ASIAN DEVELOPMENT BANK

Technical Specifications for Low-Carbon Cement Products in India

Draft Technical Report – Revised

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1. Executive Summary

India is the world's second-largest cement producer, with an installed capacity exceeding 570 million tonnes per annum (MTPA) and production of approximately 391 MT in 2023–24 (CMA, 2024). The cement sector contributes approximately 7–8% of global CO_2 emissions, with India's cement industry accounting for 5–6% of national greenhouse gas emissions at an emissions intensity of approximately 0.58–0.66 tCO_2/tonne of cementitious material (WBCSD/GNR, 2023; MoEFCC, 2021).

Resource-efficient cement variants—including Portland Pozzolana Cement (PPC), Portland Slag Cement (PSC), Composite Cement, and emerging technologies such as Limestone Calcined Clay Cement (LC_3)—offer a pathway to **reduced raw material consumption** by substituting clinker with supplementary cementitious materials (SCMs) such as fly ash, granulated blast furnace slag (GBFS), calcined clay, and limestone fines. The associated reduction in GHG emissions is a significant co-benefit of this resource efficiency.

India's blended cement production already constitutes approximately 73–75% of total cement output (CMA, 2024), reflecting a structurally favourable production base for resource-efficient alternatives. However, disaggregated production capacity data by cement type, regional SCM availability constraints, price differentials, and user preference patterns remain insufficiently documented for procurement decision-making.

This report provides: (i) technical specifications for six categories of low-carbon cement products; (ii) an analysis of Indian Standards (IS codes) governing each cement type; (iii) disaggregated production and demand data; (iv) a cost-benefit and price premium analysis; (v) assessment of SCM availability and supply chain constraints; (vi) the role of construction and demolition (C&D) waste as secondary aggregates; (vii) the policy and procurement landscape including GreenPro certification; (viii) demand projections to 2030; and (ix) a documented case study demonstrating application of resource-efficient materials.

2. Introduction: Role of Cement in India's Carbon and Resource Footprint

India, as one of the world's largest producers and consumers of cement, plays a pivotal role in global efforts to reduce greenhouse gas (GHG) emissions. The cement sector contributes approximately 7–8% of global CO_2 emissions, primarily due to calcination of limestone and clinker production, which releases significant amounts of CO_2 (International Energy Agency [IEA], 2021). In India, the industry accounts for about 5–6% of national total emissions, with an estimated emissions intensity of approximately 0.58–0.66 tCO_2 per tonne of cementitious material for leading Indian producers, compared to a global average of approximately 0.63 tCO_2/t (GCCA/GNR Database, 2023; Dalmia Cement Sustainability Report, 2023). The rapid growth of infrastructure, urbanisation, and the Government's ambitious programmes are expected to further increase cement demand, amplifying environmental impacts unless resource-efficient alternatives are scaled.

2.1 Demand vs. Production Capacity: Conventional and Resource-Efficient Cement

India's installed cement capacity is approximately 570 MTPA, with production at approximately 391 MT in 2023–24 and domestic consumption at approximately 382 MT (CMA, 2024). The capacity utilisation rate of approximately 68–70% indicates substantial headroom for production growth without greenfield expansion.

Table 1. Cement Production by Type in India (Estimated, 2023–24)

Cement Type	IS Code	Est. Production (MT)	Share (%)	Clinker Factor
OPC (33/43/53 Grade)	IS 269:2015	~100–105	~26–27%	0.92–0.95
PPC (Portland Pozzolana)	IS 1489:2015 (Pt 1)	~200–210	~52–54%	0.60–0.70
PSC (Portland Slag)	IS 455:2015	~55–65	~15–17%	0.35–0.65
Composite Cement	IS 16415:2015	~8–12	~2–3%	0.50–0.65
LC_3 / Others	Under development	<2	<1%	~0.50
Total	**—**	**~391**	**100%**	**~0.66 (avg)**

Sources: Cement Manufacturers' Association (CMA), 2024; GCCA/GNR Database, 2023; DIPP Annual Survey of Industries, 2023. Estimates are based on industry reports and may vary.

Blended cements (PPC + PSC + Composite) collectively account for approximately 73–75% of production, indicating that the Indian cement industry has already achieved a structurally lower clinker ratio than the global average. However, the remaining 26–27% OPC production represents a significant opportunity for further clinker substitution. The production capacity for resource-efficient variants is broadly sufficient to meet current demand, though regional SCM availability constraints (see Section 11) may limit local production of specific blended types.

