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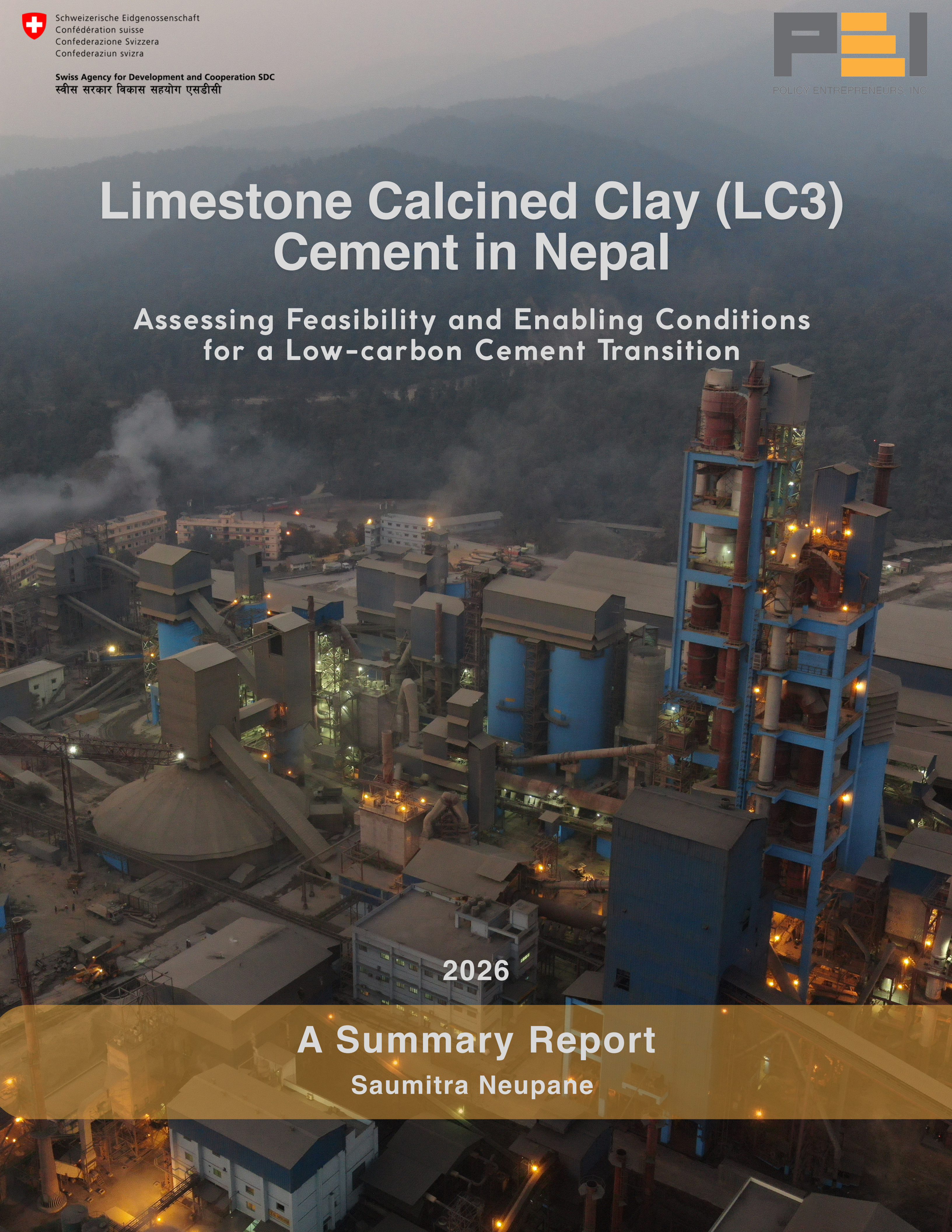

Limestone Calcined Clay (LC3) Cement in Nepal

Assessing Feasibility and Enabling Conditions for a Low-carbon Cement Transition

2026

A Summary Report

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Executive Summary

Context. Nepal's cement sector sits at the intersection of three structural pressures: high and rising carbon emissions, deep dependence on imported coal and supplementary cementitious materials, and finite domestic limestone reserves. Despite achieving clinker self-sufficiency, the sector imports over one million tons of coal annually and relies almost entirely on India for the fly ash and blast furnace slag that enable blended cement production.

