Pathways for the Energy Transition and Decarbonisation in the Cement Industry of Viet Nam

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Project

German Vietnam Energy Partnership in cooperation with the IKI.

The bilateral Energy Partnerships, Energy Dialogues, along with Hydrogen Partnerships, are key instruments of the Federal Ministry for Economic Affairs and Energy's foreign energy and climate policy, involving 32 partner countries. These partnerships and dialogues are creating a valuable global network between Germany and countries striving to transform their energy systems for a sustainable energy transition.

Authors

Trinh Thi Cham and Le Viet Hung (Vietnam Institute for Building Materials (VIBM))

Manuela Farghadan, Helmut Berger, Ambra Muca (ALLPLAN GmbH)

Editors

Michel Arnd, Truong Thi Quynh Trang (GIZ)

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Acronym/Symbol	Full Term	Definition / Explanation
AFR	Alternative Fuels and Raw Materials	Non-traditional fuels and raw materials (RDF, biomass, sludge, waste) used to replace fossil fuels and virgin raw materials in cement production.
BAT	Best Available Techniques	Internationally recognized best-performing technologies and practices (e.g., EU BAT).
BAU	Business-as-Usual	Baseline scenario assuming no additional low-carbon interventions.
CAC	Calcium Aluminate Cement	A high-performance cement used for fast-setting and high-resistance applications, especially in aggressive environments.
CBAM	Carbon Border Adjustment Mechanism	EU carbon tariff applied to imported cement, steel, fertilizers, etc.
CCS	Carbon Capture and Storage	Technology for capturing CO_2 and permanently storing it underground.
CCUS	Carbon Capture, Utilization and Storage	Capturing CO_2 for reuse (e.g., carbonation curing) and/or storage.
CEM I, II, IV, V	Portland Cement Types	Cement types classified under EN 197-1 based on clinker content and additives.
CEMS	Continuous Emission Monitoring System	Automated real-time stack emission monitoring.
Clinker Factor	–	The proportion of clinker contained in cement.
CO_2	Carbon Dioxide	A primary greenhouse gas emitted from fuel combustion and clinker production.
EPD	Environmental Product Declaration	Environmental footprint disclosure following EN 15804.
ETS	Emissions Trading System	Carbon market mechanism allowing trading of emission allowances.
GCCA	Global Cement and Concrete Association	Global industry association for cement and concrete producers.
GHG	Greenhouse Gas	Gases contributing to climate change (CO_2, CH_4, N_2O…).
IEA	International Energy Agency	International body providing global energy statistics and scenarios.
IPCC	Intergovernmental Panel on Climate Change	UN climate-science body producing standardized emission factors and guidelines.
LC3	Limestone Calcined Clay Cement	Low-clinker cement replacing ~50% clinker using calcined clay + limestone.
LCA	Life Cycle Assessment	Methodology for assessing environmental impacts across the life cycle.
MOC	Ministry of Construction	Vietnamese Ministry of Construction.

MRV	Measurement, Reporting, Verification	Framework for quantifying and validating GHG emissions.
NFBM	Non-fired building materials	Non-fired building materials such as: cement-aggregate masonry brick/block, aerated autoclave block/panel, foam concrete block/panel, hollow-core wall panel, etc.
NSP kiln	New Suspension Preheater kiln	Modern dry-process rotary kiln with a multi-stage preheater and precalciner.
Oxy-fuel	Oxy-fuel Combustion	High-purity oxygen combustion to facilitate CO_2 capture.
OPC	Ordinary Portland Cement	Conventional Portland cement with high clinker content.
PCM concrete	Phase-Change Material Concrete	Concrete incorporating thermal-storage materials for energy savings.
PCC	Precast Concrete Components	Factory-made concrete elements (panels, beams, slabs).
RDF	Refuse-Derived Fuel	Pre-processed solid waste used as a fuel substitute.
RMC	Ready-Mixed Concrete	Commercial concrete mixed at batching plants.
SBU	Standard Brick Unit	Non-fired masonry unit with various sizes is calculated to equivalent standard brick unit 220x105x60 mm.
SCM	Supplementary Cementitious Materials	Mineral additions reducing clinker content (fly ash, slag, limestone, metakaolin…).
T-VER	Thailand Voluntary Emission Reduction	Thai carbon-crediting scheme used for WHR/AFR projects.
TCVN	Vietnamese Standards	National technical standards of Viet Nam.
QCVN	Vietnamese Technical Regulations	National technical regulations of Viet Nam.
TSR	Thermal Substitution Rate	Share of heat energy derived from AFR relative to total kiln heat input.
VICEM	Vietnam National Cement Corporation	Vietnam's state-owned cement industry group.
WHR	Waste Heat Recovery	Technology converting kiln waste heat to electricity.
WR	Water Reducer	Concrete admixture reducing water demand.

Introduction

Background of the Assignment

Viet Nam's cement industry plays a critical role in national economic development but is also one of the largest industrial emitters of greenhouse gases (GHGs), due to the energy-intensive nature of clinker production and the process emissions released during limestone calcination. In recent years, the sector has faced increasing pressure to transition towards low-carbon production models, driven by Viet Nam's commitment to achieving net-zero emissions by 2050, its obligations under the Paris Agreement, and new global regulatory frameworks such as the EU Carbon Border Adjustment Mechanism (CBAM).

As Viet Nam advances its Nationally Determined Contributions (NDCs) and implements its national climate change strategies, detailed sectoral analyses and decarbonisation pathways are required for hard-to-abate industries. The cement sector, which accounts for a substantial share of industrial energy consumption and CO_2 emissions, is therefore a priority for targeted technical support and policy development.

This assignment contributes to these national efforts by providing a comprehensive analysis of technological options, policy conditions, and feasible transition pathways to reduce energy use and GHG emissions from cement production and cement-based building materials. The work also supports capacity building for enterprises in GHG accounting, technology assessment, and the planning of emission reduction actions.

Objectives and Scope

Objectives

The primary objective of this assignment is to support Viet Nam in formulating a technically sound and policy-relevant roadmap for the energy transition and decarbonisation of its cement and cement-based building materials sector. The assignment aims to produce actionable insights that align with the country's commitments under the Paris Agreement and its 2050 net-zero target.

More specifically, the assignment seeks to:

- Analyse the status of Viet Nam's cement industry, including production technologies, energy consumption patterns, clinker ratios, and GHG emissions.
- Assess the development of cement-based building materials, such as concrete, mortars, and non-fired bricks, and evaluate their influence on cement demand and emissions.
- Review international technological advancements and emerging product trends, identifying opportunities for Viet Nam to adopt high-efficiency, low-carbon, and innovative solutions.

- Explore energy-efficiency measures and decarbonisation pathways for cement production, including fuel substitution, process optimisation, digitalisation, renewable electricity, and clinker substitution.
- Provide evidence-based recommendations on product innovation, technology application, investment needs, and enabling policy frameworks to accelerate the low-carbon transition of the cement sector.
- Support dissemination and stakeholder engagement through presentations, workshops, and consultations with industry associations, enterprises, and government agencies.

Scope of Work

The scope of this report includes the collection and analysis of quantitative and qualitative data on the cement and building materials sectors, as well as the assessment of relevant international technologies and product trends.

The expert team contributes to the development of energy-efficiency and decarbonisation options by analysing the interactions between cement production and cement-using building materials, evaluating the implications for clinker demand, production capacity, and emissions. The assignment also supports the formulation of feasible transition pathways and recommendations for technology deployment, investment planning, and policy enabling conditions.

Methodology and Approach

A local expert team on cement and building materials implements the assignment using a systematic, collaborative approach in collaboration with an international consultant team.

Data collection covers domestic market information, cement production and consumption trends, technology profiles, energy use, emission factors, and relevant policy documents, as well as consultations with industry stakeholders, associations, and government agencies. The analysis draws upon official statistics, enterprise reports, sectoral development plans, and international databases.

Building on the compiled data, the local and international consultants reviewed and assessed global trends in low-carbon technologies, clinker substitutes, CO_2-mitigation options, and emerging building material innovations. The evaluation considered technology readiness, energy-saving potential, GHG-reduction benefits, investment and operational costs, and commercial viability. These insights are contextualised for Viet Nam and used to identify feasible transition scenarios for the cement and building materials sector.

Beyond technical analysis, the approach also examines enabling and constraining factors-including policy frameworks, financing mechanisms, infrastructure readiness, and market dynamics. This integrated methodology ensures a holistic understanding of the sector and provides a robust basis for designing realistic decarbonisation pathways.

The final outputs of the assignment include a comprehensive report, a set of summary slides, and contributions to workshops and stakeholder meetings organised by

GIZ and its partners. These products are intended to support evidence-based policymaking and guide investment decisions for Viet Nam's energy transition and the decarbonisation of its cement industry.

Chapter 1. Analysis of the Current Status of the Cement Industry and Cement-Related Building Materials in Viet Nam

1.1. Overview of Viet Nam's Building Materials Market

The buildings sector accounted for 34% of global final energy demand and 37% of energy- and process-related CO_2 emissions (in 2022), of which building materials (concrete, steel, aluminium, glass, bricks) represented about 9% of energy-related CO_2 emissions (Construction 2024).

Viet Nam's building materials (BM) industry has a long history and plays a critical role in the country's industrialisation and modernisation. Building materials provide essential inputs for the entire field of civil and industrial construction, technical and social infrastructure, and national defence and security. According to the Ministry of Construction (MOC 2024), the principal categories of building materials include: cement, ceramic tiles, sanitary ware, building glass, masonry materials (fired clay bricks and non-fired bricks), construction steel, and concrete. In 2024, the building materials sector generates an estimated production value of about VND 600,000 billion (approx. EUR 19.2 billion/USD 22.8 billion), accounting for nearly 6% of national GDP. In addition to its economic contribution, the building sector employs millions of workers. For environmental protection co-processing of waste in cement kilns and the production of green building materials is foreseen.

Between 2010 and 2020, building materials production grew strongly, making Viet Nam one of the world's largest producers of cement, ceramic tiles, and building glass. In 2020, the total cement production capacity is approximately 120 million tonnes per year, ranking third globally; ceramic tile output exceeds 800 million m^2 per year; building glass output is 330 million m^2 per year; and sanitary ware output totals 26 million pieces per year. The quality of Viet Nam's building materials generally meets international standards, and products have been exported to more than 100 countries.

The growth drivers of the construction materials market in the coming period stem from several key factors:

(i) accelerated disbursement of public investment, particularly for major national infrastructure projects such as the North–South Expressway, Long Thanh International Airport, and the Bien Hoa–Vung Tau Expressway;

(ii) Viet Nam's urbanisation rate, currently around 44%, is expected to reach 50% by 2030, which will increase demand for housing (with average urban residential floor area projected to reach 28 m^2/person in 2025 and 32 m^2/person by 2030 (Resolution No. 06-NQ/TW 2022; Decision No. 891/QD-TTg 2024), as well as for civil, commercial, and urban infrastructure projects and an expected further growth potential in infrastructure and urbanisation (a target urbanisation rate of 70-75% by 2050) (Decision No. 891/QD-TTg 2024);

(iii) the real estate market, following a period of regulatory adjustment during 2022–2023, is forecast to recover from 2024 onward, becoming an essential driver of construction material demand.

(iv) demand for construction of coastal and island works and climate-resilient infrastructure.

(v) opportunities from green, low-carbon materials (LC3, geopolymers, concrete utilising fly ash and GGBFS); and

(vi) (iv) the trend toward international market integration, particularly as cross-border carbon tariffs (the EU's CBAM) will accelerate the greening of cement and building materials production.

Domestic development trends in building materials

The Report of Viet Nam Institute for Building Materials (VIBM) on the Strategy for the Development of Building Materials to 2030, Vision 2050 (VIBM, 2020) and the Report of Ministry of Construction (MOC 2024) indicate a cement oversupply. The domestic cement demand reached only 65.19 million tonnes by 2024. This represents a ~ 15 % increase from 2023, but 55 tonnes less than production, and is forecasted to reach 100-110 million tonnes by 2030. Demand for concrete is estimated at 200-220 million m^3 in 2025, increasing to 250-270 million m^3 by 2030. For non-fired building materials, output is expected to rise rapidly from 12 billion units in 2020 to 16-20 billion units by 2030, while fired clay brick production remains stable (22-25 billion units per year).

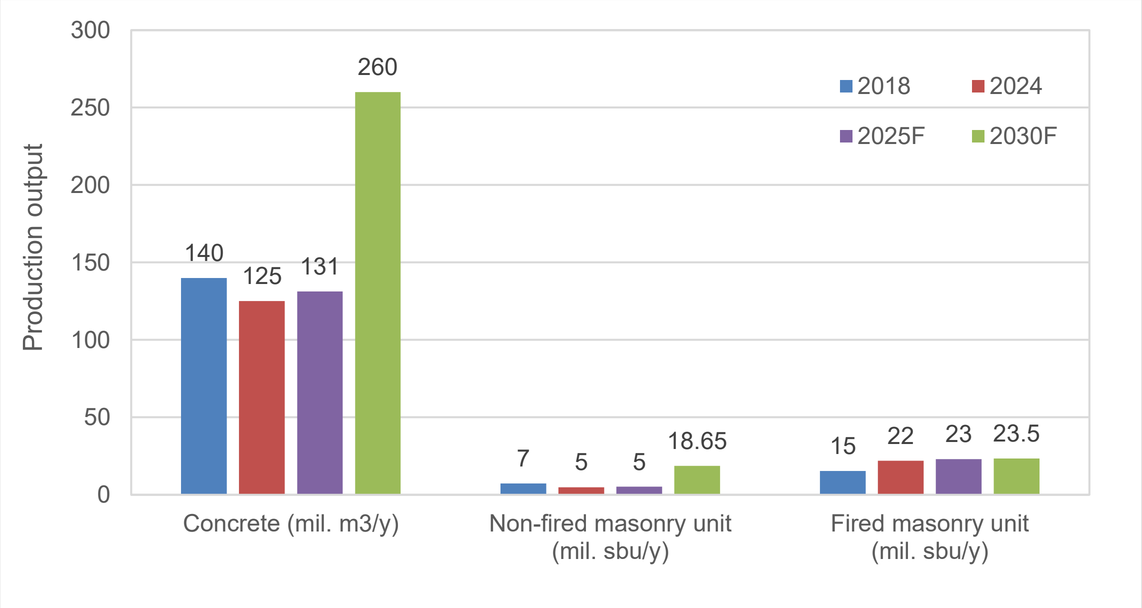


Figure 1. 1 Production outputs of concrete and mansory unit in Viet Nam in 2018, 2024 and forecasted to 2030

(Source: adapted from (VIBM 2020) and (MOC 2024)

The VIBM-Report (ibid.) indicates a trend in domestic demand to increasingly prioritise energy-efficient, resource-saving materials compatible with low-carbon cement products. This transformation is occurring in parallel with the maturation of the cement industry, which has reached a design capacity exceeding 121.6 million tonnes/year but faces tightening environmental and market constraints due to oversupply.