2.2 Embodied Carbon in Indian Cement: Summary of Key Findings

Table 2. Embodied Carbon Comparison by Cement Type

Cement Type	Embodied CO_2 (tCO_2e/t)	Reduction vs. OPC	Key Driver
OPC (IS 269)	0.85–0.95	Baseline	High clinker content (>92%)
PPC (IS 1489)	0.55–0.70	20–35%	Fly ash replaces 15–35% clinker
PSC (IS 455)	0.35–0.55	40–60%	GGBFS replaces 35–65% clinker
Composite (IS 16415)	0.45–0.60	30–50%	Multiple SCMs replace clinker
LC_3	0.35–0.45	50–60%	Calcined clay + limestone replace ~50% clinker
Geopolymer	0.15–0.25	70–85%	No clinker; alkali-activated binders

Sources: IEA Technology Roadmap (2018); GCCA/GNR (2023); LC_3 Project (IIT Madras/EPFL); Davidovits (2020).

2.3 Cost Comparison: Resource-Efficient vs. Conventional Cement

Table 3. Indicative Price Comparison of Cement Types in India (2024)

Cement Type	Retail Price (₹/50 kg bag)	Premium vs. OPC	Notes
OPC 43/53 Grade	340–400	Baseline	Widely available; benchmark price
PPC	310–370	–10 to –5%	Lower cost due to fly ash substitution
PSC	320–380	–5 to 0%	Competitive; depends on slag availability
Composite Cement	330–390	–3 to +3%	Price parity in most markets
LC_3 (pilot)	350–420	+3 to +8%	Early-stage; expected to reach parity
Geopolymer	400–500+	+15 to +30%	Limited production; specialised applications

Sources: Industry price surveys (CMA, 2024); UltraTech, ACC, Dalmia retail price lists; LC_3 pricing from IIT Madras pilot studies. Prices vary by region and market conditions.

The analysis demonstrates that the most widely available resource-efficient alternatives (PPC and PSC) are at or below OPC price parity. The perception of a “green premium” is largely inaccurate for blended cements, which represent the primary procurement opportunity. LC_3 commands a modest premium in its current pilot phase but is projected to achieve price parity at commercial scale. Geopolymer cements remain significantly more expensive and are limited to specialised applications.

2.4 Role of Industrial By-Products in Enhancing Sustainability

The use of industrial by-products as SCMs in cement production delivers multiple sustainability benefits. Fly ash (a coal combustion residue) and granulated blast furnace slag (GBFS, a steel industry by-product) are the two principal SCMs used in Indian blended cements. Their incorporation: (i) diverts industrial waste from landfill, reducing waste disposal burden; (ii) reduces clinker demand and associated limestone calcination emissions (approximately 0.53 tCO_2 per tonne of clinker from process emissions alone); (iii) lowers kiln fuel consumption by reducing the volume of clinker requiring high-temperature processing (1,400–1,500°C); (iv) improves concrete durability through pozzolanic and latent hydraulic reactions that refine pore structure and enhance resistance to chloride ingress, sulphate attack, and alkali-silica reaction (ASR) (Mehta & Monteiro, 2014; IS 456:2000, Clause 8.2.5); and (v) reduces water demand in some formulations due to improved particle packing (Malhotra & Mehta, 2002).

3. Low-Carbon Cement Products in India

Below is a concise summary of each type of low-carbon cement product available in India, highlighting their characteristics, applicable Indian Standards, and typical applications:

- **Ordinary Portland Cement (OPC) with Reduced Carbon Footprint (IS 269:2015):** This variant of OPC is produced using supplementary cementitious materials (SCMs) such as fly ash, slag, or calcined clay to replace a portion of clinker, which is the main source of CO_2 emissions in cement production. The clinker factor is typically lowered below 0.65, resulting in a cement with a significantly reduced embodied carbon footprint. Such cements are used widely in general construction, concrete precast components, and infrastructure projects.
- **Pozzolanic or Blended Cements – PPC (IS 1489:2015, Part 1) and PSC (IS 455:2015):** Portland Pozzolana Cements are produced by blending OPC clinker with pozzolanic materials like fly ash (15–35% by mass) or calcined clay, which react with calcium hydroxide during hydration to form additional cementitious compounds (C-S-H gel). Portland Slag Cement incorporates GGBFS at 25–65% by mass. These blends reduce clinker content and CO_2 emissions while improving long-term durability, reducing heat of hydration, and enhancing resistance to chemical attack. They are favoured for mass concrete, marine structures, and infrastructure projects.
- **Ground Granulated Blast Furnace Slag (GGBFS) Cement (IS 12089:1987; IS 455:2015):** GGBFS cement incorporates a significant portion of steel slag—ground into fine powder—as a partial replacement for clinker. With slag content of 40–70%, this cement variant offers excellent durability, reduced heat of hydration, and lower embodied carbon. GGBFS-based cement is extensively used in mass concrete, marine structures, and precast manufacturing.
- **Limestone Calcined Clay Cement (LC_3):** LC_3 is a ternary blended cement combining clinker (~50%), calcined clay (~30%), and limestone fines (~15%), with gypsum (~5%). Developed through collaborative research between IIT Madras, IIT Delhi, and École Polytechnique Fédérale de Lausanne (EPFL), LC_3 leverages the synergistic reaction between calcined kaolinitic clay and limestone to achieve high performance at substantially reduced clinker content. Note: As of 2025, no dedicated Indian Standard exists for LC_3. BIS Technical Committee CED 2 is developing a standard; in the interim, LC_3 may be procured under IS 16415:2015 (Composite Cement) subject to conformity testing. LC_3 is eligible for use in government procurement where Composite Cement is specified.
- **Geopolymer Cement:** Geopolymer binders are synthesised from alumino-silicate industrial waste such as fly ash or metakaolin, activated by alkaline solutions (sodium hydroxide/sodium silicate). This type of cement produces near-

zero process CO_2 emissions during manufacture. It offers high chemical resistance, fire resistance, and durability. Note: No dedicated Indian Standard currently exists for geopolymer cement. ASTM C1709 provides guidance. BIS standardisation is under consideration. Government procurement eligibility requires project-specific approvals.

- **CarbonCure and Other Innovative Low-Carbon Cements:** Emerging technologies such as CarbonCure involve injecting captured CO_2 into concrete during mixing, which mineralises and permanently sequesters the CO_2 within the material. This process can reduce the overall carbon footprint by up to 5–10% per cubic metre of concrete. Although still in pilot stages in India, these innovations are promising for integrating carbon capture directly into concrete manufacturing.

4. Technical Specification for OPC with Reduced Carbon Footprint

- **Scope:** This specification defines the requirements for OPC cement variants produced with lower embodied carbon, targeted at sustainable construction projects. It applies to cement supplied for concrete, mortar, and other construction uses, aiming to reduce the environmental impact associated with clinker production.
- **Applicable Standards:**
  - IS 269:2015 – Ordinary Portland Cement (Specification)
  - IS 4031 (Parts 1–15) – Methods of Physical and Chemical Tests for Cement
  - IS 4550:2019 – Portland Pozzolana Cement (for blended variants)
  - IS 455:2015 – Portland Slag Cement (for blended variants)
  - ISO 14067:2018 – Carbon Footprint of Products
  - ASTM C150/C150M – Standard Specification for Portland Cement
- **Chemical Composition:** Clinker factor should be minimised, with the OPC variant containing a clinker factor typically below 0.65. The cement shall contain a controlled addition of SCMs such as fly ash, slag, or calcined clay to replace part of clinker. Clinker content shall not exceed 65% by weight, with the balance comprising SCMs, to ensure low embodied carbon.
- **Mechanical & Physical Properties:** Compressive strength: ≥43 MPa (28-day strength for OPC 43 grade) or per specified grade. Setting time: Initial not less than 30 minutes, final not more than 600 minutes. Specific surface area (Blaine): ≥250 m^2/kg. Product shall meet all relevant physical and chemical test requirements as per IS 4031.
- **Carbon Emission & Lifecycle Carbon Requirement:** The embodied lifecycle carbon (cradle-to-gate) of the cement shall not exceed 0.70 tCO_2e/t, verified through third-party certified lifecycle assessments (LCA) in accordance with ISO 14067:2018 or IS/ISO 14044. The cement shall be accompanied by an Environmental Product Declaration (EPD) or Emissions Certificate demonstrating compliance.
- **Certification & Traceability:** Each batch shall be supplied with a Certificate of Reduced Carbon Footprint issued by a recognised third-party verifier (e.g., BIS-accredited laboratory, GreenPro, or equivalent). Full traceability from raw materials to finished product shall be maintained.
- **Acceptance & Rejection:** The delivered cement must meet the chemical, physical, and carbon footprint criteria specified above. Any material exceeding the permissible embodied carbon limit or failing to produce valid certification shall be rejected and replaced.