Opportunity. Limestone Calcined Clay Cement (LC3) presents a technically validated and economically attractive pathway to address all three pressures simultaneously. By replacing up to 50 percent of clinker with calcined clay and limestone, LC3 can reduce cement-related carbon emissions by 30–40 percent, cut coal consumption by approximately 36 percent per ton of cement, and reduce dependence on imported SCMs — while delivering raw material cost savings of up to NPR 2,500 per ton of cement produced.

Constraints. Three interrelated constraints shape the transition: (1) residual uncertainty around the mineralogical quality and commercial viability of domestic clay resources; (2) the absence of a Nepal Standard for LC3, which is the single most binding barrier to adoption; and (3) differential firm-level incentives that create a misalignment between who has the strongest motivation to adopt and who has the capacity to drive regulatory change.

Conclusion. The transition to LC3 is not constrained by capital intensity or technological barriers — payback periods for required investments range from one to three years under moderate utilization. What is missing is institutional alignment. A narrow window of opportunity is open, shaped by improving geological data, India’s adoption of an LC3 standard in 2023, and rising cost pressures across the sector. The priority action is clear: initiate LC3 standards development through NBSM without delay.

1.0 Background and LC3 Overview

The global cement sector is responsible for approximately 7–8 percent of total carbon dioxide emissions, making it one of the largest industrial sources of greenhouse gases. Clinker production — the most energy- and emissions-intensive step in cement manufacturing — accounts for 85–90 percent of these sector-level emissions. Clinker is produced by heating limestone in rotary kilns at approximately 1,450°C, generating emissions both through fossil fuel combustion and through the chemical calcination of calcium carbonate to calcium oxide.

Reducing the clinker-to-cement ratio — the clinker factor — has emerged as the most immediate and scalable decarbonization pathway. The global average clinker factor currently stands at approximately 0.76, against a 2050 target of 0.59. The primary mechanism is the expanded use of Supplementary Cementitious Materials (SCMs), which partially replace clinker in cement formulations. The two most widely used SCMs — fly ash from thermal power plants and blast furnace slag from steel production — face long-term supply constraints as coal phase-outs accelerate globally. These pressures have driven growing interest in clay-based SCMs, and specifically in LC3.

Developed through research led by EPFL and its international partners, LC3 replaces up to 50 percent of clinker with a blend of calcined clay and limestone. The key mechanism is the transformation of kaolinite — a clay mineral — into metakaolin through calcination at 600–800°C. Metakaolin is a highly reactive pozzolanic material that enables clinker substitution while maintaining strength performance. Research confirms that clays containing a minimum of 40 percent kaolinite are most suitable for LC3-50 formulations, achieving compressive strengths comparable to Portland cement after seven days. LC3 is a proven technology, commercially operational in Europe, Africa, Latin America, and India. India adopted a national LC3 standard — IS 18189:2023 — in 2023, a development of direct relevance to Nepal's regulatory pathway.

Clinker reduction pathways and performance across cement types

Cement Type	Clinker Share	Main SCMs	CO_2 Intensity	Performance Notes
OPC	90–95%	Gypsum only	~800–900 kg/ton	High early strength; structural benchmark
PPC	65–75%	Fly ash / pozzolana	~600–700 kg/ton	Slower early strength; comparable long-term durability
LC3	~50%	Calcined clay (~30%), limestone (~15%)	~500–600 kg/ton	Comparable strength; superior chloride resistance

2.0 Nepal's Cement Sector

Industry structure and overcapacity

Nepal's cement industry has undergone a rapid structural transformation over the past decade. Following the 2015 earthquake reconstruction period, installed production capacity expanded to approximately 20 million tonnes per annum (MTPA) against domestic demand of only 7–9 MTPA. The sector now operates under chronic overcapacity: ~ 50 percent load factor.

Approximately 65 firms are currently operational, including around 23 integrated producers that control limestone mining, clinker kilns, and cement grinding, and over 42 milling-only firms that depend on purchased clinker. Integrated producers account for the largest share of the market, with five to seven firms each holding roughly 10–15 percent of total market share. Milling-only firms occupy a more commercially exposed position: they depend on integrated producers for clinker supply, giving them limited control over their input cost base.

This structural differentiation is central to understanding the LC3 transition. Integrated producers are best positioned technically to adopt LC3 — they control kilns, laboratories, and raw material supply chains. Milling-only firms have the strongest financial incentive, since clinker represents their largest cost component at approximately NPR 8,500 per ton. The gap between incentive and capability is one of the key dynamics shaping the sector's response to LC3.

