International Development Organization (UNIDO) to initiate efforts to decarbonise the cement industry by addressing financial, technical, structural, regulatory, and behavioural barriers.[85] Key strategies include (1) setting up green public procurement; (2) de-risking private-sector investment, to enable the uptake of low-carbon options like LC3 and SCMs that reduce clinker use; and (3) promoting WHRS. Vietnam is also developing a national decarbonisation roadmap, standards for low-clinker cement, and carbon-management tools. Supported by the Ministries of Agriculture & Environment and Industry & Trade, this effort is being developed in conjunction

[85] UN Industrial Development Organization, "UNIDO Launches Initiative to Support Decarbonization of Vietnam's Cement Industry," news release, March 13, 2026, https://www.unido.org/news/unido-launches-initiative-support-decarbonization-viet-nams-cement-industry#:~:text=Viet%20Nam's%20cement%20sector%20is,and%20the%202050%20net%2Dzero%20commitment.

with the Vietnamese Cement Association and the Vietnam Institute of Building Materials, to ensure a coordinated approach across government and the private sector. While Vietnam, like other ASEAN nations, is collaborating with GCCA India and TERI to share best practices in decarbonisation approaches, it is developing its own tailored programme.

The policies that have been most successful in reducing cement sector emissions in Vietnam have been the regulatory mandates to use waste heat recovery in plants, reducing clinker with the use of SCMs, and adopting alternative blended cements like LC3. Alternative fuels and co-processing are gaining traction with some firms achieving a TSR of 40%,[86] but this has yet to scale nationally because the waste collection and sorting infrastructure is fragmented.[87] The Vietnamese Government has set a goal of expanding the usage of alternative fuels to 15% by 2030 and 30% beyond that.[88]

Other Asian Countries

Although Thailand (27 tonnes per year, or tpy), Malaysia (40 tpy), and Indonesia (69 tpy), produce less cement[89] than India, they share similar urbanisation trends and infrastructure needs (highways, ports, rail), even as the rate and scale vary. Like India, each of these markets also relies on bagged cement products to a large degree.

Indonesia

Indonesia is implementing strategies used by China and India but may also offer useful lessons from a practical field perspective.[90] The Indonesian Ministry of Industry of Standardization and the Industrial Services Policy Agency recently announced a five-pillar cement decarbonisation strategy that includes (1) process optimization, (2) alternative fuels

[86] Legal Framework Needed to Promote Waste Co-processing in Cement Plants." Viet Nam News (2025). https://vietnamnews.vn/environment/1726645/legal-framework-needed-to-promote-waste-co-processing-in-cement-plants.html

[87] "Vietnam Cement Industry Aims for Sustainable Development," Bach Dang Cement (2024), https://ximangbachdang.vn/en/vietnam-cement-industry-aims-for-sustainable-development/.

[88] "Co-processing waste in cement kilns has huge potential in Vietnam." Moitruongachau (2022). https://moitruongachau.com/en/co-processing-waste-in-cement-kilns-has-huge-potential-in-vietnam.html

[89] Global Cement, "Global Cement Top 100 2026," November 24, 2025, https://www.globalcement.com/magazine/articles/1390-global-cement-top-100-2026.

[90] Institute for Essential Services Reform, "Webinar: Accelerating Cement Decarbonization in Indonesia Towards 2050: Learning from India and China," September 8, 2025, https://iesr.or.id/en/agenda-iesr/webinar-accelerating-cement-decarbonization-in-indonesia-toward-2050-learning-from-india-and-china/#:~:text=Under%20the%20Perform%2C%20Achieve%2C%20and,Europe%20and%20the%20United%20States.

and raw material substitution, (3) technology upgrades, (4) electrification/renewables, and (5) carbon capture.[91]

Indonesia has leveraged clinker reduction successfully by blending materials like fly ash, slag, and limestone to reduce its clinker-to-cement ratio from a 2010 baseline of 81% to 68% as of 2026.[92]

Malaysia

Malaysia's cement decarbonisation strategy draws on its National Energy Transition Roadmap (NETR), which drives the transition to low-carbon energy for high-emission industries like cement,[93] its New Industrial Master Plan (NIMP) 2030, which seeks to decarbonise industry through energy efficiency and regulatory support for green technology,[94] and the ASEAN Regional Cement Decarbonisation Roadmap. Malaysia aims to have a net-zero cement industry by 2050 by (1) reducing its clinker ratio with materials like fly ash; (2) promoting alternative fuels like biomass using industrial and municipal waste in waste-to-energy schemes to reduce coal in kilns up to 60%; (3) becoming more energy efficient; and (4) adopting CCUS.