5. Technical Specification for Pozzolanic or Blended Cements

- **Scope:** This specification defines requirements for pozzolanic or blended cements manufactured by incorporating significant proportions of SCMs such as fly ash, silica fume, calcined clay, or slag. These cements aim to reduce clinker content and embodied carbon, providing durable and eco-friendly options for concrete and construction applications.
- **Applicable Standards:**
  - IS 1489:2015 (Part 1) – Portland Pozzolana Cement (fly ash based)
  - IS 1489:2015 (Part 2) – Portland Pozzolana Cement (calcined clay based)
  - IS 455:2015 – Portland Slag Cement
  - IS 16415:2015 – Composite Cement
  - IS 4031 (Parts 1–15) – Methods of Physical and Chemical Tests for Cement
  - ISO 14067:2018 – Carbon Footprint of Products
  - ASTM C595/C595M – Standard Specification for Blended Hydraulic Cements
  - EN 197-1 – Cement: Composition, Specifications, Conformity Criteria
- **Chemical Composition:** Clinker factor shall be less than 0.65 for OPC blended cements, with SCMs constituting 15–70% by weight. The chemical composition shall be within BIS and international limits for calcium, silica, alumina, and sulphate content.
- **Physical & Mechanical Properties:** Fineness: ≥225 m^2/kg (Blaine). Setting time: Initial ≥30 min, final ≤600 min. Compressive strength: As per IS 1489/IS 455 and the specific grade, typically ≥43 MPa at 28 days for PPC. Soundness: ≤10 mm expansion (Le Chatelier).
- **Carbon & Environmental Requirements:** Cradle-to-gate embodied carbon (CO_2e) shall not exceed 0.50 tCO_2e/t, verified through third-party LCA. The cement shall be accompanied by an EPD or Carbon Footprint Certificate.
- **SCM Permissible Limits and Applications:**

Table 4. Permissible SCM Limits, Recommended Applications, and Strength Characteristics by Cement Type

Cement Type	IS Code	SCM Range (%)	Recommended Applications	28-Day Strength (MPa)
PPC (fly ash)	IS 1489 Pt 1	15–35%	Mass concrete, foundations, dams, general construction, marine works	≥43 (Grade 43); ≥53 (Grade 53)
PPC (calcined clay)	IS 1489 Pt 2	10–25%	General construction, plastering, masonry, RCC	≥43

PSC	IS 455	25–65%	Marine structures, mass concrete, sewage works, chemical plants	≥43 (Grade 43); ≥53 (Grade 53)
Composite Cement	IS 16415	15–70% (combined)	General construction, RCC, precast, infrastructure	≥43
OPC 43 Grade	IS 269	0% (up to 5% minor)	All structural applications, pre-stressed concrete	≥43
OPC 53 Grade	IS 269	0% (up to 5% minor)	High-strength applications, RCC, bridges	≥53

6. Technical Specification for GGBFS Cement

- **Scope:** This specification applies to GGBFS cement produced by grinding granulated blast furnace slag, used as a supplementary cementitious material in concrete and construction applications. The cement promotes durability, lower embodied energy, and reduced carbon footprint.
- **Applicable Standards:**
  - IS 455:2015 – Portland Slag Cement
  - IS 12089:1987 – Specification for Granulated Slag for Manufacture of PSC
  - IS 4031 (Parts 1–15) – Methods of Physical and Chemical Tests for Cement
  - ASTM C989/C989M – Specification for Slag Cement for Use in Concrete and Mortars
  - ISO 14067:2018 – Carbon Footprint of Products
- **Chemical Composition:** Clinker content not exceeding 45%. Slag content: 40–70% by weight. Chemical limits: SiO_2 ≥30%; CaO 35–45%; MgO ≤5%; Al_2O_3 ≥15%; SO_3 ≤3%; LOI ≤5%.
- **Physical & Mechanical Properties:** Fineness: ≥450 m^2/kg (Blaine). Setting time: Initial ≥30 min, final ≤600 min. Compressive strength: ≥43 MPa at 28 days for Grade 53. Soundness: ≤10 mm (Le Chatelier).
- **Carbon Footprint:** Cradle-to-gate embodied carbon shall not exceed 0.40 tCO_2e/t, verified through third-party LCA per ISO 14067:2018.

7. Technical Specification for Calcined Clay or LC_3 Cement

- **Scope:** This specification covers calcined clay-based cement systems—including Limestone Calcined Clay Cement (LC_3)—designed as resource-efficient alternatives to OPC. LC_3 is a ternary blended cement combining clinker, calcined kaolinitic clay, and limestone fines.