(1) **Cement:** Concrete and mortar currently account for more than 95% of national cement consumption, with a visible shift from on-site mixing toward **ready-mixed concrete (RMC)** and **precast concrete components (PCC).** This transition is driven by stricter quality requirements for high-rise buildings, labour shortages, and the need for accelerated construction schedules in urban centres. VIBM estimates that concrete output increased from 140 million m^3 in 2018 to 151 million m^3 in 2022. This is likely to continue rising as urban floor-area demand grows under Resolution No. 06-NQ/TW (2022). The Strategy (1266/QĐ-TTg) explicitly encourages expansion of industrialized concrete production, including high-performance, ultra-high-performance, and prefabricated systems to reduce material intensity and construction waste.

(2) **Non-fired building materials (NFBM)** are developed as a replacement for fired clay bricks. By 2024, Viet Nam had approximately 1,200 production facilities with a total design capacity of 12.4 billion standard bricks/year, yet actual utilisation remains low at around 40%, with production of only ~5 billion standard bricks in 2024. Cement usage in this segment accounts for approximately 2.3% of national cement consumption (about 1.4 million tonnes/year). Despite under-utilisation, policy momentum is strong: key instruments, such as Decision 567/QĐ-TTg (2010), Directive 10/CT-TTg (2012), and the ongoing implementation of 1266/QĐ-TTg (2020), require the gradual replacement of fired-clay bricks in urban projects, aiming to reduce agricultural soil extraction and air pollution. Growth is expected particularly in autoclaved aerated concrete (AAC) panels and hollow concrete wall systems (e.g., Acotec) for mid- and high-rise buildings due to advantages in speed, labour savings, and seismic and fire performance.

(3) **Green and resource-efficient materials** become more prevalent. VIBM identifies increasing application of high-SCM cement blends, thermal-insulating wall systems, low-emissivity coatings, and high-performance concrete for infrastructure exposed to aggressive environments. Integration of recycled aggregates from construction and demolition waste-aligned with the circular-economy objectives of Decision 687/QĐ-TTg (2022) - is in early stages but expected to expand as provincial regulations tighten landfill restrictions. The Strategy (1266/QĐ-TTg) also prioritizes local sourcing of mineral additives, including limestone powder, fly ash, slag, and calcined clay, supporting the transition toward LC3 and low-clinker cement products.

Looking ahead, domestic development trends indicate that cement-based materials will remain central to Viet Nam's construction sector, but their composition, manufacturing technology, and market structure will evolve. Demand growth will be concentrated in RMC and precast systems serving transport corridors, industrial parks, and urban housing programs. Non-fired materials are expected to scale once utilisation improves and procurement rules incorporate carbon-intensity criteria. The combined effect of policy enforcement, industrial modernisation, and sustainability requirements will shift the market from high-volume traditional materials toward standardised, low-carbon, and industrialised building systems, positioning the sector to meet both domestic needs and long-term net-zero commitments.

1.2. Economic data and market structure of the cement and cement-based building materials sector

1.2.1. Macroeconomic role and GDP contribution

The cement and concrete sector are one of the main pillars of Viet Nam's building materials industry, closely linked to economic growth, public investment, infrastructure development, and real estate.

The concrete industry (including ready-mixed concrete, precast concrete, and NFBM products based on cement) has an annual scale of tens of trillions of VND, serving as the direct output of the cement sector and accounting for a large share of construction value. According to statistics from VIBM, concrete output in 2024 contributed approximately VND 190,000 billion (~ EUR 6.1 billion/USD 7.2 billion) in revenue.

Beyond economic value, the sector provides direct employment for hundreds of thousands of workers across more than 80 cement plants, thousands of RMC batching stations and PCC factories nationwide, and over 1,200 NFBM production facilities.

1.2.2. Capacity, production, and consumption of cement

Number, distribution, and production capacity

As of 2024, there are a total of 87 operating rotary kiln cement lines, with a total design capacity of 121.6 million tonnes/year. Cement plants are distributed across 23 out of 63 provinces/municipalities nationwide (in 2024). Four localities-Ha Nam, Ninh Binh, Thanh Hoa, and Nghe An-account for over 60% of total capacity. In 2025, the cement industry is expected to add three production lines into operation-Hoang Long Cement (Hoa Binh-Phu Tho), Xuan Son Cement (Hoa Binh-Phu Tho), and Lien Khe Cement (Hai Phong)-with a combined capacity of about 6.2 million tonnes (Ximang.vn 2025). Production output remains around 120 million tonnes/year. The distribution of the number of plants, design and operating capacities, and kiln sizes across the three regions-North, Central, and South-of Viet Nam's cement industry is presented in **Error! Reference source not found.**, **Error! Reference source not found.**, and the nationwide distribution of cement plants is shown in Figure 1. 3.

Table 1. 1 Regional classification of cement plants in Viet Nam

Item	Number of plants (with clinker production) by region		
	North	central (Nghệ An - Quảng Nam)	South
Number of plants	46	11	4
Number of integrated production lines	69	13	05
Designed cement capacity, million tonnes/year	96.07 (79%)	17.6 (14%)	8.06 (7%)

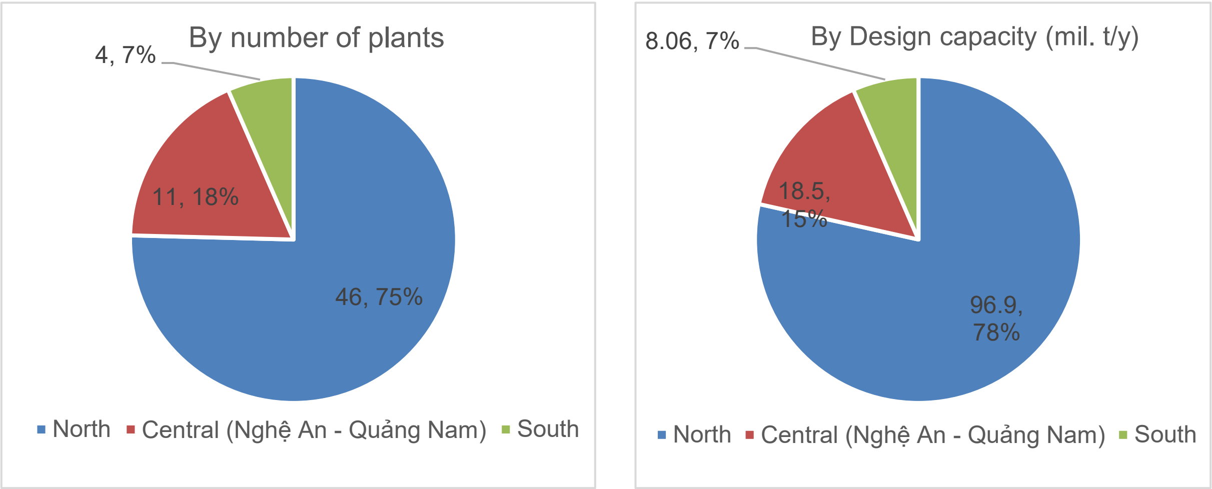
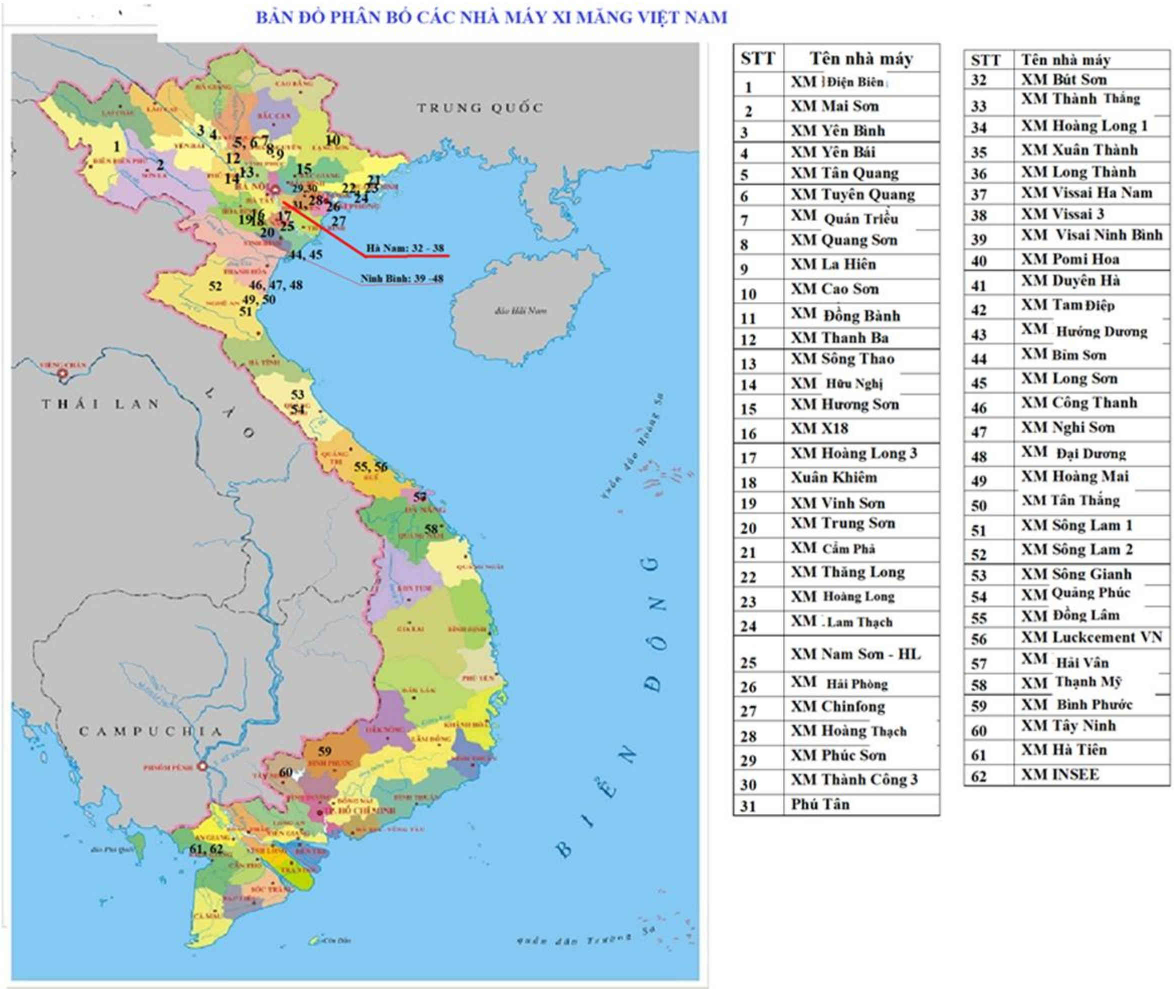


Figure 1. 2 Statistic of number of plant and design capacity of Vietnamese cement industry by region

(Source: adapted from Viet Nam Cement Association)



STT	Tên nhà máy
1	XM Điện Biên
2	XM Mai Sơn
3	XM Yên Bình
4	XM Yên Bái
5	XM Tân Quang
6	XM Tuyên Quang
7	XM Quán Triều
8	XM Quang Sơn
9	XM La Hiên
10	XM Cao Sơn
11	XM Đồng Bành
12	XM Thanh Ba
13	XM Sông Thao
14	XM Hữu Nghị
15	XM Hương Sơn
16	XM X18
17	XM Hoàng Long 3
18	Xuân Khiêm
19	XM Vinh Sơn
20	XM Trung Sơn
21	XM Cẩm Phả
22	XM Thăng Long
23	XM Hoàng Long
24	XM Lam Thạch
25	XM Nam Sơn - HL
26	XM Hải Phòng
27	XM Chinfong
28	XM Hoàng Thạch
29	XM Phúc Sơn
30	XM Thành Công 3
31	Phú Tân

STT	Tên nhà máy
32	XM Bút Sơn
33	XM Thành Thắng
34	XM Hoàng Long 1
35	XM Xuân Thành
36	XM Long Thành
37	XM Vissai Ha Nam
38	XM Vissai 3
39	XM Visai Ninh Bình
40	XM Pomi Hoa
41	XM Duyên Hà
42	XM Tam Điệp
43	XM Hướng Dương
44	XM Bỉm Sơn
45	XM Long Sơn
46	XM Công Thanh
47	XM Nghi Sơn
48	XM Đại Dương
49	XM Hoàng Mai
50	XM Tân Thắng
51	XM Sông Lam 1
52	XM Sông Lam 2
53	XM Sông Gianh
54	XM Quảng Phúc
55	XM Đồng Lâm
56	XM Luckcement VN
57	XM Hải Vân
58	XM Thạnh Mỹ
59	XM Bình Phước
60	XM Tây Ninh
61	XM Hà Tiên
62	XM INSEE

Figure 1. 3 Map of the distribution of cement plants in Viet Nam

(Source: adapted from Viet Nam Cement Association)

Production and consumption of Vietnamese cement industry since 2014 to 2030 (forecasted) show in Figure 1. 4 and figures on cement production and consumption in Viet Nam in 2023 and 2024 is presented in **Error! Reference source not found.**.

Consumption

In 2024, private domestic cement manufacturers had a market share of 47% (27.76 Mt) of the total domestic cement consumption of 65.19 Mt. The second-largest share 27% (18.23 Mt) is attributed to the state-owned enterprises under the VICEM Group, while foreign-invested companies reached 19% (12.85 Mt) market share.

The southern region's consumption share was 36%, almost equivalent to the 35% of the northern region, mainly driven by the demand from major national key projects such as the North-South Expressway, Long Thanh International Airport, the expressway network in the Mekong Delta, Ring Road No. 3 in Ho Chi Minh City, and infrastructure projects in major cities (Ximang.vn 2025).