In Malaysia, the most viable cement decarbonisation technologies in the near term include reducing clinker, using alternative cements, and alternative fuels.[95]

Thailand

Thailand is working with UNIDO and Canada to increase the share of low-carbon sources in its cement and concrete sector. The first implementation phase is focused on policy, research, technology development, and capacity-building efforts.[96] On the policy front, the key areas include (1) advancing green public procurement to send strong demand signals to the marketplace, (2) strengthening regulatory frameworks and aligning them with its national cement manufacturer association roadmap, and (3) conducting pilots and demonstrations of co-processing approaches to clarify techno-economic viability. In terms of techno-economic viability, they are assessing (a) using municipal solid waste and sludge as alternative fuels or raw materials; (b) using carbon capture technologies, including mobile capture options, that

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[91] Global Cement, "Indonesian Government Backs Cement Industry 5-pillar Decarbonisation Strategy, April 17, 2026, https://www.globalcement.com/news/20661-indonesian-government-backs-cement-industry-s-five-pillar-decarbonisation-strategy.

[92] "Indonesia Reports Lower Cement Emissions as Decarbonisation Roadmap Advances," *Cemnet*, April 21, 2026, https://www.cemnet.com/News/story/181196/indonesia-reports-lower-cement-emissions-as-decarbonisation-roadmap-advances.html.

[93] Ministry of Economy of Malaysia, *National Energy Transition Roadmap*.

[94] *Reuters*, "Malaysia Keen to be Green," October 28, 2025, https://www.reuters.com/plus/malaysia-keen-to-be-green.

[95] "Malaysia's Cement Change for a Greener Environment," ASH Development Association of Australia, 2024, https://www.adaa.asn.au/2024/07/malaysias-cement-change-for-a-greener-environment/.

[96] UN Industrial Development Organization, "Thailand Advances Cement Decarbonization Through UNIDO-Supported Project," news release, March 23, 2026, https://www.unido.org/news/thailand-advances-cement-decarbonization-through-unido-supported-project.

can be transported between cement plants; and (c) using limestone calcined clay blended cements. Once scaled and deployed, such technologies are expected to reduce almost two-thirds (16 million tpy) of the emissions from Thailand's cement sector. Additionally, innovative technologies that are validated through the UNIDO Accelerate-to-Demonstrate Facility may also be considered for future deployment to further reduce emissions, boost industrial competitiveness, and participate in regional scaling of low-carbon cement options over the long term.

In Thailand, implementing alternative cements like LC3 and using alternative fuels like agricultural and municipal waste are the main near-term strategies to drive down emissions from the sector.[97]

8.3 Brazil

Brazil's cement sector is one of the lower-emitting industries globally, and averages 564 kg of CO_2 per tonne of cement.[98] This is also well below the global average and largely due to a reliance on renewable alternative fuels and a low clinker-to-cement ratio. India and Brazil both have large and growing populations, urbanisation, large-scale infrastructure needs, government-backed housing, and challenges in evenly deploying cement technologies across the nation due to differing regional geographies and needs. In Brazil, bagged cement is 65–68% of the market, more than bulk cement. The reliance on bagged cement is primarily due to a high-volume informal construction sector, individual home builders, and small-scale renovations.

Brazil is actively developing policy frameworks to continue decarbonising the cement industry and align with its goal of 67% greenhouse gas emission reductions by 2035. The national strategy involves a mix of carbon pricing, regulatory standards for low-carbon products, and investments in alternative fuels and technology.

The Brazilian Cement Roadmap[99] outlines several decarbonisation focus areas, including: (1) additions and clinker substitutes, such as by-products from other industrial activities; (2) alternative fuels (biomass, high calorie waste); (3) energy-efficient equipment to reduce power and thermal consumption; (4) innovative and emerging technologies such as CCUS; (5) promoting standards for low-carbon cements; (6) supporting pilots and demonstrations of innovative technologies in conjunction with research and development institutions like

[97] UNIDO, *Thailand Advances Cement Decarbonisation*.

[98] Sindicato Nacional da Indústria do Cimento, *Brazil Cement Technology Roadmap* (2024), http://snic.org.br/assets/pdf/roadmap/cement-technology-roadmap-brazil.pdf.

[99] Sindicato Nacional, *Brazil Cement Technology Roadmap*.

academia and laboratories; and (7) identifying financing models to support industry in adopting energy-efficient technologies and equipment.