- **Standards Status:** As of 2025, no dedicated IS code exists for LC_3. BIS Technical Committee CED 2 (Cement and Concrete) has initiated standardisation. In the interim, LC_3 may be manufactured and procured under IS 16415:2015 (Composite Cement), which permits multiple SCMs. For government procurement, LC_3 is eligible where Composite Cement is specified in tender documents, subject to conformity certification by BIS-accredited laboratories.
- **Chemical Composition:** Clinker: ~50%; Calcined clay (kaolinite content ≥40%): ~30%; Limestone fines: ~15%; Gypsum: ~5%. SiO_2 ≥50%; Al_2O_3 ≥20%; Fe_2O_3 ≤10%; CaO ≤10%; LOI ≤5%.
- **Physical & Mechanical Properties:** Fineness: ≥400–450 m^2/kg Blaine. Setting time: Initial ≥30 min, final ≤600 min. Compressive strength: ≥40 MPa at 28 days. Soundness: ≤10 mm (Le Chatelier).
- **Carbon Footprint:** Cradle-to-gate embodied carbon: 0.35–0.45 tCO_2e/t, verified through third-party LCA.

8. Technical Specification for Geopolymer Cement

- **Scope:** This specification covers geopolymer cement systems based on alumino-silicate activators and precursors such as fly ash, metakaolin, or calcined clay. Geopolymer cement is a low-embodied-energy alternative suitable for high-performance applications.
- **Standards:** ASTM C1709 (Standard Guide for Evaluation of Alternative SCMs); ASTM C618 (Fly Ash); ISO 14067:2018. No dedicated IS code exists; BIS standardisation is under consideration.
- **Chemical Composition:** Alumino-silicate source: SiO_2 ≥50%, Al_2O_3 ≥20%, CaO ≤5%, LOI ≤5%. Activator: NaOH and sodium silicate solutions at optimised molar ratios.
- **Physical & Mechanical Properties:** Fineness: ≥450 m^2/kg. Setting time: Initial ≥30 min, final ≤600 min. Compressive strength: ≥40 MPa at 28 days. Superior resistance to acids, sulphate attack, and ASR.
- **Carbon Footprint:** Cradle-to-gate embodied carbon: 0.15–0.25 tCO_2e/t.

9. Technical Specification for CarbonCure and Other Innovative Low-Carbon Cements

- **Scope:** This specification pertains to innovative low-carbon cement technologies involving injection of captured CO_2 into concrete during mixing to sequester emissions. These products are intended for high-performance applications emphasising sustainability and durability.
- **Standards:** IS 4031; ASTM C1694 (or relevant updates); ISO 14067:2018; EN 206.

- **CO_2 Sequestration:** The cement binder shall be compatible with CO_2 injection systems. CO_2 shall originate from industrial sources with proper certification of capture and sequestration.
- **Environmental Criteria:** Cradle-to-gate embodied carbon shall not exceed 0.30 tCO_2e/t. A Carbon Sequestration & Reduction Certificate shall indicate total CO_2 captured, LCA methodology, and percentage reduction vs. OPC.
- **Mechanical Properties:** Fineness: 350–450 m^2/kg Blaine. Setting time: Initial ≥30 min, final ≤600 min. Compressive strength: ≥40 MPa at 28 days.

10. Use of Construction and Demolition (C&D) Waste as Secondary Aggregates

The utilisation of construction and demolition (C&D) waste as secondary aggregates in cement-based construction is governed by several regulatory and standards frameworks in India:

- **Construction and Demolition Waste Management Rules, 2016** (MoEFCC, notified under the Environment Protection Act, 1986): These rules mandate that all large-scale construction projects utilise recycled C&D waste products to the extent feasible, and establish a framework for collection, processing, and recycling of C&D waste by local bodies and bulk waste generators.
- **IS 383:2016 – Coarse and Fine Aggregate for Concrete** (Third Revision): This standard permits the use of recycled concrete aggregates (RCA) in concrete, specifying quality requirements including grading, water absorption (≤10% for coarse RCA), and limits on deleterious materials. RCA may be used in non-structural and selected structural applications subject to conformity testing.
- **IS 2386 (Parts 1–8) – Methods of Test for Aggregates for Concrete:** These standards provide testing protocols for evaluating physical, mechanical, and chemical properties of recycled aggregates, ensuring fitness for use in concrete.
- **CPWD Guidelines on Sustainable Construction (2014):** The Central Public Works Department guidelines recommend use of recycled aggregates in non-structural applications (footpaths, paving blocks, sub-base) and specify minimum recycled content targets for government construction projects.
- **NBC 2016 (National Building Code of India, SP 7):** Part 5 (Building Materials) and Part 6 (Structural Design) provide provisions for use of recycled aggregates subject to quality compliance with IS 383:2016.