Meanwhile, the North accounts for the largest share of production capacity, strong export logistics, and a concentration of limestone resources. The central region hosts several large coastal plants with export orientation. The South is the largest consumption market but has limited production capacity, relying on clinker transported from the north and central regions.

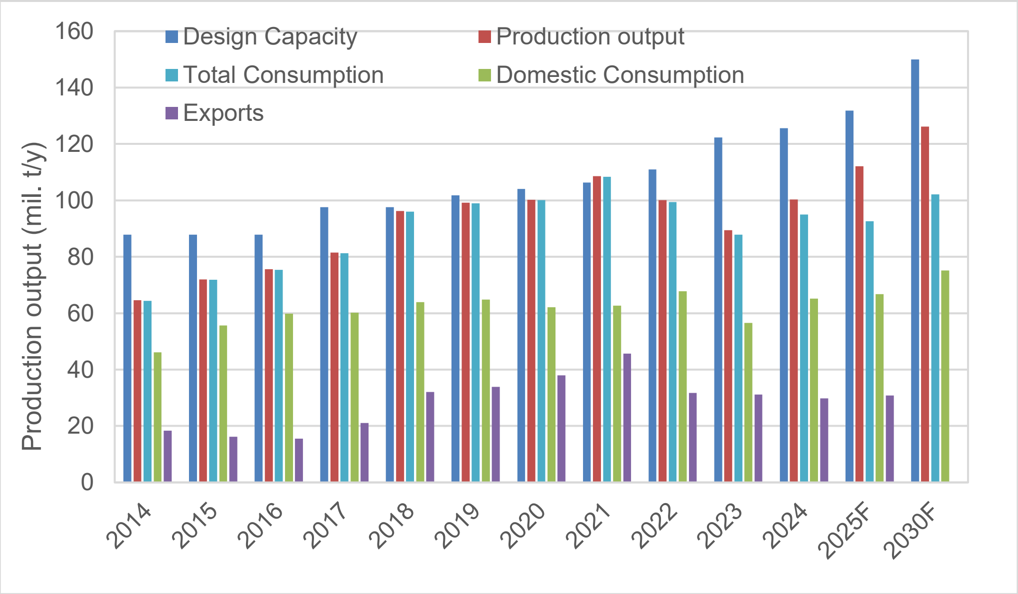


Figure 1. 4 Production and consumption of Vietnamese Cement industry since 2014 to 2030 (2025F and 2030F are forecasted figures)

(Source: adapted from (MOC 2024), (Ximang.vn 2025), (FPT Securities 2025)

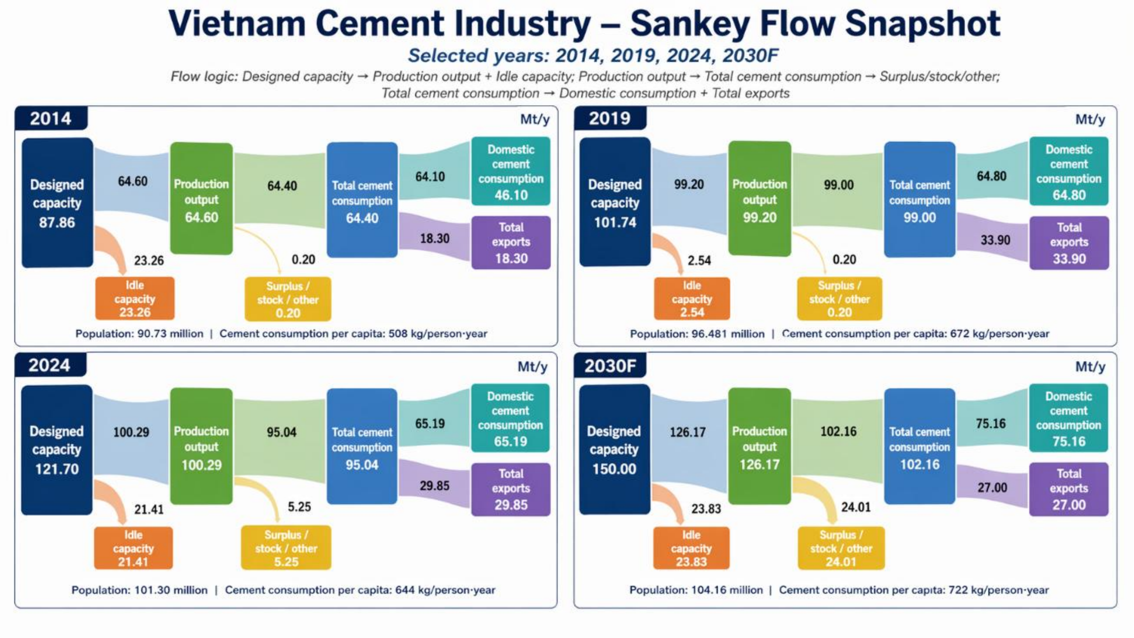


Figure 1. 5 Summary of indicators of Vietnamese cement sector from 2014 to 2024 and forecasted for 2025 and 2050

(Source: adapted from (Ximang.vn 2025), (VNCA 2024))

Exports

Between 2018 and 2021, Viet Nam remained one of the world's three largest exporters of clinker, with export volumes peaking at approximately 31–35 Mt per year (Ximang.vn 2025). However, since 2022, export performance has declined significantly due to weakened demand in key markets such as China, the Philippines, and Bangladesh, combined with import restrictions and regional oversupply. According to the Ministry of Construction (MOC 2024), total cement and clinker exports in 2023 fell to around 26–28 million tonnes, more than a 20% decrease from the 2021 peak, with clinker accounting for 60–65% of total export volume. Export prices have also come under pressure. Data from FPT Securities (2024) indicates that Viet Nam's FOB clinker price dropped from USD 48-52/tonne in 2021 to USD 37-41/tonne in 2023-2024, driven by heightened competition from China and Indonesia and increased freight costs. Large private producers with integrated logistics advantages - such as The Vissai, Xuan Thanh, Long Son, and Thanh Thang - have been more resilient in sustaining export volumes compared with the broader market.

Looking ahead to 2025, the export outlook is expected to show only modest recovery, contingent on construction demand in Bangladesh and the Philippines while facing emerging risks, including the EU CBAM and policies promoting domestic clinker self-sufficiency in importing countries. In response, the Ministry of Construction's long-term direction emphasizes reducing reliance on bulk clinker exports, shifting towards higher-value cement products. To further limit excessive clinker and low-value cement exports, a combination of structural, market, and policy measures can be considered:

(i) Supply–demand rebalancing through stricter control of new capacity, consolidation, and the gradual phase-out of small and inefficient production lines would help raise overall capacity utilisation;

(ii) Export strategies should progressively shift from bulk clinker to higher-value cement products, including blended and low-carbon cements with higher SCM content;

(iii) Domestic demand can be strengthened by integrating green public procurement and embodied-carbon criteria into large infrastructure and housing programmes, thereby absorbing part of the surplus capacity;

(iv) Improving energy efficiency, increasing AFR use, and expanding waste-heat recovery will lower production costs and reduce the need for price-based competition in export markets. In parallel, the gradual introduction of carbon pricing and Measurement, Reporting, Verification (MRV) systems will internalise the carbon cost of clinker exports, making low-value exports less attractive;

(v) Aligning export orientation with the net-zero roadmap will encourage Vietnamese cement producers to compete on quality, carbon performance, and value added rather than volume, improving long-term resilience and sustainability of the sector.

Table 1. 2 Price of cement and clinker of Viet Nam and surrounding countries

Region/Country	Cement Price (USD/t)	Clinker Price (USD/t)	Year	Source
Southeast Asia (average)	65–75	–	2024	Global Cement Report 2024
Global average	70–85	–	2024	GCCA 2024
Viet Nam domestic	54-64	–	2024	VICEM / ximang.vn 2024
Viet Nam FOB clinker export	–	34–40	2024	VICEM / ximang.vn 2024
China domestic (estimate)	60–70	–	2024	Global Cement Report 2024
Middle East (GCC region)	50–60	–	2024	World Bank Commodities Outlook 2024

Capacity Utilisation Rate

Viet Nam’s effective capacity utilisation in recent years at approximately 52-60%, average of 59%, calculated from an installed capacity of 88-121.7 million tonnes/year and domestic consumption of only 46–66 million tonnes/year (plus 15–30 million tonnes of exports). This level is slightly lower than international norms. Globally, cement capacity utilisation typically ranges between 70–75%, which is considered the threshold for financially sustainable operation (NZGBC 2023); (IEA 2024). Regional comparisons show in 2021-2024:

- China: utilisation declined from ~80% (2010s) to ≈60% in recent years due to structural overcapacity and demand slowdown;
- India: Utilisation generally 65–70%, supported by strong domestic infrastructure demand;
- European Union: 75–85%, reflecting stable demand, limited new capacity, and stricter efficiency policies;

- Southeast Asia (excluding Viet Nam): commonly 60–70%, although Thailand's utilisation has also fallen below 65% due to market contraction.

By comparison, Viet Nam's ≈ 59% utilisation rate is below the global and regional range, indicating that current operating levels are not typical nor sustainable in the long term. This structural oversupply leads to persistent price competition and compressed profit margins, periodic kiln shutdowns (as seen in 42/92 lines temporarily suspended in 2023–2024), limited financial capacity for reinvestment in low-carbon technologies, and increased dependence on low-value clinker exports rather than higher-value domestic markets.

The outlook suggests that without demand stimulation (e.g., public infrastructure, green procurement) and capacity rationalisation, utilisation rates are unlikely to return to international norms before 2030. Conversely, aligning with low-carbon product development (LC3, high-SCM cement, precast systems) may help shift from volume-driven to value-driven growth, improving utilisation quality rather than simply increasing tonnage.

1.2.3. Market structure of the cement sector

The structure of Viet Nam's cement market is highly competitive and increasingly fragmented, shaped by oversupply conditions and regional concentration of capacity. As of 2024, the market comprises three main enterprise groups:

1. State-owned enterprises (SOEs): Viet Nam Cement Industry Corporation (Vicem) controls approximately 30% of national clinker and cement capacity and owns major plants such as Hoang Thach, Ha Tien, Bim Son, and But Son. Vicem-based enterprises maintain dominant positions in the North–Central regions and have historically influenced pricing and supply stability.

2. Domestic private enterprises: Private conglomerates, including The Vissai, Xuan Thanh, Long Son, Thanh Thang, and Nghi Son 2, account for roughly 45% of total capacity, making this the fastest-expanding segment. Growth has been driven by modern large-scale rotary kilns (≥10,000 t/day), coastal locations with access to ports, and aggressive export-oriented strategies.

3. FDI and joint ventures: Foreign-invested companies such as Nghi Son (Japan), INSEE Viet Nam (Thailand), SCG (Thailand), and Thang Long Cement (Indonesia) represent around 20–25% of national capacity. This group is highly competitive in environmental compliance, WHR deployment, AFR utilization, and product diversification (e.g., low-carbon cement).

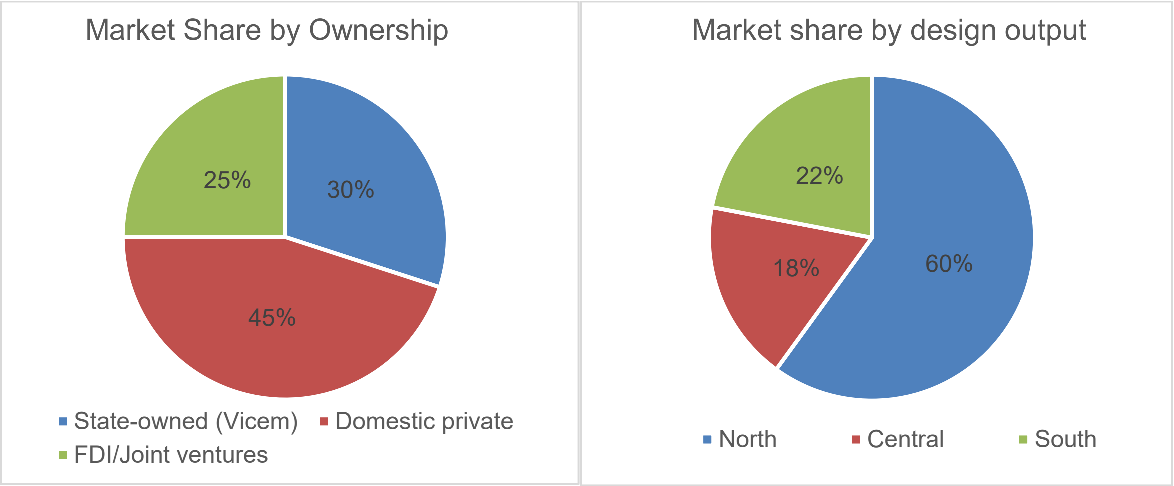


Figure 1. 6 Cement market structure in Viet Nam

(Source: adapted data from (Ximang.vn 2025))

Market characteristics and competitive dynamics: Oversupply remains the defining structural condition, with an estimated surplus of 30-35 million tonnes/year. As a result, price-based competition is intense, especially in the Northern market where capacity concentration exceeds 60%. Domestic cement prices in Viet Nam (≈ USD 54–64/t), remain among the lowest in Southeast Asia on an ex-factory basis (around USD 45–55 per tonne), compared with Thailand (≈ USD 60–75/t) and the Philippines (≈ USD 75–90/t). Clinker export prices have fallen sharply, averaging USD 34–40/t in 2024 (FOB), significantly lower than Indonesia and India, reducing profit margins for export-dependent producers (VNCA 2024; VNCR 2024; Global Cement Report 2024).

Overall, Viet Nam's cement market structure reflects both growth potential and structural stress: high-capacity concentration, thin margins, and increasing competition from low-carbon performance requirements. This underscores the need for strategic consolidation, diversification into low-carbon products, and alignment with emerging domestic and global market drivers

1.2.4. Scale and status of the cement-based building material industry

According to estimates from survey data on the production and use of basic construction materials in the Report on studying of a strategy for developing construction materials in Viet Nam to 2050 (VIBM 2020), the overwhelming majority of cement consumption is concentrated in concrete and mortar production, accounting for more than 95% of total domestic cement use. NFBM, including concrete blocks and wall panels, currently represent only about 2.3% of cement demand despite rapid capacity expansion in recent years. Cement use in soil stabilization and ground improvement remains limited, contributing less than 1% of total consumption, mainly within roadbed and embankment projects. Roofing and other niche construction materials account for an even smaller share-below 0.2% - and do not significantly influence overall market demand. This distribution indicates that any future shift toward low-carbon cement products will be driven primarily by the concrete sector, with supplementary growth potential in non-fired materials as policies and market adoption strengthen.