Import dependencies and supply risk

Although Nepal has achieved self-sufficiency in clinker and cement production, the sector remains structurally dependent on imported inputs. Clinker production requires between 120 and 180 kilograms of coal per tonne of clinker, with coal imported primarily from India and third countries. The cement industry accounts for the single largest share of Nepal's industrial coal consumption, importing over one million tons per year.

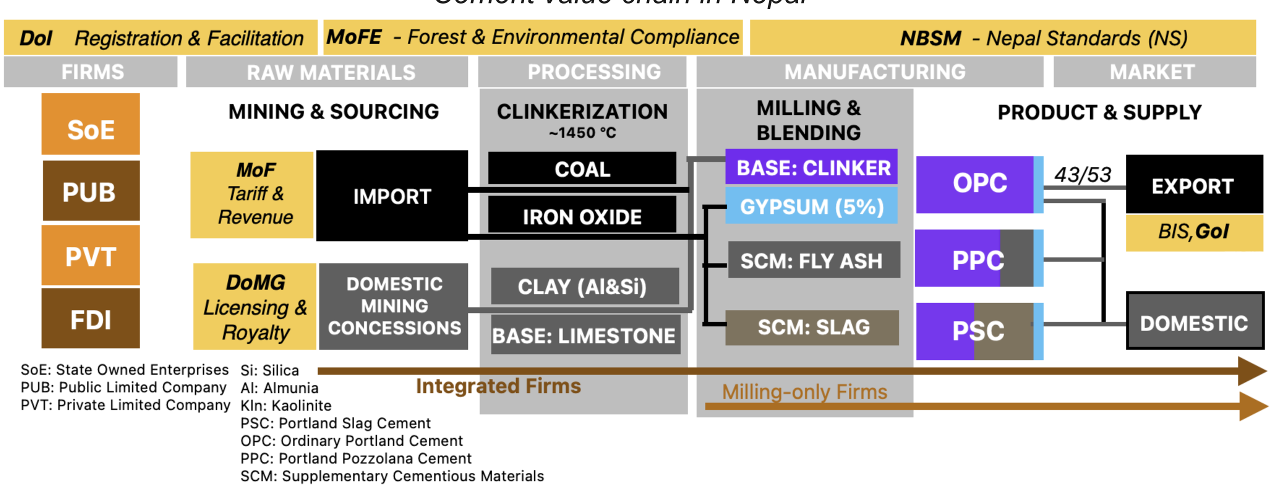
Blended cements — PPC and PSC — now account for roughly 50–60 percent of domestic demand, reflecting a gradual shift toward lower clinker intensity. However, the fly ash and blast furnace slag that enable this blending are sourced almost entirely from India. Nepal's deepening reliance on these imported SCMs is an important vulnerability: India's own clean energy transition is already tightening fly ash availability and increasing costs, with early signs of supply imbalances visible in rising prices and intermittent availability.

Regulatory and institutional framework

The formal regulatory framework governing the sector is administered by several agencies with distinct mandates. The Nepal Bureau of Standards and Metrology (NBSM) administers national cement standards — Nepal Standards (NS) — which are mandatory for all cement products sold in Nepal, whether locally produced or imported. The Department of Mines and Geology (DoMG) governs access to limestone and clay resources through mining licenses, concession approvals, and royalty administration. The Ministry of Industry, Commerce and Supplies (MoICS) chairs the national committees that authorize new product and process standards and provides the overarching policy framework for industrial development.

Existing cement standards include NS 49 (OPC), NS 384 (PSC), NS 385 (PPC), and NS 572 (OPC Grades 33, 43, and 53). No NS standard currently exists for LC3, which means the product cannot legally be produced or marketed in Nepal regardless of its technical or commercial readiness.

Cement value chain in Nepal



3.0 The Value Proposition for LC3 in Nepal

LC3 offers Nepal's cement sector a coherent response to each of its structural vulnerabilities. The economic, environmental, and resource security benefits are mutually reinforcing.

36% coal reduction vs. OPC ~51.5 kg per ton of cement	**NPR 2,500** Raw material savings vs. OPC per ton of cement produced	**30–40%** CO_2 reduction vs. OPC ~125 kg CO_2 per ton cement	**37%** limestone savings ~0.55 tons per ton of cement

Energy and import savings

Lowering clinker content reduces the most energy-intensive stage of cement production. Because clay calcination occurs at 600–800°C compared to 1,450°C for clinker, LC3 substantially reduces overall thermal energy requirements per ton of cement, even after accounting for the additional calcination step.