In addition to its reliance on renewable energy to decarbonise its grid, Brazil is also relying on clinker reduction and alternative fuels to further reduce cement emissions. [100]

8.4 European Union

As outlined in the European Union's cement-sector decarbonisation roadmap,[101] there are four main areas of policy focus: a Carbon Border Adjustment Mechanism (CBAM) to ensure fair competition and prevent firms from leaving to avoid meeting their emissions commitments; strong financial incentives and tools to enable decarbonisation investments through grants, de-risking instruments, and providing access to funding (e.g., capital through loans); guaranteeing access to affordable and low-carbon resources such as energy and raw materials and the necessary infrastructure to support large-scale pilots, demonstrations, and deployments of new or innovative low carbon technologies; and the creation of new markets for low-carbon, circular-economy products that reduce the waste in landfills or emissions at the smokestack. In addition, Europe also promotes standards development for low-carbon products and supports the use of alternative fuels and waste heat recovery.

The European Union uses clinker reduction and alternative fuels (biomass, refuse-derived fuels, and sewage sludge instead of coal). The EU cement sector leads globally with an average fossil fuel substitution rate of over 56%, and some plants in Germany and Poland achieve as high as 80–100% substitution rates.[102,103] The European Union has also relied heavily on regulatory tools like its Emissions Trading Scheme (ETS) and the CBAM, which establish a carbon price in the market that leads to demand reduction and makes the market more efficient.[104]

Germany

Germany has a policy for contracts for differences (CfDs), also known as carbon (or clean) contracts for differences (CCfDs). CfDs are an efficient funding instrument that allows

[100] Sindicato Nacional, *Brazil Cement Technology Roadmap.*
[101] The European Cement Association, *Cement Europe's Net Zero Roadmap*.
[102] Cement Europe, *Cement Action Plan* (2025), https://www.cementeurope.eu/media/ee4a4f4r/cement-action-plan_by-cement-europe_october-2025.pdf.
[103] New Climate Institute, *Decarbonisation Pathways for the EU Cement Sector* (2020), https://newclimate.org/sites/default/files/2020/12/SGCCC-EU-Cement-paper-NewClimate_Nov2020.pdf.
[104] The European Cement Association, *Cement Europe's Net Zero Roadmap*.

investors and financiers to estimate and manage the risk associated with adopting transformative technologies. CfDs offset the additional costs incurred by companies in hard-to-abate sectors like cement that are due to the construction, capital expenses and operational expenses of innovative, lower-emission new plants compared with conventional plants; this facilitates the switch to newer plants by making costs and risks more predictable, new technologies more marketable, and enabling construction financing based on equity and debt capital.[105] Germany is the first EU member state to launch funding using CfDs. This new and innovative funding instrument was previously passed through the European Commission's approval procedure under state aid rules.

In October 2024, Germany signed 15 CfDs worth €2.8 billion with projects in several industrial sectors. The goal of the German CfD programme is to reduce emissions by an estimated 17 million tCO_2e over a 15-year period. Companies in the programme are employing the CfD instrument as a hedge against energy costs and carbon revenues, which typically are challenging to predict, because the CfD index is tied and adjusted to the energy price (e.g., electricity, hydrogen) and the carbon price under the German emissions trading system. This will directly prevent the emissions of large amounts of greenhouse gases. In total, approximately 350 MMT of carbon emissions are expected to be avoided as a result of the funding programme in the period to 2045. This corresponds to up to 20 MMT of greenhouse gas reductions a year, which is a little more than one-third of the German industrial sector's 2030 target. Additionally, expertise in the fields of financing, construction, and the operation of climate-friendly installations and markets for climate-friendly end-products (green lead markets) will also be developed. Numerous countries inside and outside the European Union intend to set up similar funding instruments in the near future.[106]

8.5 United States of America

Over the past decade, the United States has developed several policies and laws, at both the federal and state levels, that individually and collectively enable key mechanisms to transform the market for low-carbon materials and create economy-wide impacts. They include promoting green public procurement to create market demand; promoting pilots and demonstrations of low-carbon material production (e.g., calcined clay cement and concrete plants) and emission reduction technologies such as CCUS in the industrial sector;

105 Federal Ministry for Economic Affairs and Energy of Germany, "First Round of Carbon Contracts for Difference Launched," news release, March 3, 2024, https://www.bundeswirtschaftsministerium.de/Redaktion/EN/Pressemitteilungen/2024/03/20240312-first-round-of-carbon-contracts-for-difference-launched.html.