1.2.4.1 Concrete industry

Concrete used in construction in Viet Nam comes from three main sources: ready-mixed concrete (RMC), precast concrete (PCC), and concrete mixed directly on-site by contractors (manual production). In recent years, due to the increasing quality requirements of high-rise buildings and a shortage of labour, ready-mixed concrete has been gradually increasing its market share in the concrete sector. Precast concrete and prestressed concrete components are being increasingly applied in high-rise projects, bridges and roads, and metro works. This is an inevitable trend to raise construction productivity and reduce CO_2 emissions during execution by optimising cement use.

According to a survey on the concrete industry (VIBM 2023), there are about 1,500-2,000 concrete batching plants nationwide, with a designed capacity of nearly 200 million m^3/year. Calculated based on cement consumption in the “Strategy for the Development of Building Materials for the Period 2021-2030, with a Vision to 2050” (VIBM 2020), the domestic concrete volume was approximately **158 million m^3** in 2022 and 2024 nearly **152 million** m^3 (equivalent to ~350 million tonnes of material) with domestic cement consumption respectively of 67,8 and 65.2 million tonnes.

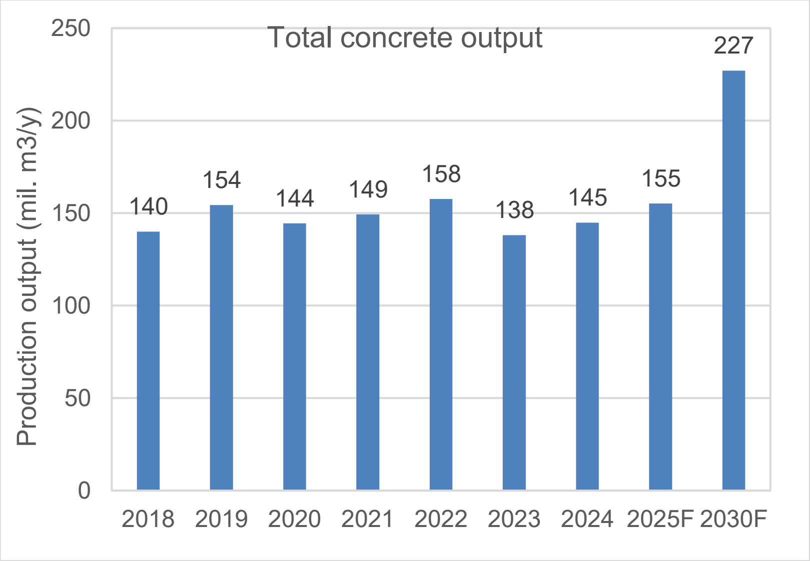


Figure 1. 7 Concrete output in recent years in Viet Nam

(Source: adapted and estimated from (VIBM 2020) (VIBM 2023), (MOC 2024)

Capacity scale and regional distribution characteristics: The capacity scales of PCC and RMC production facilities can be broadly categorised into three types.

- Small plants: capacity < 30,000 m^3/year (some facilities produce only a few thousand m^3/year). Small plants are common in the Northern midlands and mountainous region, the Central region, and the Mekong Delta.
- Medium plants: capacity 30,000-120,000 m^3/year.
- Large plants: capacity > 120,000 m^3/year, concentrated mainly in industrial zones, major cities, the Red River Delta, and the Southeast region.

1.2.4.2 Regional distribution

The North concentrates many RMC and PCC facilities in provinces/cities such as Ha Noi, Hai Phong, Ha Nam, Hai Duong, Quang Ninh, Bac Ninh, Bac Giang, Hung Yen, Nam Dinh, and Thanh Hoa. This area hosts numerous cement plants, favourable raw materials, and a great demand for both civil and industrial construction. In the Central region, clusters are found in Nghe An, Quang Binh, Quang Nam, Binh Dinh, Ninh Thuan, with relatively large, designed capacities but modest actual output, reflecting lower demand than in the North and South. In the South-Ho Chi Minh City, Dong Nai, Binh Duong, Long An, Tay Ninh, Can Tho, and the Mekong Delta-there are many large-capacity RMC plants serving infrastructure (expressways, Long Thanh Airport) and urban projects. PCC is strongly developed in industrial zones and coastal provinces, with products mainly concrete piles, bridge-road components, and pipes.

Among provinces providing information on concrete production, those with designed capacities over 10 million m^3/year include Quang Ninh (18.710 million m^3/year) and Bac Giang (13.122 million m^3/year); provinces with capacities over 5 million m^3/year include Thanh Hoa (7.954 million m^3/year), Hung Yen (7.541 million m^3/year), Gia Lai (6.014 million m^3/year), Bac Ninh (5.141 million m^3/year). Most of the remaining provinces have capacities of 1-3 million m^3/year. In general, the distribution of concrete and precast concrete manufacturing plants is uneven; in remote, mountainous, and island areas where transport infrastructure is not synchronised, delivery to project sites is difficult, leading to higher concrete costs, longer transport times, and consequently disruptions in supply and delays in project schedules.

1.2.4.3 Enterprise structure

By designed capacity, RMC accounts for about 85%, PCC about 15%; by actual output, RMC accounts for 78%, PCC 22%. This indicates that RMC remains the dominant segment of the industry, while PCC exhibits a higher capacity utilisation rate, reflecting the stability of demand for precast components in infrastructure projects.

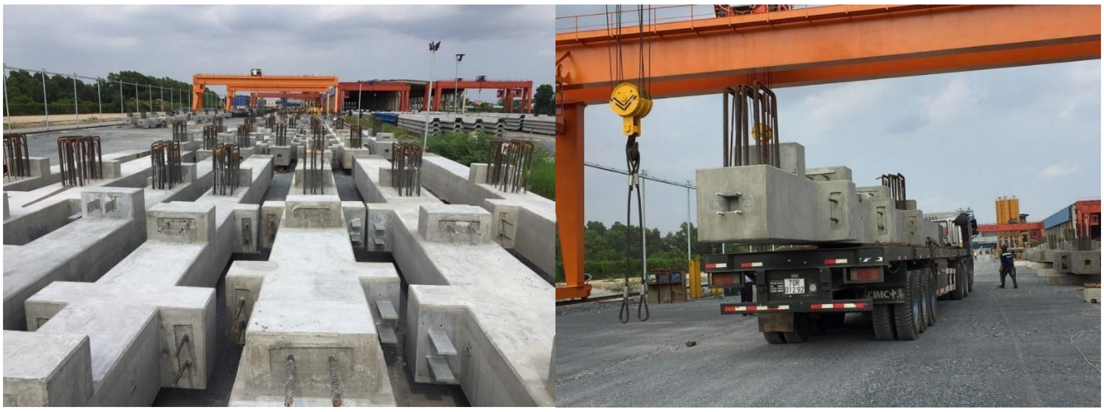


Figure 1. 8 Pipe Rack Column - the largest prefabricated precast concrete component in Viet Nam at Phan Vu Infrastructure Construction Co., Ltd

(Source: adopted from (VIBM 2023))

1.2.4.4 Non-fired building materials (NFBM) industry

In addition to ready-mixed concrete and precast components, cement is the primary raw material for many new building materials that align with the trend toward

NFBM and green buildings. Current NFBM production includes mainly aggregate concrete blocks, autoclaved aerated concrete (AAC) units and panels, hollow-core and lightweight concrete wall panels, as well as other products such as gypsum boards, 3D wall panels, split-stone products, laterite blocks, and NFBM made from hill soil, construction and demolition (C&D) waste, industrial by-products, and silicate bricks. As of 2024, Viet Nam has about 1,200 NFBM production facilities, with a total designed capacity (TDC) of approximately 12.4 billion standard brick units (sbu)/year, accounting for about 40% of the total TDC of masonry materials. The actual output of NFBM in 2023 estimated at 4.9 million standard brick units (SBU), accounting for about 30% of the total 16,5 million masonry unit consumption in 2023 (MOC 2024). The total financial investment for constructing NFBM plants is currently estimated at around VND 12,500 billion (approx. EUR 400 million/USD 470 million). Of this, financing from domestic banks and state capital is estimated to account for about 50% of the total investment.

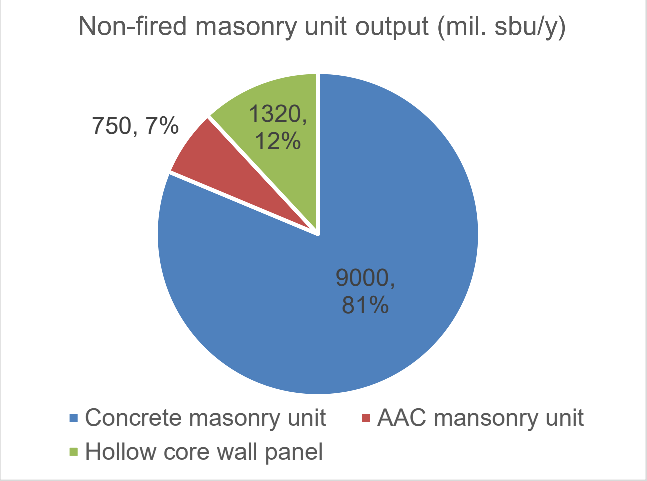


Figure 1. 9 Non-fired building materials (NFBM) market structure in Viet Nam in 2023

(Source: adapted from (MOC 2024))

Among these, concrete brick (cement-aggregate brick) represents the majority, with around 920 production facilities and a total design capacity of about 9 billion standard bricks per year. AAC is produced at four operating plants with a combined capacity of approximately 1,000,000 m³/year (equivalent to 0.75 billion standard bricks/year). Wall panel products are manufactured at 10 facilities, totalling 11 million m²/year. Foam concrete blocks are produced across 13 production lines, with capacities ranging from 4,000–12,000 m³/year, and a current combined capacity of more than 141,000 m³/year (equivalent to 0.12 billion standard bricks/year) (MOC 2024).

Figure 1. 10 Acotec and Eurowall hollow wall panels at Xuan Mai Concrete Factory (Hanoi)

(Source: adopted from (VIBM 2023)

However, actual annual output remains significantly below installed capacity, particularly for concrete block producers. Although NFBM production increased substantially between 2014 and 2019, with an average annual growth rate of approximately 11%, output peaked in 2018 at 7.3 billion standard bricks, accounting for 25% of total masonry material production, with capacity utilisation reaching around 60%. Since 2019, production has declined to around 6.0 billion bricks (a nearly 18% decrease compared to 2018).

In 2023, total output fell to approximately 4.9 billion standard bricks, or 20% of total masonry production, with utilisation dropping to 40%. In 2024, production levels remained similar, estimated at around 5 billion standard bricks. Cement–aggregate blocks are produced in both solid and hollow formats. Alongside concrete masonry units, hollow-core precast concrete wall panels (e.g., Acotec, Eurowall) have become increasingly common, especially in high-rise construction. These panels are used for exterior and partition walls installed on structural frames, offering rapid and simplified installation; no plastering is required, only skim coating, helping reduce material use and labour while enabling greater mechanisation.

The Government of Viet Nam has issued multiple policies to increase the use of NFBM as a replacement for clay-fired bricks, with the dual objectives of reducing the extraction of agricultural soil for brick production and mitigating environmental pollution. According to the Viet Nam Non-Fired Brick Development Programme led by UNDP, the CO_2 emissions of several typical masonry materials are shown below:

Table 1. 3 Baseline energy consumption and greenhouse gas emissions per standard unit

(Source: (UNDP-GEF 2013))

Material type	Energy consumption (MJ/unit)	CO_2 emissions (kg CO_2/unit)
Tunnel kiln-fired clay brick	3.317	0.500
AAC (using sand-based mix)	1.269	0.302
AAC (using fly ash)	1.461	0.365

Cement–aggregate concrete block (CBB)	0.836	0.156

According to the Program for the Development of NFBM to 2030 (Decision No. 2171/QĐ-TTg 2021), Viet Nam targets increasing the share of non-fired materials to 30-40% of total masonry units. By 2023, NFBM output is estimated at 10-12 billion standard brick units, significantly substituting traditional fired-clay bricks. Development trends in NFBM include concrete bricks, cement-aggregate bricks, AAC bricks, and lightweight panels. NFBM both reduces clay extraction and CO_2 emissions from brick firing, while creating a new market for cement and mineral additives (MOC 2024).

Average cement consumption is approximately 0.250 kg per standard brick for concrete masonry unit and concrete wall panels, and around 1.40 kg per standard brick for AAC and other lightweight NFBM. Based on 2024 output levels-approximately 5 billion concrete masonry unit equivalents and 0.9 billion lightweight NFBM equivalents-total cement consumption is estimated at around 1.4 million tons per year.

1.2.5 Challenges and development trends

1.2.5.1 For the cement manufacturing industry

a) Excess cement capacity:

The already-mentioned overall structural oversupply of Viet Nam’s cement industry drives price-based competition, erodes profit margins, and suppresses investment in carbon-reduction technologies. Heavy reliance on exports further exacerbates the issue, as the current competitive advantage is still tilted toward price rather than environmental performance.

b) Fragmented waste management system:

Viet Nam suffers from a fragmented waste-management system with low sorting rates, which limits the scaling of co-processing. 55% of waste is landfilled, 20% is burned uncontrollably, and only 10% of total waste is properly treated (B-company 2025), resulting in a shortage of waste to feed cement kilns. Deployment of waste heat recovery (WHR) faces obstacles due to the lack of guidance on grid integration and mechanisms for selling surplus electricity. At the same time, green procurement in both the public and private sectors remains insufficient to prioritise low-carbon cement.

The fragmented cement production aggravates these challenges. Numerous small-scale plants with outdated technology operate inefficiently; many facilities lack integrated clinker production lines, creating raw-material risks and lowering logistics efficiency. Low prices due to oversupply continue to impede capital investment decisions for modernisation and emissions reduction. Without sector restructuring, upgrades to waste-management infrastructure, and strengthened green procurement policies, achieving financial sustainability alongside environmental goals will be difficult.

c) Technological challenges in the decarbonisation process

Viet Nam’s production technology is old and heterogeneous, making technology upgrades difficult. Of the 87 cement production lines currently in operation, only about 11.5% are modern (less than 10 years old); the majority (76%) were built 10-20 years ago during a period of rapid industrial growth. While still operating, these lines are incompatible with advanced low-carbon technologies and require deep retrofits. Approximately 12.65% of lines are over 20 years old, concentrated largely in the North, exhibiting low energy efficiency and environmental risks. In addition, many facilities are small-scale (kiln capacity < 1 million tonnes/year).