Coal consumption and cost comparison across cement types (indicative)

Metric	OPC (95% Clinker)	PPC (70% Clinker)	LC3 (50% Clinker)
Total coal per ton cement	142.5 kg	105 kg	91 kg
Coal cost per ton cement	NPR 1,842	NPR 1,358	NPR 1,177
CO_2- coal combustion	345 kg	254 kg	220 kg
Saving vs. OPC	—	37.5 kg / NPR 484	51.5 kg / NPR 665

Based on: coal calorific value 5,500 kcal/kg; clinker coal consumption 150 kg/ton; landed coal price NPR 2.35/1,000 kcal; LC3 clay calcination ~35% of clinker thermal demand; emission factor 2.42 kg CO_2/kg coal.

Compared with OPC, LC3 enabled 36 percent reduction in thermal fuel use, translating to a direct cost saving of NPR 665 per ton at current coal prices. Even relative to PPC — which already incorporates clinker substitution through fly ash — LC3 delivers additional savings of approximately 14 kg of coal and NPR 180 per ton. At the scale of Nepal's cement sector, replacing one million tons of OPC with LC3 would reduce coal imports by approximately 51,500 metric tons annually, easing pressure on the balance of payments and reducing exposure to international price volatility.

Raw material costs and supply chain resilience

LC3 also offers significant raw material cost advantages. The table below presents indicative cost modeling across cement types at March 2025 input prices.

Raw material cost modeling by cement type (indicative, NPR/ton)

Material (NPR/ton)	OPC	PPC	LC3-65	LC3-50
Base Clinker (8,500)	8,075	5,950	5,525	4,250
SCM Fly Ash — import (3,000)	—	750	—	—
Kaolinitic Clay — import (4,000)*	—	—	800	1,200
Limestone — local (1,000)	—	—	100	150
Gypsum (9,000)	450	450	450	450
Cost per ton cement (NPR)	8,525	7,150	6,875	6,050
Saving vs. OPC (NPR/ton)	—	1,375	1,650	2,475

** Estimated price of low-grade kaolinite clay (~40% kaolinite) imported from India. Costs subject to reduction if locally available clay is substituted.*

Across all LC3 blend scenarios, raw material costs are lower than OPC. LC3-50 — the deepest clinker substitution scenario — delivers savings of NPR 2,475 per ton relative to OPC, even when kaolinitic clay is fully imported. If suitable domestic clay deposits are utilized, the cost advantage deepens further. These savings arise primarily from reduced clinker content and the associated decrease in coal consumption, not from the clay input itself.

Climate alignment and resource conservation

LC3 reduces combustion-related emissions by approximately 125 kg CO_2 per ton of cement compared to OPC, and 34 kg CO_2 per ton compared to PPC. These figures reflect fuel savings alone and exclude the additional emissions benefits from reduced limestone calcination — the largest single source of emissions in clinker production. Overall, LC3 can lower cement-related emissions by 30–40 percent relative to OPC depending on the production configuration.

These reductions align directly with Nepal's Long-Term Strategy for Net-Zero Emissions, which includes a target of reducing the national clinker factor to 75 percent. Progress toward that target through LC3 adoption would also support access to green finance mechanisms, as international infrastructure finance increasingly incorporates carbon performance criteria.

At the macroeconomic level, replacing one million tons of OPC with LC3 would conserve approximately 548,000 metric tons of limestone annually — extending the productive life of domestic quarry reserves — while generating fuel cost savings of approximately NPR 665 million (USD 5 million).

Reference scenario: macroeconomic impact of replacing 1 million tons of OPC with LC3

Category	Per Ton Impact	At 1 Million Tons
Coal reduction	51.5 kg	51,500 metric tons
Fuel cost savings	NPR 665	NPR 665 million (~USD 5 million)
Limestone savings	0.55 tons	548,000 metric tons
CO_2 emissions reduction	~382 kg	~382,500 tons

4.0 Three Constraints Shaping LC3 Transition

Despite the strength of the economic and environmental case for LC3, adoption has not occurred. Three interrelated constraints explain this gap between potential and practice.

1	2	3
Resource Certainty Uncertainty about the mineralogical quality and commercial viability of domestic kaolinitic clay resources.	**Regulatory Authorization** The absence of a Nepal Standard for LC3 — the single most binding barrier to legal production and market entry.	**Firm-Level Incentives** Differential adoption incentives across firm types, and the misalignment between who wants to adopt and who can drive change.