106 Wesley Look et al., *Contracts for Difference to Spur Clean and Competitive Industry: Options for Federal Policymakers* (ACEEE, 2025), https://www.aceee.org/research-report/i2501.

establishing standards for low-carbon products; and promoting the use of alternative fuels and energy-efficient practices. These approaches are enabled through a variety of financing mechanisms including grants, tax incentives, public loan guarantees, and public-private partnerships. Federal funding also flowed down to state-level programmes (e.g., state departments of transportation) for further disbursement to municipalities for direct state and local impacts.

Nationally, two key laws established mandates and practical mechanisms to encourage the industrial, buildings, and construction sectors to adopt next-generation manufacturing processes and use new approaches and materials to reduce their emissions. They were primarily intended to advance green procurement, pilots, and standards to enable this transformation. These laws and their implementation have undergone significant shifts as of 2026, with some portions terminated while others continue. Some of the activities that were originally covered under these laws are being continued by private-sector entities and consortia from across the market on regional and state levels.

Bipartisan Infrastructure Law (BIL) or Infrastructure Investment and Jobs Act (IIJA) of 2021. This law was aimed at modernizing national public infrastructure such as transportation, including roads, bridges, rail, and ports, drinking and wastewater systems, and power grids. As part of its holistic approach to reducing emissions across the economy, it promoted domestic energy production by investing in clean energy and technology with a goal of reducing carbon emissions by approximately 40% by 2030. The law included mandates for projects to use U.S.-produced iron, steel, and construction materials as part of the Buy in America, Build in America approach. In funding projects related to public transit, airports, and electric vehicle (EV) charging stations, and efforts to improve air and water quality, this law supported the use of low-carbon construction materials and reduced emissions from public-sector construction while also creating jobs and improving supply chain logistics.[107] A high percentage of the funding was through grants.[108]

Inflation Reduction Act (IRA) of 2022. Among its many provisions, this law set aside funds to reduce emissions in construction by increasing the demand for and use of low-carbon building materials and products like concrete, steel, asphalt, and glass. This was done through

[107] United States, "Infrastructure Investment and Jobs."
[108] William D. Eggers and John O'Leary, "Executing on the $2 Trillion Investment to Boost American Competitiveness," Deloitte Government and Public Services, March 16, 2023, https://www.deloitte.com/us/en/insights/industry/government-public-sector-services/infrastructure-bill-projects-agency-execution.html.

Buy Clean programmes for public procurement by federal government agencies like the General Services Administration, the Federal Highway Administration, and the Department of Defense. Concurrently, the policy also set up a government programme to develop a low-carbon material labelling system, emission benchmarks for products like cement and steel, and national repositories of environmental product declarations (EPDs) to help developers select sustainable options. The bulk of the funding through the IRA was via tax incentives.[109]

Pilots and demonstrations. A key element of these policies was the availability of government funding through the IIJA and IRA to subsidize research, development, demonstration and deployment costs[110] through existing and new venues; these included the Department of Energy's national lab system, the manufacturing institute system, and the Office of Clean Energy Demonstrations. Funding was also available to promote pilots, demonstrations, and commercial deployment of innovative, ready-to-commercialize new technologies such as alternative cements and concrete and CCUS through public-private partnership (PPP) programmes like the Industrial Demonstrations Program and nationally established Centers of Excellence.

Concurrent with these federal-level efforts, state and local governments pursued similar policies to amplify federal impacts and made additional efforts to maximise energy efficiency and reduce demand for energy.

Green public procurement. A key element in the push to advance low-carbon building materials regionally is being mediated by the more than 15 state and city governments that have established Buy Clean policies, mandates, or laws for green public procurement. One target for these is the cement and concrete used in state department of transportation projects; such projects typically drive 50% of the material procurements at the state level and serve as a catalyst for private-sector procurement, as this often relies on state-approved material specification lists.[111] A study by ACEEE and Global Efficiency Intelligence assessed the emissions reduction across all 50 U.S. states that would be enabled by using low-carbon options like LC3.[112] Independent studies like these identified potential hotspots for more focused policy and deployment activity. Furthermore, coordination between the national and local levels through a federal-state Buy Clean partnership was also conceived to promote

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[109] Eggers and O'Leary, "Executing on the $2 trillion."

[110] Jamie Friedman, *Cement and Concrete Companies Leading the Netzero Transition* (Center for American Progress, 2024), https://www.americanprogress.org/article/cement-and-concrete-companies-leading-the-net-zero-transition/#:~:text=30-,Public%20procurement,for%20federally%20funded%20construction%20projects.