Most plants still rely on basic dry-process kilns and ball mills, with electricity consumption > 40 kWh/tonne of cement, significantly higher than the international best practice. In older kilns, thermal energy consumption often exceeds 730 kcal/kg clinker. Dust-control systems (such as electrostatic precipitators) struggle to meet modern emission thresholds (< 20 mg/Nm^3), driving up compliance costs.

WHR has been implemented in some locations, but penetration is incomplete. As of 2025, 25 lines had yet to invest in WHR, despite regulations having been in place since 2020. The integration of WHR with deeper energy-efficiency upgrades remains rare due to the higher complexity and capital intensity. Plants with installed WHR, particularly in the South, where grid electricity prices are higher, demonstrate economic returns: systems achieve about 1.5 MW per 1,000 tonnes of clinker/day.

d) Regulatory challenges

Viet Nam’s legal framework for emission reduction is institutionally fragmented, weakening policy coherence. Although there are numerous climate-related instruments, they are developed separately by different ministries (Industry and Trade, Construction, Agriculture, Environment), leading to potentially conflicting targets, overlapping roles, and administrative complexity. In the absence of a unified, long-term legal vision for the low-carbon transition, enterprises lack a firm basis for investment.

A fundamental issue is the absence of an effective carbon price. Although Decree No. 06/2022 and the emissions-trading market scheme are under development, carbon currently has no economic value, meaning investments in low-carbon technologies (such as calcined clay and WHR) do not yield additional returns compared with conventional alternatives. The MRV system and carbon-credit programs are underdeveloped, preventing producers from monetizing greenhouse-gas reductions, thereby further weakening investment incentives.

e) Development trends:

Viet Nam’s industry and regulatory approaches the challenges with a number of countermeasures based on the National Strategy for Building Materials Development (2021-2050).

- **Restructuring, restrictions on new investments, and a focus on green technologies and CO_2 reduction:** The strategy imposes strict capacity control, with total designed capacity capped at 125 million tonnes in 2025 and 150 million tonnes in 2030; new projects must have a minimum scale of 5,000 tonnes of clinker/day.
- **Modernisation of technology, mandatory WHR installation and reducing the clinker ratio**: reduction of the maximum clinker ratio to 65% by 2030 and 60% by

2050; increased use of industrial wastes/residues as alternative raw materials to 20-30%.

- **Efficiency-environment targets**: Thermal energy consumption ≤ 730 kcal/kg (3,054 MJ/t) clinker; initial CO_2 emission cap ≤ 650 kg/tonne of cement, declining to ≤ 550 kg/tonne by 2050; alternative fuel substitution rates of 15% (2030) and 30% (2050).
- **Limited exports and higher-value products:** Limit clinker/cement exports to a maximum of 30% of capacity by 2030, decreasing to 20% by 2050, thereby compelling the industry to refocus on the domestic market, improve efficiency, and develop higher-value products rather than competing on volume.

The Government and development partners focus on improving energy efficiency. The National Energy Efficiency Program identifies this as a top priority amid electricity demand growth of around 10%/year and emphasises expanding enterprise access to energy-saving solutions.

1.2.5.2 The building materials manufacturing industry

The building materials manufacturing industry is currently facing a number of structural and market-related challenges. Although production capacity has expanded in several subsectors, actual market demand has not grown at the same pace. At the same time, product quality, market acceptance, and the pace of construction activities continue to affect the sector's overall performance.

Fragmented concrete market: many small facilities and inadequate quality control. Domestic cement consumption has declined due to a slowdown in domestic construction investment; numerous constructions works and key infrastructure projects have been slow to deploy or have had to be extended or delayed. For NFBM, most consumers still prefer traditional masonry materials-fired clay bricks-and the quality of some NFBM products remains inadequate in terms of water tightness and crack resistance, thus facing difficulties in market uptake.

NFBM: despite large capacity (12.4 billion SBU/year), consumption remains limited due to user perceptions, higher costs, and non-standardized installation techniques. Most people still habitually use traditional fired clay bricks, and the quality of some NFBM products is not yet assured in terms of water tightness and crack resistance, therefore also encountering consumption challenges.

1.3. Status of cement production technology in Viet Nam

1.3.1. Overview of cement production technology in Viet Nam

Over the past two decades, Viet Nam's cement industry has made significant technological advances. From small-scale, manual production using the wet or semi-dry process, all new production lines now adopt the dry-process rotary kiln technology with multi-stage preheater towers and calciner systems. As of September 2025, Viet Nam has 61 plants producing clinker. The total national designed capacity is 108.5 million tonnes of clinker per year, equivalent to 121.6 million tonnes of cement per year (Source: VNCA 2025).

Capacities range from 1,000-12,000 t/day. Of these, 23 lines have capacities below 2,000 t clinker/day (nearly 11% of output); 13 lines are 2,500 t clinker/day (nearly 11% of output); and 46 lines are 3,000-12,000 t clinker/day (nearly 73% of output).

Table 1. 4 Scale by designed capacity of cement plants in Viet Nam

(Long 2025)

Designed capacity, tonnes of clinker/day	**≥ 3,000 t/d**	**2,500 t/d**	**< 2,000 t/d**
Number of lines	51	13	23
Total designed output, million tonnes of cement/year	99.9	11.8	9.9
Share, %	82.15	9.73	8.12

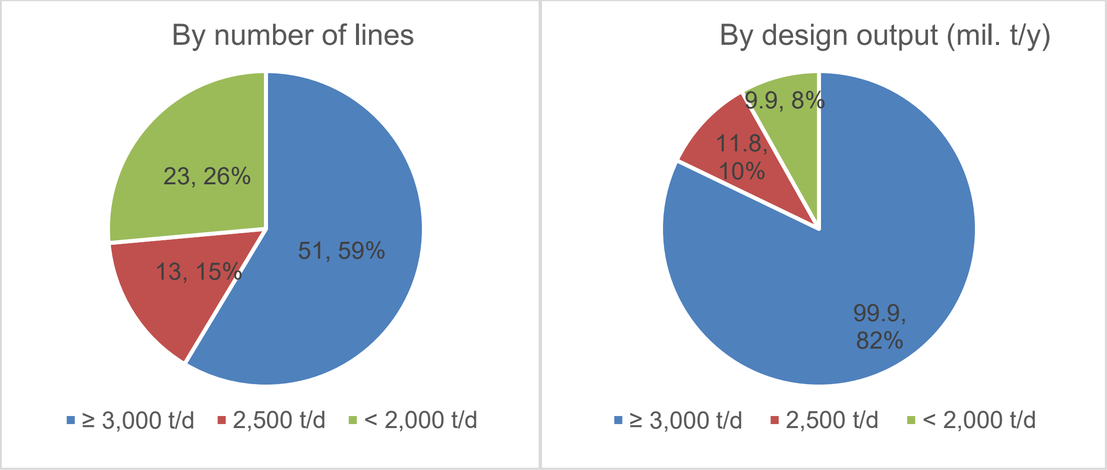


Figure 1. 11 Number of lines and share by design output of Vietnamese cement sector in 2024

(Source: adated data from VNCA 2025)

Table 1. 5 Benchmark Comparison of Raw Material Inputs for Clinker and Cement Production

Indicator	International (Mohammed and Safiullah 2018; Renó et al. 2013)	Vietnam (Mai 2024)
Total raw materials, ton/ton clinker	~1.56	1.55
Limestone share in raw mix	75–80%	~80%
Implied limestone, ton/ton clinker	~1.17–1.36	~1.24 (≈1.55×0.80)
Clay share in raw mix	20–25%	~17–18%
Implied clay ton/ton clinker	~0.31–0.43	~0.264–0.279 (≈1.55×0.17–0.18)
Gypsum in cement	3–5%	~4%

Modern plants (Nghi Son, INSEE Hon Chong, Xuan Thanh, Long Son, Song Gianh…) are invested synchronously from raw-material quarrying, raw grinding, clinker burning, to cement grinding and dispatch. Grinding technology continues to improve, with a shift from traditional ball mills to vertical roller mills (VRM), significantly reducing specific electricity consumption (Prof. Long, VNCA). Process control systems are increasingly modern with a high level of automation (DCS, SCADA) and online monitoring of operating parameters. Several pioneer plants (Vicem Hoang Thach, Xuan Thanh, INSEE) have begun deploying digital transformation, AI, and IoT for operational optimization and predictive maintenance.

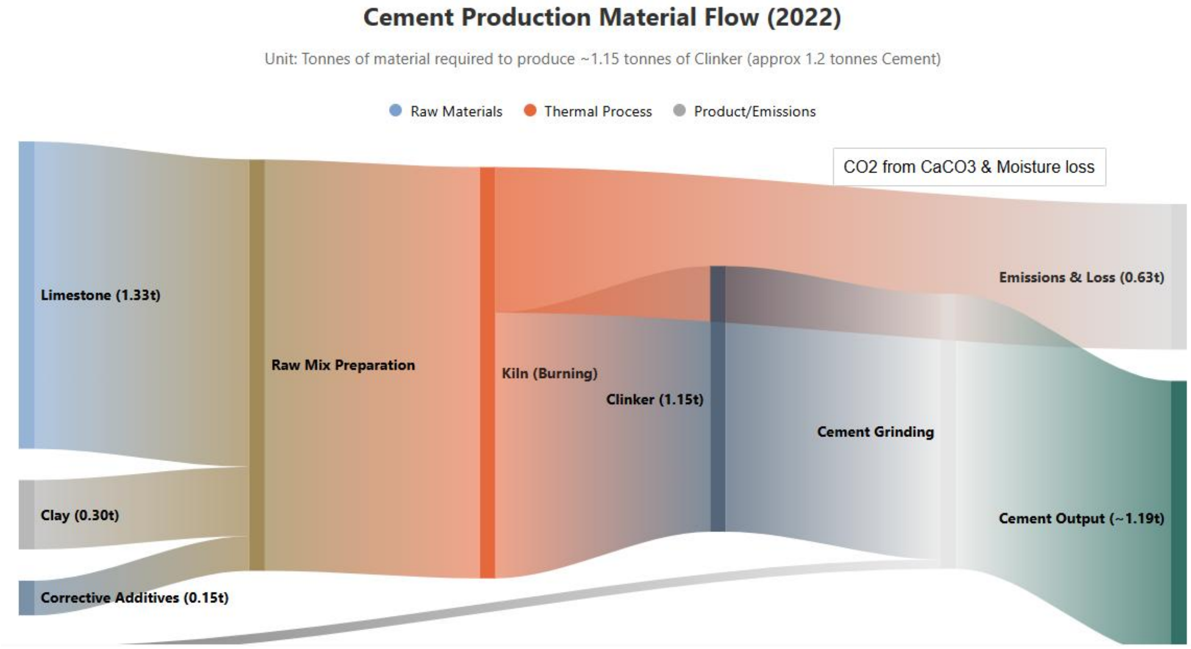


Figure 1. 12 Typical Cement production Material Flow of Viet Nam’s cement sector

(Source: VNCA 2022)

1.3.2. Characteristics of energy consumption in cement production

Cement production is an energy-intensive industry. The main energy types include thermal energy (from coal, oil, and gas) used in the clinker burning process and electricity used for raw grinding, fans, cement grinding, packing, and conveying. According to reports by the Ministry of Construction and the Viet Nam Cement Association, energy consumption in Viet Nam’s cement industry is as follows (MOC 2024; Ximang.vn 2025; Luong Duc Long-VNCA 2025):

Fuel consumption: Coal is the primary energy source for cement production. Other fuels such as oil, biomass, and wastes contribute a smaller share to emissions. Plants in Viet Nam feature an average specific heat consumption of 780-820 kcal/kg clinker (3,263-3,431 MJ/t clinker), while modern plants achieve 730-750 kcal/kg (3,054-3,138 MJ/t clinker), approaching the international BAT benchmark of 680-700 kcal/kg clinker (2,845-2,929 MJ/t clinker).

Electricity consumption: Most electricity is purchased from the grid. Across the sector, 34 plants have installed WHR power systems with a total capacity of 264.7 MW, capable of replacing 20-30% of grid electricity demand at installed sites. On average, plans have specific electricity consumption of 58-65 (average of 62.6) kWh/tonne of clinker and 85-105 kWh/tonne of cement (Hoan 2025). Optimized lines achieve 85-90 kWh/tonne, while the international BAT is 80-85 kWh/tonne of cement.

Cement grinding: In cement grinding, ball mills (with or without pre-grinding) typically consume 36.4-38.4 (average of 37.3) kWh/tonne of cement, whereas VRMs consume 33.3 kWh/tonne of cement. On average, the cement grinding consumed about 36.2 kWh/tonne of cement.

Thus, compared with the ASEAN average (780-800 kcal/kg clinker and 105-110 kWh/tonne of cement) Viet Nam's cement energy efficiency is relatively good, yet further improvement potential remains to reach best-in-class levels.

1.3.3. Current status of kiln technology and equipment ***in cement production***

-Dry-process rotary kilns: used across all large-capacity lines. Preheater towers generally have 5 stages with a calciner.

- Grinding equipment:

+ Raw materials: predominantly VRM.

+ Cement: a substantial share still uses ball mills, but the trend is toward VRM or hybrid VRM-ball systems to save electricity.

- Dust-collection systems: electrostatic precipitators (ESP) and bag filters (BF) are used, meeting current emission standards (QCVN 19:2024/BTNMT).

- Seaports and logistics: many private plants have invested in dedicated seaports (Xuan Thanh, Long Son, The Vissai), helping reduce transport costs and indirectly lowering energy-related emissions.

1.4. Conclusion

Chapter 1 establishes the baseline context for assessing the transition of Viet Nam's cement and cement-based building materials sector toward a low-carbon and net-zero pathway. The analysis confirms that building materials remain a strategic industry underpinning infrastructure development, urbanisation, and economic growth. However, future demand is increasingly shaped not only by volume expansion but also by sustainability requirements, including energy efficiency, resource conservation, and reduced embodied carbon in construction materials.