Constraint 1: Resource certainty

The feasibility of LC3 production in Nepal is shaped less by the overall availability of clay than by its mineralogical quality, geographic distribution, and commercial viability. Existing geological assessments by the Department of Mines and Geology (DoMG) and independent studies indicate that most clay deposits in Nepal contain kaolinite concentrations in the range of 15–35 percent — below the approximately 40 percent benchmark associated with optimal LC3-50 performance.

Clay availability in Nepal follows a dual structure. First, widespread low-grade clays exist across the Lesser Himalayan Sequence, particularly within the Nawakot Complex. Empirical studies confirm a mixed illite–chlorite–kaolinite assemblage in the Kunchha and Nourpul formations, where kaolinite content is consistent but rarely dominant. The saprolitic weathering layer contains higher kaolinite concentrations than unweathered bedrock, making it the most viable extraction target. Second, localized pockets of high-purity kaolin exist at specific sites, including Daman and Palung (Makwanpur), Panchmane (Kathmandu), and Jitpurphedi and Dalchhap. These high-grade deposits provide high-reactivity material suitable for pilot production, but their irregular distribution constrains supply at scale.

Nepal's geology explains this pattern. High-grade kaolin deposits typically form under stable conditions with prolonged chemical weathering of feldspar-rich rocks. Nepal's landscape is shaped instead by tectonic uplift, erosion, and metamorphism — conditions that limit the formation and preservation of extensive high-purity kaolinite reserves. Nepal is therefore structurally predisposed toward mixed, lower-grade clay systems.

> **This constraint is declining, not static.**
> DoMG is currently testing approximately 150 clay samples within a 50-kilometre radius of major cement plants, with results expected by 2026. As geological knowledge improves, resource uncertainty is becoming manageable rather than prohibitive. High-grade deposits can support early pilots; low-grade clays — blended selectively with small quantities of imported high-grade kaolin where needed — provide the scalable longer-term resource base. The binding constraint is shifting toward regulatory alignment and investment decisions, not geology.

Constraint 2: Regulatory authorization

Nepal's cement sector operates under a mandatory standards regime. Without an approved Nepal Standard (NS) for LC3, producers cannot legally manufacture or market the product, regardless of technical readiness or commercial incentive. This makes regulatory authorization the single most critical prerequisite for adoption across the sector.

Two specific steps are required before LC3 can enter Nepal's market: (1) development and notification of a new Nepal Standard defining LC3 cement composition parameters, performance requirements, and testing procedures; and (2) establishment of a Scheme of Testing and Inspection (STI) governing certification and ongoing quality assurance. Both steps must be completed before any producer can legally manufacture or sell LC3 cement.

Standards development follows a clear institutional logic: regulatory authorities require adequate resource validation, laboratory testing, and performance data before standards can be approved. From NBSM's perspective, the sequence is explicit — standards before the product. This reflects the high public safety implications of cement as a structural construction material, and the institutional imperative to maintain regulatory credibility. Industry actors broadly support this sequencing, with both integrated producers and milling firms citing formal standards recognition as a prerequisite for commercial experimentation.

A clear regulatory precedent exists and is ready to use.
Nepal's standards have historically been adapted from the Bureau of Indian Standards (BIS) framework. India adopted IS 18189:2023 — its national LC3 standard — in 2023. This provides a technically validated reference that NBSM can draw on directly, substantially reducing the effort required to develop a Nepal-specific standard. Procedurally, standards development can be completed within three to six months once the process is initiated with coordinated engagement among NBSM, industry, and technical institutions.

Constraint 3: Firm-level incentives and techno-economic feasibility

The economic case for LC3 is strong, but incentives are distributed unevenly across the sector. Integrated producers are technically best positioned to adopt LC3 — they control kilns, laboratories, and raw material supply — but operate in a low-demand environment with high fixed costs that reduces urgency to innovate. Milling firms have the strongest financial incentive, since clinker represents their largest single cost component, but they lack the production facilities and institutional influence to drive regulatory change independently. This creates a fundamental misalignment: those with the most to gain from LC3 cannot move without it being unlocked by those with less immediate urgency to do so.

Capital investment requirements

Transitioning to LC3 requires investment in clay calcination infrastructure. Two technology pathways exist: retrofitting existing rotary kilns, and installing new flash calcination systems. Rotary kiln retrofits represent the lower-cost entry point — particularly relevant in Nepal, where several integrated plants operate underutilized or idle clinker lines. Flash calciners offer higher energy efficiency and superior product uniformity, but require greater capital and sustained operational consistency to justify the investment.