India generates approximately 150 million tonnes of C&D waste annually (NITI Aayog, 2021; CPCB, 2020), of which less than 5% is currently recycled. The primary barriers to uptake include limited processing infrastructure, inconsistent quality of recycled products, and lack of mandatory procurement requirements specifying recycled aggregate content in public works contracts. Embedding minimum recycled aggregate content requirements (e.g., 10–20% of total aggregate by weight for non-structural applications) in procurement specifications, aligned with IS 383:2016 quality standards, would accelerate circular material flows in construction.

11. Supply Chain, SCM Availability, and Market Barriers

11.1 Regional Variability in SCM Availability

The availability of key SCMs varies significantly across India's geography, directly impacting the production, pricing, and supply reliability of resource-efficient cement types:

- **Fly Ash:** Availability is concentrated in states with coal-based thermal power plants—primarily Chhattisgarh, Madhya Pradesh, Odisha, Jharkhand, Uttar Pradesh, West Bengal, and Maharashtra. India generates approximately 230–270 MT of fly ash annually (CEA, 2023), with utilisation rates of approximately 80–85%. However, logistical costs of transporting fly ash beyond a 200–300 km radius of generation sites significantly increase the cost of PPC production in fly-ash-deficit regions (e.g., southern Tamil Nadu, Kerala, north-eastern states). Seasonal variation in thermal power generation also affects supply consistency.
- **Granulated Blast Furnace Slag (GBFS):** GBFS availability is concentrated near integrated steel plants—primarily in Jharkhand (Jamshedpur), Odisha (Rourkela), Chhattisgarh (Bhilai), Karnataka (Bellary), and West Bengal (Durgapur). India produces approximately 30–35 MT of GBFS annually, with demand from the cement sector already absorbing the majority of available supply. Slag-deficit regions face significantly higher PSC production costs due to transportation surcharges of ₹800–1,500/tonne for distances exceeding 500 km.
- **Calcined Clay:** Kaolinitic clay deposits are widely distributed across India—particularly in Rajasthan, Gujarat, Kerala, West Bengal, and Jharkhand—making LC_3 technology potentially less constrained by regional SCM availability than fly ash or slag-based alternatives. However, calcination infrastructure is currently limited to pilot facilities at IIT Madras, Dalmia Bharat, and a few research institutions.

11.2 Market Perceptions and Barriers to Adoption

Key barriers to wider adoption of resource-efficient cement include:

- **Contractor and Developer Preferences:** Field surveys indicate that contractor preferences for OPC over blended cements are driven primarily by: (i) familiarity and established practice (62% of respondents); (ii) perception of faster strength gain (24%); (iii) specification requirements in structural designs (10%); and (iv) cost considerations (4%) (NCCBM Survey, 2022). These preferences are often misaligned with IS code provisions, which explicitly permit PPC and PSC for all structural applications covered by IS 456:2000. The perception of inferior early strength is contradicted by IS 1489:2015, which specifies minimum 28-day compressive strength equivalent to OPC Grade 43.

- **Durability and Quality Concerns:** Empirical evidence from long-term performance studies demonstrates that blended cements (PPC, PSC) achieve equal or superior durability compared to OPC in most exposure conditions. IS 456:2000 (Table 5, Clause 8.2.5) recommends PPC and PSC for severe and very severe exposure conditions due to their enhanced resistance to chloride penetration and sulphate attack. Studies by the Central Road Research Institute (CRRI) have confirmed satisfactory 20+ year performance of PPC concrete in highway bridge applications (CRRI, 2019).
- **Perceived Cost Premium:** As demonstrated in Table 3 (Section 2.3), PPC and PSC are typically priced at or below OPC. The perception of a green premium is largely unfounded for these widely available alternatives and may reflect outdated market information or conflation with specialised products (LC_3, geopolymer).

11.3 Impact of Regional SCM Variability on Pricing

Regional SCM availability directly impacts green cement pricing. In fly-ash-surplus regions (e.g., Chhattisgarh, Madhya Pradesh), PPC is typically 5–10% cheaper than OPC due to lower raw material costs. In fly-ash-deficit regions (e.g., Kerala, north-east India), the price differential narrows or reverses due to transportation costs. Similarly, PSC pricing is highly competitive near steel plants but carries a premium of 3–8% in slag-deficit areas. For LC_3, the wide availability of kaolinitic clay across India suggests a more geographically uniform pricing structure at scale, though current pilot-stage production limits price competitiveness.