From a market and structural perspective, Viet Nam's cement industry has entered a mature and structurally constrained phase. Design capacity significantly exceeds domestic demand, resulting in persistent oversupply, low-capacity utilisation, and strong price-based competition—particularly in clinker exports with limited value added. Cement consumption is overwhelmingly driven by concrete production, while non-fired building materials, despite their environmental advantages, remain under-utilised. This structural context weakens traditional growth strategies based on capacity expansion and exports, but at the same time creates strong incentives for upgrading existing assets and shifting toward higher-value, lower-carbon products.

In terms of production technology, the industry has achieved a relatively high level of modernisation, with most clinker lines based on dry-process kilns and large plants approaching international energy-performance benchmarks. Nevertheless, average thermal and electrical energy intensities remain above best-available technology levels, and significant performance gaps persist across plant groups. Waste supply for cofiring is a significant barrier for further investments into the technology. These gaps highlight substantial “no-regret” mitigation potential through energy efficiency, waste heat recovery, clinker substitution, and alternative fuels—measures that are directly aligned with near-term emission-reduction targets under Viet Nam’s NDC and long-term net-zero commitments.

Overall, Viet Nam’s cement industry combines three critical characteristics: high emissions intensity, limited room for volume-driven growth, and a relatively strong technical foundation for efficiency improvement. Together, these factors make the sector both a priority and a viable candidate for deep decarbonisation. This baseline assessment sets the stage for Chapters 2–4, which further analyse international decarbonisation pathways, technology options, market drivers, and policy instruments to translate these structural pressures into a coherent transition strategy for low-carbon cement and concrete in Viet Nam.

Chapter 2: International Product Trends and Emerging Technologies

2.1 Overview

2.1.1 Production process - Cement Overview

The following chart provides an overview of the cement production value chain.

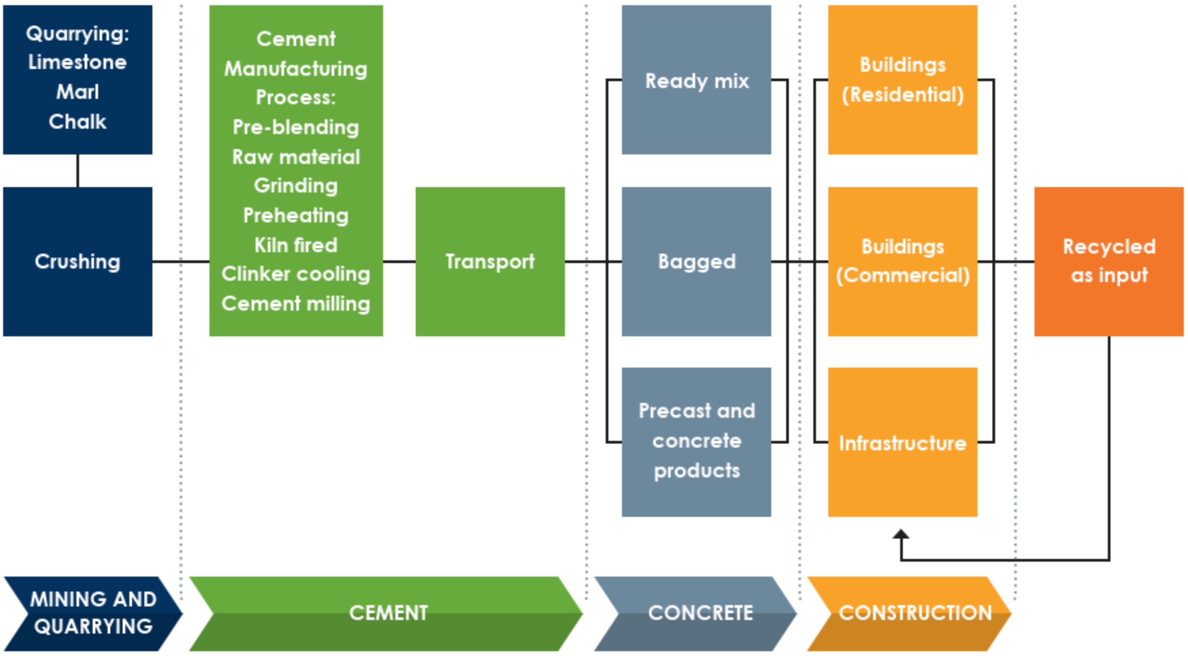


Figure 2. 1 Cement Production Value Chain

Source: (NCPC 2023)

The present analysis focuses on the cement and concrete production as well as on alternative options to be used in the building sector.

Basis for cement is clinker production which is associated with considerable process emissions due to the calcination process, which is the chemical process of transforming calcium carbonates (CaCO3) to calcium oxides (CaO), which results in significant amounts of CO_2:

Production equation: CaCO3 + Heat => CaO + CO_2 (Fraction CaO = 0.646)

(The Oxford Institute for Energy Studies, 2022)

This means that unlike other industrial applications, the improvement of production process and change of fuels alone, will not be sufficient for comprehensive decarbonization. Instead, options to modify the composition of cement or other alternative materials, but also options for recovery of carbon need to be analysed.

The following diagram illustrates the different stages of the cement production process.

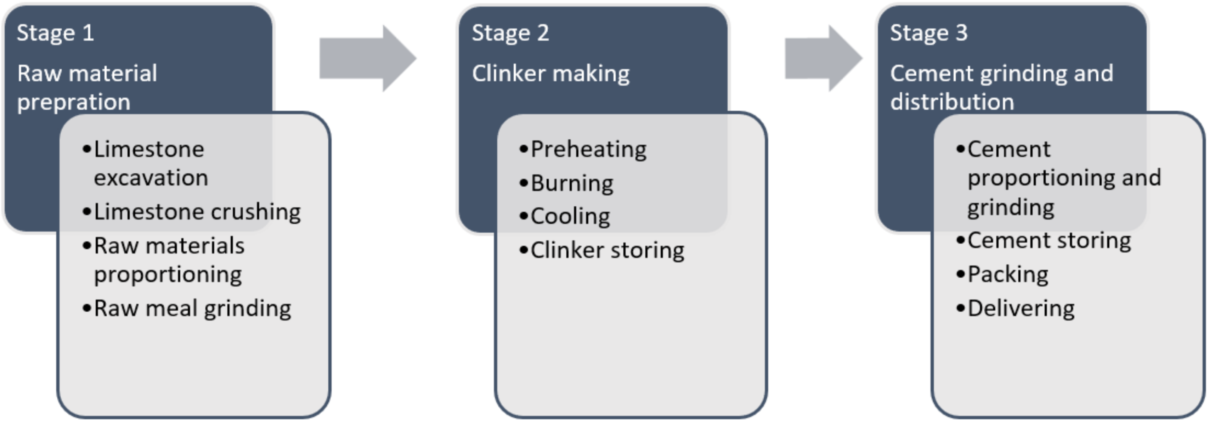


Figure 2. 2 Production Process Overview

Source: (NCPC 2023)

The cement manufacturing process has undergone many changes over the past decades. There are four different methods of cement production: wet kiln method, semi-wet kiln method, semi-dry kiln method, and dry kiln method.

The **wet process** is typically preferred whenever the raw material has a moisture content of more than 20% by weight. The clay is mixed with water while crushing and it is further mixed with limestone and other ingredients into a slurry of high concentration. In order to decrease kiln fuel consumption, water addition is controlled during raw material grinding. This way, the amount of water used is at a minimum, but the slurry still meets the required flow and pumpability characteristics (32% to 40% water). Wet processes are more energy-consuming and, thus, more expensive (Institute for Prospective Technological Studies 2013).

In the **semi-wet method**, materials coming out from the mill are like slurry material. Before entering the kiln, these materials are filtered by pressing and fed into the kiln in cubiform. Factories using semi-dry processes are likely to move on to the dry method whenever an upgrade or significant improvement is required. Plants using wet or semi-wet methods usually have access only to moist raw materials.

All above-mentioned methods include the following processes:

- Raw materials – storage and preparation
- Fuels – storage and preparation
- Clinker making
- Clinker cooling
- Cement–preparation and storage (finish grinding)
- Packaging and dispatch (ALLPLAN GmbH. 2021)

The best available technology for clinker production is a **dry process kiln** with multi-stage preheating and pre-calcination, using waste heat recovery. Simplified energy and raw material flows are depicted below.

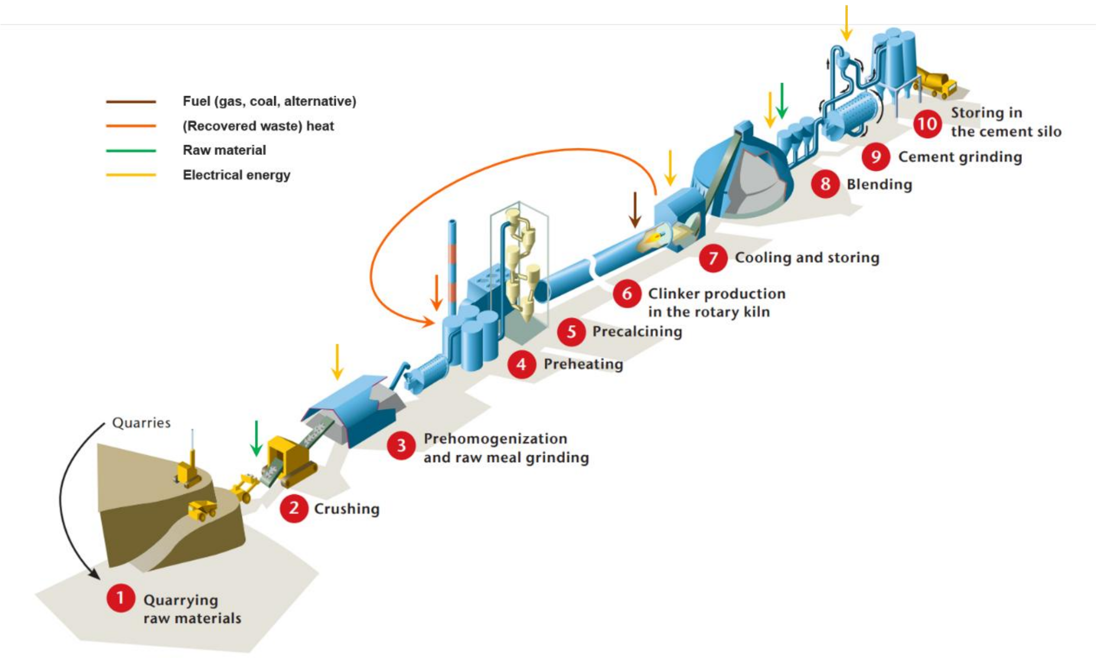


Figure 2. 3 Overview Energy and Material Flows, adapted from: (IEA, 2018)

In 2019, the most efficient process (i.e. Dry with preheater and pre-calciner) required 3.51 GJ/t clinker (on a global average and for the production of grey clinker), while less efficient processes such as wet or shaft kilns required 5.51 GJ/t clinker.

Typically applied technologies are shown below[1]:

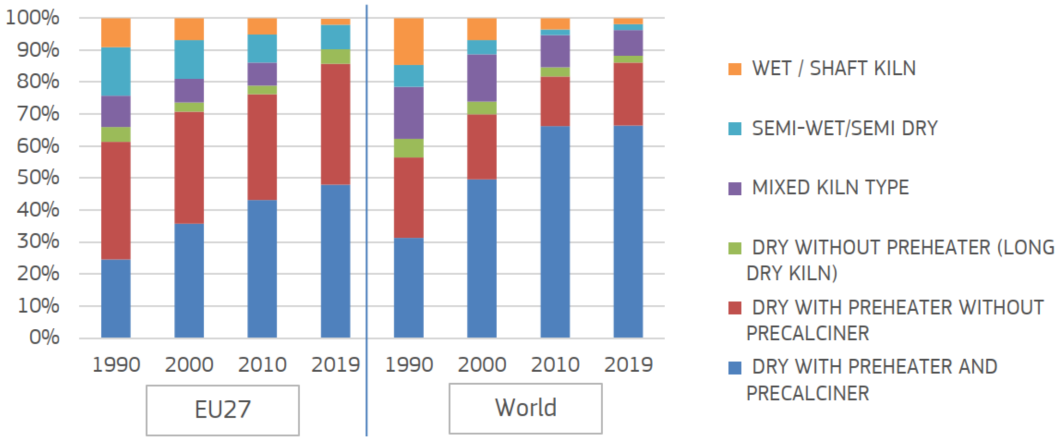


Figure 2. 4 Shares of technologies in grey clinker production

Source: (Marmier, A., 2023)

2.1.2 Decarbonisation options

When analysing the pathways for energy transition and decarbonization in the cement industry the following options can be identified:

Improvement in the cement production process itself or linked to it:

- Energy efficiency improvements
- Change in Fuels

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[1] Comment from original source: Low data coverage for specific regions in GCCA Getting the Numbers Right initiative may alter the accuracy of the results: One can for instance expect that new plants (with higher thermal efficiency) are more accurately represented than older plants (with lower thermal efficiency).

- Change in Raw Materials for cement production.

Or measures outside the core cement production such as:

- Alternative materials for the building sector
- Re-carbonisation and Recycling
- Carbon capture and storage.

The following chapter describes the technical background of potential options, economic implication and current use both internationally and in Viet Nam.

2.2 Energy Efficiency improvements

Energy efficiency is one of the most important levers for reducing both operating costs and greenhouse gas emissions in cement production. Since cement manufacturing is highly energy-intensive, improvements in efficiency directly translate into lower fuel and electricity consumption, reduced CO_2 emissions, and enhanced competitiveness of plants.

A wide range of technological and operational measures is available, targeting different stages of the production process. The following subsections provide an overview of selected key technologies and strategies, highlighting their baseline situation, possible improvements, and potential impacts on energy use and emissions.

2.2.1 High efficiency separators and classifiers

2.2.1.1 Description of Baseline Situation and Energy Consumption

Separators and classifiers are essential both in raw meal preparation and in finish-grinding operations. Their performance must always be evaluated in direct connection with the grinding technology in use. In certain systems, such as vertical roller mills, grinding and classification are carried out within the same equipment.