[111] Nora Wang Esram, Pavitra Srinivasan, and Jonah Eisen, *Planned Strategically, Federal Buy Clean Investment Can Increase its Impact* (ACEEE, 2023), https://www.aceee.org/topic-brief/2023/03/planned-strategically-federal-buy-clean-investment-can-increase-its-impact.

[112] Ali Hasanbeigi et al., *Adoption of Limestone Calcined Clay Cement and Concrete in the U.S. Market* (ACEEE and GEI, 2024), www.aceee.org/research-report/i2401.

alignment of policies and strengthen market signals through regional carbon intensity benchmarks, harmonised labelling programmes, and definitions for low-carbon for materials like cement and concrete.

Energy efficiency, alternative fuels, and reduced energy demand. In some U.S. states, legislation has been passed or is currently being considered to advance the use of alternative fuels such as waste-derived fuels, biomass, and industrial by-products in cement kilns instead of coal and petcoke. Some state governments, like Colorado, have fuel-switching mandates for industrial facilities.[113] Others, like California, have passed laws[114] to remove economic barriers faced by large energy consumers like cement plants so they can more easily implement energy efficiency measures like industrial process heat recovery (IPHR); IPHR reduces emissions by 30% while generating carbon-free electricity for on-site use during the manufacturing process.[115]

Many of these U.S. policies corroborate similar strategies being considered in the Indian market. They also offer a framework for integrating national, state, and local efforts. However, a key difference is that about 75% of the U.S. concrete market relies on bulk or ready-mix concrete and about 11% of it is pre-cast products. Bagged cement is largely for individual homeowner use and represents about 10–15% of the market. The use of ready-mix and pre-cast offers some innate advantages and barriers to new cement and concrete implementation, and the strategies to overcome them will differ in the Indian market, which substantially relies on bagged cement and hollow-core slabs (precast). However, with the increasing use of ready-mix concrete in India, the United States can provide lessons on how to accelerate the transition to new low-carbon materials and avoid known issues.

Carbon pricing and markets. While there is no carbon price or emissions trading system established at the national level, there are cap-and-trade and cap-and-invest programmes in certain states and regions. For example, the state of California operates the largest multi-sector cap-and-invest programme in North America (since 2013). Additionally, the state of Washington has an economy-wide cap-and-invest programme that took effect in 2023, and it

[113] Colorado Department of Public Health & Environment, "Greenhouse Gas Emissions and Energy Management for Manufacturing (GEMM) Phase 2 Rule," accessed June 2026, https://cdphe.colorado.gov/apcd/GEMM-phase-2-rule.
[114] California State Assembly, "Assembly Bill 2109, Electricity: Surcharge Exemption: Industrial Process Heat Recovery," February 5, 2024, https://legiscan.com/CA/text/AB2109/id/2915472.
[115] ACEEE, "Regulatory Filing on Industrial Process Heat Recovery in Cement Plans," October 16, 2024, https://www.aceee.org/regulatory-filing/2024/10/industrial-process-heat-recovery-cement-plants.

auctions allowances. The Regional Greenhouse Gas Initiative is a cap-and-trade system among 10 northeastern and Mid-Atlantic states (including Maryland, New York, Massachusetts, and New Jersey) that limits CO_2 emissions from the power sector, which indirectly leads to a reduction in embodied carbon for cement products manufactured using grid power.[116]

The United States has successfully implemented green public procurement through its Buy Clean programs in several states and is supporting pilots and demonstrations of new products as part of both publicly and privately funded projects.

8.6 Concluding Remarks

This brief review of global policy options supports the recommendations made in this report around expanding green public procurement, conducting pilots for CCUS and alternative cements, developing performance standards for low-carbon products, expanding the use of alternative fuels and waste heat recovery, continuously improving energy efficiency where feasible, and addressing demand side issues. It also offers additional innovative financing ideas for consideration in the short, medium, and long term. As these ideas are explored further, differing needs at the local and national level in India will require that polices adapted from other countries be further studied, with a view to designing options to suit the Indian context.

Additionally, since India exports cement to countries in Asia, Africa, and the European Union, this review underscores that the Indian cement sector's is making progress on decarbonisation that is in alignment with evolving global policy developments, including the European Union's Carbon Border Adjustment Mechanism and the increasingly ambitious climate commitments in key export markets.

[116] Center for Climate and Energy Solutions, "US State Carbon Pricing Policies," last updated January 2025, https://www.c2es.org/document/us-state-carbon-pricing-policies/.

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