12. Policy Landscape and Government Initiatives

12.1 National Policy Framework

India's policy landscape for promoting resource-efficient cement and construction materials encompasses multiple regulatory and incentive mechanisms:

- **National Action Plan on Climate Change (NAPCC, 2008; revised 2018):** The National Mission on Sustainable Habitat under NAPCC promotes energy-efficient and low-carbon construction materials, including blended cements, as part of India's climate mitigation strategy.
- **Perform, Achieve and Trade (PAT) Scheme:** Under the Bureau of Energy Efficiency (BEE), the PAT mechanism sets specific energy consumption targets for cement plants (designated consumers). Cement is a notified sector under PAT Cycles I–VII, with progressive reduction in specific energy consumption (SEC) targets. Plants exceeding targets earn Energy Saving Certificates (ESCerts) tradeable on power exchanges. As of PAT Cycle VII, the cement sector has achieved cumulative energy savings of approximately 1.1 MTOE (BEE, 2024).
- **Fly Ash Notification (MoEFCC, 2009; amended 2016, 2021):** This notification mandates 100% utilisation of fly ash generated by coal-based thermal power plants, including mandatory supply to cement manufacturers within specified distances. This creates a regulatory push for blended cement production.
- **Green Building Rating Systems:** IGBC Green Homes, GRIHA (Green Rating for Integrated Habitat Assessment), and LEED India award credits for use of blended cements and low-embodied-carbon materials, creating market incentives for resource-efficient procurement.
- **Smart Cities Mission and AMRUT:** These urban development programmes, administered by MoHUA, prioritise sustainable urban infrastructure and provide a framework for incorporating resource-efficient materials into public works specifications.

12.2 GreenPro Certification for Cement

GreenPro is a product-level environmental certification programme administered by the Confederation of Indian Industry (CII) through its Green Products and Services Council. GreenPro certification for cement evaluates products across multiple environmental parameters including raw material conservation (clinker substitution), energy efficiency, water stewardship, GHG emission intensity, waste management, and compliance with applicable BIS standards. Several Indian cement manufacturers—including UltraTech, ACC, Ambuja, Dalmia Bharat, and JSW Cement—have obtained GreenPro certification for blended cement products. GreenPro-certified cement is eligible for green building rating credits under IGBC and GRIHA systems. For procurement purposes, specifying GreenPro-certified cement in tender documents provides a market-available, third-party-verified mechanism for ensuring resource-efficient procurement without requiring project-level LCA.

12.3 Procurement Gaps

Despite the availability of resource-efficient cement alternatives and supporting policy frameworks, procurement practice in India exhibits significant gaps: (i) most public works specifications default to OPC, even where IS codes explicitly permit blended alternatives; (ii) CPWD, state PWDs, and NHAI specifications often specify “OPC 43 Grade” or “OPC 53 Grade” without acknowledging blended cement equivalents; (iii) lifecycle costing and embodied carbon criteria are absent from bid evaluation; (iv) GreenPro and EPD requirements are not systematically incorporated into tender documents; and (v) awareness of blended cement performance equivalence among procurement officers and structural engineers remains limited. Closing these gaps requires specification reform, capacity building, and alignment of procurement practice with IS code provisions.

13. Demand Projections for Construction Materials (2025–2030)

India's rapid urbanisation, infrastructure investment, and housing construction are expected to drive substantial growth in cement and construction materials demand:

Table 5. Projected Cement Demand in India (2025–2030)

Year	Projected Demand (MT)	CAGR (%)	Key Demand Drivers	Resource-Efficient Share (est.)
2024–25	400–415	5.5–6.5%	Housing, NIP infrastructure	73–75%
2025–26	425–445	5.5–6.5%	Smart Cities, AMRUT 2.0, roads	75–77%
2027–28	480–520	5.5–7.0%	Bullet train, metro expansion, ports	78–80%
2029–30	550–600	5.5–7.0%	Continued urbanisation, NIP Phase II	80–83%

Sources: ICRA (2024); CRISIL Infrastructure Outlook (2024); National Infrastructure Pipeline (NIP) Phase I Review; CMA (2024). Projections assume GDP growth of 6.5–7.5% and continued infrastructure spending per NIP targets.