The fundamental purpose of a separator is particle size classification. As described by (Hardy 2021), air separation “distinguishes particles by size by utilizing the fact that they achieve different velocities when moving in a fluid under a given force.” In practical terms, this technique divides dry particulate matter into two streams: one finer and one coarser than a defined cut-point, typically in the range of ~1–300 microns. Beyond cement, this principle is also widely applied in industries such as coal, ceramics, pulp and paper, fertilizers, and pharmaceuticals.

In grinding circuits, separators split the mill discharge into fines, which are removed as product, and coarse material, which is returned for re-grinding. Additionally, they can be employed to adjust product characteristics, such as producing a more desirable particle size distribution. In many cases, classification also improves the performance of downstream processes. (Hardy 2021)

Broadly, separators are categorized as static or dynamic. Static separators contain no moving parts and are therefore inexpensive to operate, whereas dynamic separators use mechanical components to enhance efficiency. Dynamic separators are commonly grouped into three generations:

- **First generation (turbo separators):** equipped with an internal fan; separation efficiency around 50–60%.
- **Second generation (cyclone separators):** incorporating improved air recirculation and centrifugal separation; efficiency typically 60–75% (Worrell, Kermeli, and Galitsky 2013).
- **Third generation (cage or high-efficiency separators):** more advanced designs offering sharper cut size and significantly higher separation efficiency (see 2.2.1.2).

2.2.1.2 Suggested Measures of Improvement

A key improvement measure is the installation of **high-efficiency separators** in new grinding circuits or the retrofit of existing mills with less efficient units. Modern third-generation classifiers typically achieve **separation efficiencies in the range of 80–90%**, supported by optimized air distribution systems and advanced airflow control. The extended residence time of material in the separator results in sharper cut sizes and reduced over-grinding, leading to higher product quality and energy savings (Worrell, Kermeli, and Galitsky 2013).

These separators, originally developed in the early 1980s, retain similarities to second-generation designs in that an external fan generates the airflow required for separation. Material is continuously conveyed into the separator and dispersed in the air stream via a distribution plate. Fine particles are entrained with the airflow and discharged through external cyclones or bag filters, while coarse material is rejected and returned for further grinding.

The core separating element is a **cylindrical rotor** operated by a variable-speed drive. The rotor, constructed like a cage with closely spaced blades, determines the cut size through its rotational speed and the resulting swirl intensity in the classification zone.

Particle movement inside the separator is governed by three main forces:

- Centrifugal force from the dispersing plate, driving particles outward,
- Drag force from the air stream, pulling fines into the rotating cage,
- Gravitational force, acting downward on the particle mass.

As a result, coarse particles are rejected at the bottom of the classifier (cone or discharge device), while fine particles pass through the rotor cage and are carried away with the airflow. The figure below illustrates a modern high-efficiency classifier. (Office. 2021)

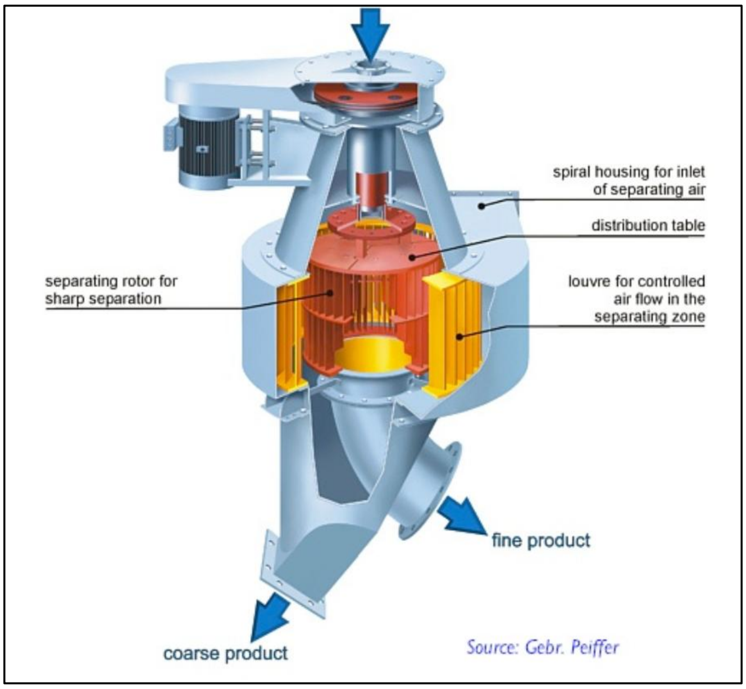


Figure 2. 5 High efficiency classifier

Source: Gebr. Pfeiffer, cited in: (Productivity. 2021)

2.2.1.3 Potential Energy Savings and Greenhouse Gas Emission Reduction

High-efficiency separators improve grinding performance by producing a larger fraction of fines, which lowers mill recirculation and can raise throughput by up to 15%. They also reduce the specific energy demand of grinding circuits compared to older separator types, contributing about 5–8% savings in grinding energy.

Overall, this translates into total energy reductions of 10–15%, equivalent to 2.3–4.5 kWh per tonne of cement. In parallel, indirect CO_2 emissions decline by roughly 1.3–2.5 kg per tonne of cement, depending on the carbon intensity of the electricity used (European Cement Research Academy, Ed, 2022).

In economic terms, investment costs are estimated at approximately **€1.5 million** for a reference plant with a clinker capacity of 2 Mt/a. Both new installations and retrofits fall within this range. Operational costs are expected to decrease by €0.2–0.4 per tonne of cement, with potential savings rising to €0.5 per tonne by 2030. These savings mainly result from reduced electrical energy demand in cement grinding (European Cement Research Academy, Ed, 2022).

Table 2. 1 Key facts of measure – High- Efficient Separators and Classifiers

Sources: (ALLPLAN GmbH, 2021), updated: (European Cement Research Academy, Ed, 2022)

Key facts of measure – High efficiency Separators and Classifiers	
Investment Cost:	€1.5 million/ Operational Costs**:** Decrease of 0.2–0.4 EURO/t $_{cem}$ VIET NAM price: - O-sepa system: + FL-Smidth: $ 0.5-1 mil. (€ 0.43-0.85 mil.) + From China: $ 0.25-0.5 mil. (€ 0.22-0,44 mil.)
Energy Savings: (electricity)	2.3-4.5 kWh/t_{cem} decrease of electrical energy demand
CO_2 mitigation:	1.3-2.5 kg CO_2/t_{cem}
Advantage:	- Reduction of electricity consumption

	• Increase of throughput • Improved product quality
Disadvantage:	• Difficulty to reach optimum seal system • Physical layout of the grinding system must allow retrofitting
TRL/international use	TRL 2022: 9
Current use in Vietnam	Most grinding systems of cement plants in Viet Nam have high-efficiency separators and classifiers.

2.2.1.4 Current status of deployment of high efficiency separators and classifiers in Viet Nam's cement industry

Separators and classifiers play a critical role in the fine grinding process, exerting a decisive influence on both productivity and cement product quality. Accordingly, all cement plants in Viet Nam are equipped with separators and classifiers, either installed as standalone units or integrated with grinding mills as combined grinding-separation systems. Many plants are increasingly shifting towards vertical roller mills (VRMs) combined with high-efficiency separation and classification systems. In addition, grinding systems are increasingly integrated with advanced process control and optimisation technologies, including dynamic classifiers, real-time particle size monitoring, and automated feedback control, to further enhance energy efficiency and product consistency. In addition, shifting toward VRM combined with high-efficiency separators and classifiers, cement plants in Viet Nam have also implemented a range of energy-saving equipment and optimization measures across their production lines. Some plants have replaced large motors and industrial fans with high-efficiency models equipped with variable frequency drives (VFDs), enabling flexible speed control and achieving 10–20% reductions in electricity consumption. At the same time, the level of process automation has been significantly enhanced through centralized control systems (DCS/SCADA), which allow real-time monitoring and optimization, ensuring stable temperature and pressure profiles throughout the kiln and heat-exchange system. The integration of energy-efficient equipment together with advanced control solutions not only reduces operational losses and extends equipment lifespan but also improves clinker quality and lowers indirect emissions associated with grid electricity use.

2.2.2 Process control optimization in clinker making

2.2.2.1 Description of Baseline Situation and Energy Consumption

Clinker production is among the most energy-intensive steps in cement manufacturing. When process control is absent or not optimized, the kiln system operates under unstable conditions, leading to unnecessary heat losses and frequent operational disturbances. Consequently, fuel demand increases, overall efficiency declines and the service life of key equipment, such as the refractory lining, is shortened under fluctuating operation. Inadequate process control also results in higher emissions of pollutants, including NO_x, SO_2, and dust (ALLPLAN GmbH, 2021).

2.2.2.2 Suggested Measures of Improvement

Process control systems are a key measure to optimize combustion conditions and maintain stable kiln operation at optimum levels. Improved process control not only reduces fuel demand and heat losses but also enhances clinker quality and grindability, for example by improving reactivity and hardness, which in turn facilitates more efficient clinker grinding. As a co-benefit, emissions of NO_x, SO_2, and dust are reduced (International Finance Corporation, 2017 and Schorcht, Kourti, Scalet, Roudier, & Sancho, 2013).

Process control optimization applies to all kiln types and includes both technical and organizational measures. Key actions involve operator training, raw meal homogenization, uniform coal dosing through gravimetric feed systems, and improved cooler operation. Steady and reliable fuel supply also depends on appropriate design of hoppers, conveyors, and feeders (Schorcht, Kourti, Scalet, Roudier, & Sancho, 2013).

Modern process control systems with faster and more precise measuring and control equipment continuously track oxygen, CO concentration, and temperature in the kiln. This allows earlier detection of combustion irregularities and prevents automatic kiln shutdowns due to CO peaks (“CO trips”). Avoiding such CO trips stabilizes kiln operation and, when electrostatic precipitators are used, reduces dust emissions as well as the release of substances adsorbed onto the dust, such as metals.

In addition, online analysers provide real-time data on the chemical composition of raw meal and clinker, enabling immediate adjustments to maintain consistent process conditions. Beyond weighing and blending automation, other critical parameters, such as airflow, mass flow, and temperature distribution, are continuously monitored and optimized. A schematic overview of the main control points and parameters in a kiln system is shown in **Error! Reference source not found.**, illustrating how process status measurements, manipulated parameters, and automated feedback loops are integrated into modern kiln management systems.

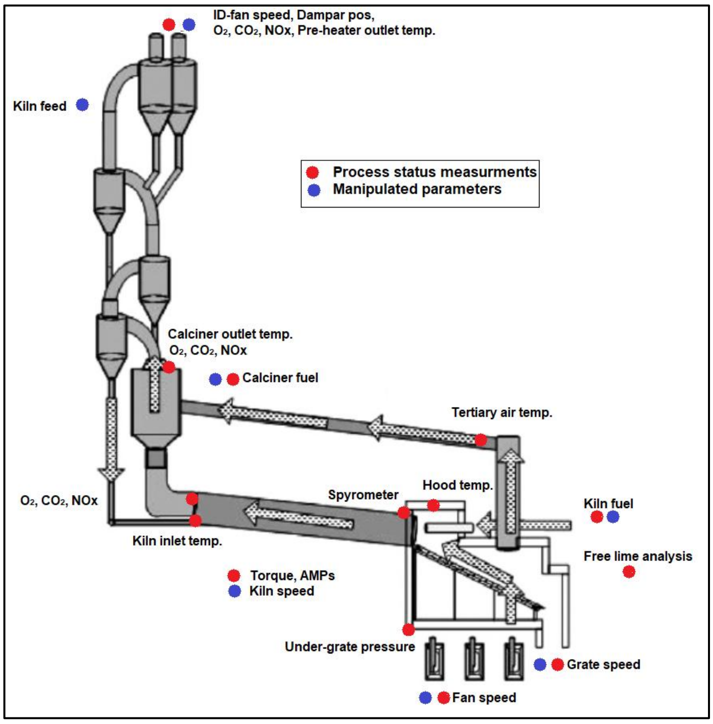


Figure 2. 6 Control points and parameters in a kiln system control

Source: Adapted from (IFC 2017b)

Modern process control systems go beyond classical proportional–integral–derivative (PID) control. They employ expert/rule-based and fuzzy-logic strategies that mimic experienced operators by combining signals from multiple process stages. Recent digitalisation enables model-predictive control (MPC), AI-based optimisation (see Chapter 2.5.3), and soft sensors (virtual measurements inferred from other signals). Together, these tools provide real-time monitoring, adaptive setpoints, and remote multi-user access, improving process stability, energy efficiency, and product quality (European Cement Research Academy, Ed, 2022).

2.2.2.3 Potential Energy Savings and Greenhouse Gas Emission Reduction

The implementation of advanced process control (APC) systems in cement plants can deliver notable reductions in both thermal and electrical energy demand. Reported thermal energy savings typically range from 20 to 170 MJ/t clinker, while electrical savings are in the range of 1.5 to 3.2 kWh/t clinker. These reductions are strongly dependent on plant configuration, the quality of instrumentation and data acquisition, and the stability of plant operations.

In terms of CO_2 mitigation, APC measures can achieve an indirect reduction of 0.9 to 1.8 kg CO_2/t cement and direct reductions of up to 11 kg CO_2/t clinker, primarily through improved kiln and process stability. By optimizing process parameters such as fuel use, kiln throughput, and clinker quality, APC can also enhance heat recovery and reduce refractory consumption.

Cost assessments indicate relatively low investment requirements compared to other energy efficiency measures. New installations or retrofits typically require €0.25–5 million, with operational savings estimated at €0.2–0.8 per ton of cement (European Cement Research Academy, Ed, 2022).