LC3 investment scenarios — returns across capacity, utilization, and technology (indicative)

Scenario	Technology	Est. CAPEX	Annual Output	Annual Savings	Payback Period
500 TPD – 100 days	Rotary kiln	USD 3.5–5.5M	50,000 t	NPR 125M	4–5 years
500 TPD – 200 days	Rotary kiln	USD 3.5–5.5M	100,000 t	NPR 250M	2–3 years
500 TPD – 300 days	Rotary kiln	USD 3.5–5.5M	150,000 t	NPR 375M	1.5–2 years
1000 TPD – 300 days	Rotary kiln	USD 7–10M	300,000 t	NPR 750M	1–1.5 years
500 TPD – 200 days	Flash calciner	USD 12–16M	100,000 t	NPR 250M	6–8 years
1000 TPD – 300 days	Flash calciner	USD 22–28M	300,000 t	NPR 750M	2–3 years

Based on estimated material savings of NPR 2,500 per ton of LC3 relative to OPC. TPD = tonnes per day.

The economics are compelling across all realistic utilization scenarios. At 200 operating days per year — a conservative assumption for Nepal's current market — a mid-scale rotary kiln retrofit (500 TPD) achieves payback in two to three years on a capital outlay of USD 3.5–5.5 million. At 300 days, payback falls to 1.5 years or less. Large integrated plants operating at 1,000 TPD achieve payback in one to 1.5 years even at conservative utilization rates. These are among the strongest capital returns available in Nepal's cement sector under current market conditions.

The persistence of low adoption therefore does not reflect weak fundamentals. It reflects institutional fragmentation: each key actor — regulators, firms, and resource agencies — is waiting for signals from the others before acting. Regulators seek validated data and industry readiness; firms seek regulatory clarity and market assurance; resource agencies continue generating data without immediate commercialization pathways. What is missing is not incentive, capability, or capital — it is alignment.

5.0 Pathways and Recomendations

Three structural dynamics are already pushing the sector toward clinker substitution, even in the absence of formal reform. Nepal's cement sector faces persistent overcapacity and rising fuel costs that make clinker-intensive production increasingly unattractive. India's adoption of IS 18189:2023 has created a directly applicable regulatory precedent. And DoMG's ongoing geological validation is progressively transforming clay from a speculative resource into a bankable input. These processes are converging. If they can be aligned — linking resource validation, standards development, and firm-level demonstration — the current transition bottleneck may shift toward adoption. If they remain uncoordinated, LC3 is likely to remain technically viable but institutionally deferred.

The sequence of action matters. Regulatory authorization must come first. Without a Nepal Standard for LC3, no other action can unlock adoption at scale. Standards development is also the one action that requires the least new evidence — India's IS 18189:2023 provides a ready technical baseline, and procedural completion is achievable within three to six months of initiation.

Priority actions for policymakers, regulators, and the cement industry

Priority	Recommended Action	Lead Actor(s)
1 — Immediate	Initiate LC3 standards development through NBSM, referencing India's IS 18189:2023 as a technical baseline	NBSM, MoICS
2 — Immediate	Establish a technical working group of regulators, producers, and independent experts to guide standards formulation and testing protocols	NBSM, CMAN, Producers
3 — Near-term	Facilitate pilot production trials with technically capable cement producers to generate local performance data for regulatory validation	Industry, Research Institutions
4 — Near-term	Support laboratory capacity for clay characterization, including TGA equipment, within research institutions and industry labs	DoMG, Research Institutions
5 — Near-term	Consolidate and publish DoMG's ongoing geological clay assessment data to build producer confidence in domestic raw material supply	DoMG
6 — Medium-term	Position LC3 within Nepal's Long-Term Strategy for Net-Zero Emissions and NDC frameworks; explore green and climate finance access	MoICS, MoF, MoFE
7 — Medium-term	Incorporate LC3 into public infrastructure procurement guidelines once regulatory authorization is secured	MoICS, Procurement Bodies

About this Report

This summary report presents the findings of a sectoral assessment of the prospects for introducing Limestone Calcined Clay Cement (LC3) in Nepal, examining the institutional, regulatory, and market dynamics shaping the transition. The assessment was commissioned by the Swiss Agency for Development and Cooperation (SDC) and conducted by Policy Entrepreneurs Inc. (PEI). It draws on desk research, geological and technical literature, cost modelling, and key informant interviews with government regulators, industry producers, and sector specialists. The views expressed are those of the authors and not that of the funding agency.

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