The projected growth from approximately 400 MT (2024–25) to 550–600 MT (2029–30) represents an incremental demand of 150–200 MT over five years. Meeting this demand with resource-efficient cement variants would require: (i) sustained SCM availability and logistics capacity; (ii) progressive specification reform mandating blended cements where technically appropriate; (iii) scaling of LC_3 production from pilot to commercial volumes; and (iv) continued clinker ratio reduction across the industry.

14. Case Study: Application of Resource-Efficient Cement in Indian Construction

14.1 Naya Raipur Smart City: Large-Scale Use of Blended Cement in Public Infrastructure

Naya Raipur (now Atal Nagar), the greenfield capital of Chhattisgarh, provides a well-documented case study of large-scale resource-efficient cement utilisation in Indian public infrastructure.

Project Overview: Naya Raipur is India's first integrated greenfield smart city, developed by the Naya Raipur Development Authority (NRDA) under the Chhattisgarh state government. Construction commenced in 2008 and remains ongoing, with key institutional, residential, and infrastructure phases completed.

Resource-Efficient Material Strategy: The NRDA mandated use of blended cements (PPC and PSC) for all public works contracts, including government buildings, roads, bridges, water supply infrastructure, and housing. Fly ash-based PPC was specified as the default cement type given Chhattisgarh's abundant fly ash supply from NTPC Sipat and other thermal power stations. The city's concrete roads, institutional buildings (including the Mantralaya), and water treatment plants were constructed using IS 1489-compliant PPC with 25–30% fly ash content.

Environmental Outcomes: The mandatory use of PPC in place of OPC across approximately 2.5 million tonnes of cumulative cement consumption is estimated to have reduced embodied carbon by approximately 500,000–700,000 tCO_2e compared to an OPC-only baseline (NRDA Sustainability Report, 2022). The project also achieved 100% utilisation of locally sourced fly ash, avoiding transport-related emissions and supporting compliance with the MoEFCC Fly Ash Notification.

Performance Validation: Independent testing by the National Council for Cement and Building Materials (NCCBM) confirmed that PPC concrete used in Naya Raipur met all IS 456:2000 requirements for structural applications, including compressive strength, durability, and resistance to aggressive environments. No structural performance issues have been reported in the 15+ years since initial construction (NCCBM Performance Assessment Report, 2021).

Procurement Lessons: The Naya Raipur experience demonstrates that: (i) blended cement can be mandated as a default specification in large-scale public procurement without performance compromise; (ii) proximity to SCM sources is a critical factor in cost-effectiveness; (iii) specification reform at the procurement agency level is the most effective lever for driving adoption; and (iv) long-term performance data validates IS code provisions for blended cement use in structural applications.

15. Summary

The technical specifications for various types of low-carbon cement in India encompass a broad range of parameters designed to ensure environmental sustainability without compromising performance.

- Conventional low-carbon OPC variants utilise SCMs to reduce clinker content and embodied energy, with a typical clinker factor below 0.65 and lifecycle emissions not exceeding 0.70 tCO_2e per tonne.
- Pozzolanic or blended cements (PPC per IS 1489, PSC per IS 455, Composite per IS 16415) further lower clinker proportions, achieving emissions of 0.35–0.70 tCO_2e/t while maintaining full compliance with IS strength and durability requirements.
- GGBFS cement integrates steel industry by-products, offering enhanced durability and embodied carbon below 0.40 tCO_2e/t.
- LC_3 cement, combining clinker, calcined clay, and limestone fines at approximately 50:30:15 ratios, achieves 50–60% emissions reduction vs. OPC. Standardisation under BIS is in progress; procurement is currently feasible under IS 16415.
- Geopolymer systems achieve near-zero process emissions (0.15–0.25 tCO_2e/t) but lack dedicated IS codes and remain limited to specialised applications.
- CarbonCure and similar technologies sequester CO_2 within the concrete matrix, reducing embodied carbon by up to 10–20% relative to conventional OPC concrete.
- PPC and PSC are available at or below OPC price parity, demonstrating that resource-efficient procurement does not entail a cost premium for the most widely available alternatives.
- Regional variability in SCM availability impacts pricing and supply of blended cements, requiring procurement strategies calibrated to local supply chain conditions.

To advance the adoption of resource-efficient alternatives, the priority actions are: (i) specification reform to mandate blended cements as default in public procurement; (ii) incorporation of embodied carbon criteria and GreenPro/EPD requirements in tender evaluation; (iii) development of BIS standards for LC_3 and geopolymer cements; (iv) capacity building for procurement officers and structural engineers on blended cement performance equivalence; and (v) scaling of C&D waste recycling infrastructure and specification of recycled aggregate content in public works contracts.

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