Table 2. 2 Key Facts of Measure – Process Control Optimization in Clinker Making Technology

Sources: (European Cement Research Academy 2022)

Key Facts of Measure – Process Control Optimization in Clinker Making	
Investment Cost:	€0.25–5 million/ Operational Costs**:** Decrease of 0.2–0.8 EURO/t_{cem} VIET NAM price: No data
Energy Savings: (Thermal and Electricity)	20–170 MJ/$t_{clinker}$ (5.6–47.2 kWh/$t_{clinker}$) decrease of thermal energy demand 1.5 – 3.2 kWh/ $t_{clinker}$ decrease of electrical energy demand
CO_2 Mitigation:	1-11 kgCO_2/$t_{clinker}$
Advantage:	• Improve heat recovery • Improve material throughput • Reliable control of free lime content in the clinker • Decrease fuel consumption • Decrease refractory consumption • Lower maintenance costs
Disadvantage:	• A high educational level of operators and staff is critical for process control and optimization.
TRL/international use	TRL 2022: 8-9

Current use in Vietnam	Only a limited number of plants have invested in this system

2.2.2.4 Current status of deployment of Process control optimization in clinker making in Viet Nam’s cement industry

The adoption of advanced energy-monitoring systems and artificial intelligence (AI) for production optimization in Viet Nam’s cement industry remains limited compared with global best practices. While most plants have deployed basic DCS/SCADA platforms for process control, the use of real-time energy dashboards, predictive analytics, and AI-driven optimization algorithms is still in its early stages. Currently, only a small number of pilot “smart plant” initiatives have been implemented, most notably at Vicem Hoàng Thạch and Xuân Thành, where AI models are being tested to support kiln-coating stability prediction, optimized fuel-air ratio control, and early detection of abnormal operating patterns. International experience shows that AI-based kiln optimization can reduce heat consumption by 3-7% and enhance clinker quality consistency, yet such benefits have not been fully realized in Viet Nam due to constraints in data quality, limited connectivity of field instrumentation, and the high cost of digital transformation. As the government promotes energy efficiency and low-carbon technologies, wider deployment of AI solutions-and integration with high-resolution sensors, energy management systems, and advanced process simulators-is expected to become a key driver for reducing electricity and heat consumption across Vietnamese cement plants in the coming decade.

2.2.3 Low-pressure drop cyclones for suspension preheaters

2.2.3.1 Description of Baseline Situation and Energy Consumption

Cyclone preheaters in cement production usually consist of four to six stages, arranged vertically in towers reaching 50 to 120 meters in height. In this counter-current setup, the hot exhaust gas from the rotary kiln flows upward through the cyclones, while the raw meal is fed from the top and gradually heated as it descends through each stage. This design ensures effective heat exchange between the gas and the raw meal, preparing the feed material for the kiln.

The number of cyclone stages is determined by several factors beyond raw material drying, including construction cost, fuel and electricity prices, heat exchange efficiency, gas conditioning requirements, radiation losses, and particularly the pressure drop across the cyclones. The pressure drop is one of the most critical parameters, as it directly affects the fan power demand and thus the overall energy consumption of the preheater system.

Typically, a 4-stage preheater exhibits a pressure drop of around 500–550 mmwg (millimetres of water gauge). Adding more cyclone stages increases fuel efficiency by enhancing heat recovery, but also raises the overall pressure drop, which can offset the gains through higher fan power consumption (Equipment. 2021).

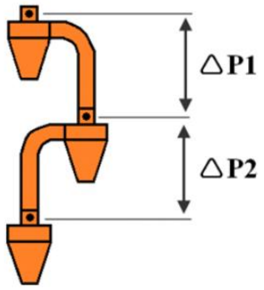


Figure 2. 7 Pressure drop across one stage of cyclones

Source: (Equipment. 2021)

2.2.3.2 Suggested Measures of Improvement

The pressure drop across cyclones is directly linked to the fan power demand required for operating the preheater system. Reducing this pressure drop is therefore a key measure to improve energy efficiency. One approach is to optimize the geometry of cyclone inlets. By redesigning the inlet shape, such as using axial or horizontal configurations, the inlet gas velocity can be reduced, which lowers pressure losses while maintaining dust collection efficiency (Equipment. 2021).

Modern low-pressure drop cyclones achieve this improvement through optimized flow guidance and enhanced separation efficiency. These designs reduce the overall power consumption of the kiln exhaust gas fan system and, at the same time, improve the heat transfer in the preheater. As a result, the specific fuel demand decreases, since more efficient separation ensures that less dust is carried into downstream process stages (IFC 2017a), (European Cement Research Academy 2022).

In practice, plants with conventional 4-stage preheaters have been upgraded to 5 or 6 stages using low-pressure drop cyclones. This development enables a significant reduction in fuel consumption, while the additional power demand of the fan increases only marginally. Indeed, in modern systems the pressure drop across a 6-stage preheater equipped with low-pressure cyclones can be comparable to, or even lower than, that of older 4-stage designs (European Cement Research Academy 2022).

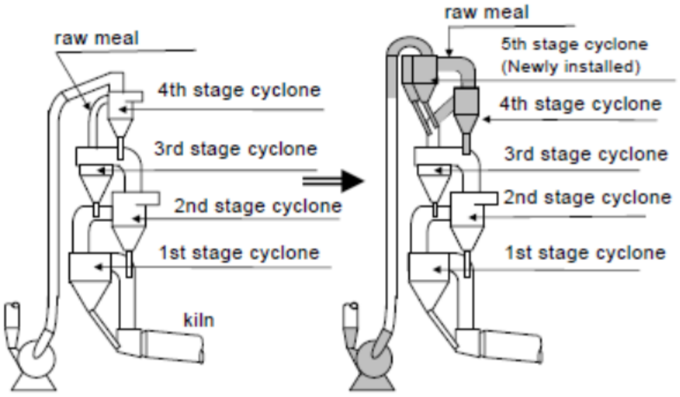


Figure 2. 8 Adding low-pressure cyclone

Source:(Equipment. 2021)

As illustrated in **Error! Reference source not found.**, additional low-pressure cyclone stages can be integrated into existing preheater towers, enabling these efficiency improvements without fundamentally changing kiln operation.

2.2.3.3 Potential Energy Savings and Greenhouse Gas Emission Reduction

The installation of low-pressure-drop cyclones reduces the pressure losses in the preheater system, thereby lowering the energy demand of the kiln exhaust gas fan. According to (ECRA 2022), this can lead to electricity savings of up to 1.5 kWh per tonne of clinker. In addition, improved gas–solid distribution in modern designs enhances heat transfer efficiency, resulting in thermal energy savings of up to 33 MJ per tonne of clinker. Case studies also indicate production increases of about 5 %, which further improves the specific thermal efficiency of the kiln system (European Cement Research Academy 2022), (Worrell, Kermeli, and Galitsky 2013).

These energy savings correspond to a direct CO_2 reduction of up to 3 kg CO_2 per tonne of clinker, and an indirect reduction of up to 0.8 kg CO_2 per tonne of clinker due to decreased electricity demand.

From an economic perspective, the retrofitting of existing preheater systems with three low-pressure drop cyclone stages is estimated to require an investment of €8–10 million for a reference clinker plant with a capacity of 2 Mt/a. The expected operational cost reductions amount to approximately €0.19–0.21 per tonne of cement, primarily resulting from decreased fan power demand. However, actual costs can vary considerably depending on site-specific factors, including fan efficiency, cyclone geometry, and the structural requirements of the preheater tower (European Cement Research Academy 2022).

Table 2. 3 Key Facts of Measure – Low-Pressure Drop Cyclones for Suspension Preheaters

Sources: (ALLPLAN GmbH, 2021), updated: (European Cement Research Academy, Ed, 2022)

Key Facts of Measure – Low-Pressure Drop Cyclones for Suspension Preheaters	
Investment Cost:	€8–10 million / Operational Costs: Decrease of 0.19–0.21 EURO/t_{cem} VIET NAM price: for a 5,000 tpd clinker kiln, supplied from China + a single replacement cyclone: $90,000–150,000 (€76,900–128,200) + a complete five-stage preheater tower: $0.5-1.5 mil. (€0.43 –1.3)
Energy Savings: (Thermal and Electricity)	up to 33 MJ/$t_{clinker}$ (up to 9 kWh/$t_{clinker}$) decrease of thermal energy demand up to 1.5 kWh/ $t_{clinker}$ decrease of electrical energy demand
CO_2 Mitigation:	up to 3 kgCO_2/$t_{clinker}$
Advantage:	• Power consumption reduction • Fuel consumption reduction • Increase incapacity
Disadvantage:	• Preheater tower need to modify • Increase overall dust loading
TRL/international use	TRL 2022: 9
Current use in Vietnam	The plants invested after 2022 have integrated this technology

2.2.4 Oxygen enrichment technology

2.2.4.1 Description of Baseline Situation and Energy Consumption

Cement rotary kilns require extremely high combustion temperatures to ensure proper clinker burning. Achieving and maintaining such flame temperatures depends on several factors, including fuel type, fuel supply, kiln heat losses, and the oxygen content in the combustion air. To minimize heat losses, kilns are generally operated at the lowest feasible level of excess oxygen. Increasing the oxygen concentration in the primary air system allows oxygen molecules to fully react with the fuel, thereby ensuring more complete combustion. If oxygen is insufficient, the flame temperature drops, reducing heat transfer efficiency to the clinker and ultimately lowering the kiln temperature. As a result, the oxygen balance in the kiln has a direct impact on combustion efficiency, fuel use, and overall energy consumption.

2.2.4.2 Suggested Measures of Improvement

Oxygen enrichment involves the injection of oxygen, either directly into the combustion zone or as an addition to the combustion air stream, in order to increase the efficiency of combustion. By raising the oxygen concentration in the combustion air (from typical levels of 23–25 vol.% up to 30–35 vol.% in enrichment applications), flame temperatures increase, heat transfer rates improve, and overall kiln stability is enhanced (European Cement Research Academy, Ed, 2022).

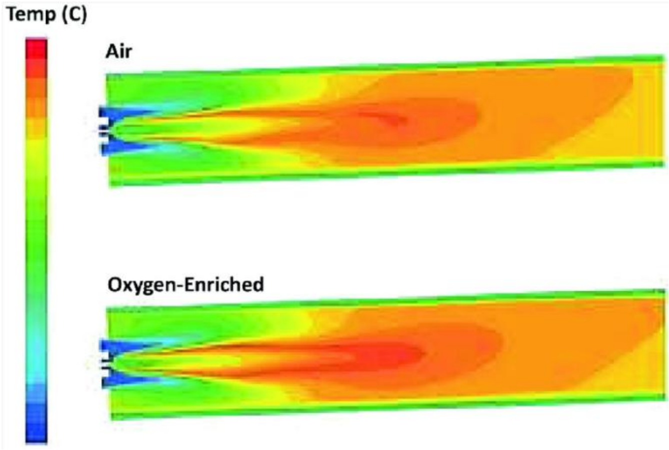


Figure 2. 9 A flame profile in a kiln with and without oxygen enrichment

Source: (Mittal, Saxena, and Mohapatra 2020)

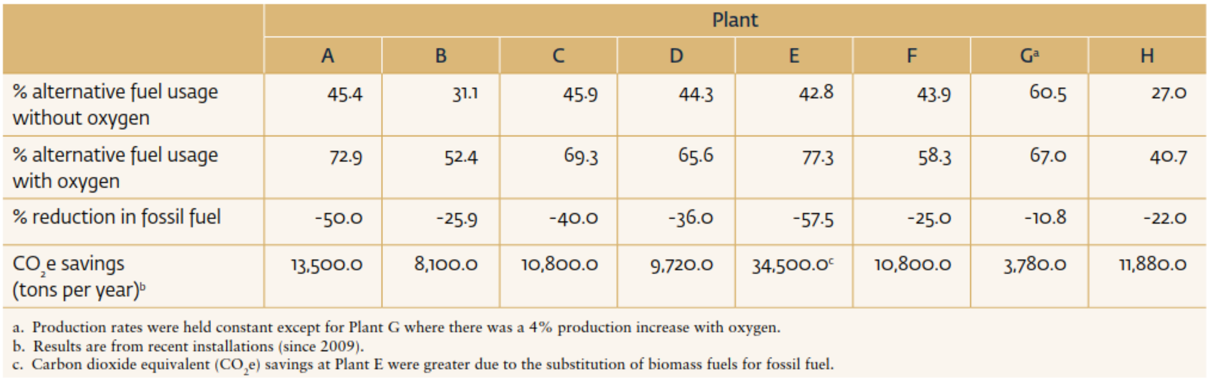
As shown in **Error! Reference source not found.**, oxygen enrichment increases the temperature in the hottest zone at the core of the flame, while the wall temperature of the kiln remains comparable to that of conventional air combustion. This allows for more efficient heat transfer without significantly increasing thermal stress on the kiln walls.

Practical applications and plant trials have demonstrated clear benefits. Reported production gains have reached up to 25%, with reduced specific dust losses and improved clinker coating, thereby supporting better kiln stability and clinker quality (IFC 2017a). Furthermore, experience indicates that oxygen enrichment can lower the specific energy demand of clinker production by up to 5%, which translates into reduced fuel consumption and associated CO_2 emissions (European Cement Research Academy 2022).

Oxygen enrichment also provides significant advantages for the co-processing of alternative fuels, particularly those with low heating values or larger particle sizes. The injection of oxygen into the flame source accelerates ignition, devolatilization, and complete combustion of such fuels. As shown in **Error! Reference source not found.**, this leads to more stable operation, higher flexibility in the use of alternative fuels, and measurable production increases in several cement plants.

Table 2. 4 Production gains achieved in different plants using oxygen enrichment technology

Source: (International Finance Corporation, 2017)



	Plant							
	A	B	C	D	E	F	G[a]	H
% alternative fuel usage without oxygen	45.4	31.1	45.9	44.3	42.8	43.9	60.5	27.0
% alternative fuel usage with oxygen	72.9	52.4	69.3	65.6	77.3	58.3	67.0	40.7
% reduction in fossil fuel	-50.0	-25.9	-40.0	-36.0	-57.5	-25.0	-10.8	-22.0
CO_2e savings (tons per year)[b]	13,500.0	8,100.0	10,800.0	9,720.0	34,500.0[c]	10,800.0	3,780.0	11,880.0

a. Production rates were held constant except for Plant G where there was a 4% production increase with oxygen.
b. Results are from recent installations (since 2009).
c. Carbon dioxide equivalent (CO_2e) savings at Plant E were greater due to the substitution of biomass fuels for fossil fuel.

2.2.4.3 Potential Energy Savings and Greenhouse Gas Emission Reduction

This measure is especially useful for plants that need additional capacity or want to maximize alternative fuel use. It requires an oxygen source and dedicated air separation plants, which are capital intensive. Increased electricity use for oxygen production must be included in the plant energy balance.

With oxygen enrichment, thermal energy consumption can be reduced by 100 to 170 MJ per tonne of clinker, while electricity consumption typically increases by 10 to 35 kWh per tonne of clinker. Direct CO_2 emissions are lowered by 9 to 15 kg CO_2 per tonne of clinker due to reduced fuel use, whereas indirect emissions may increase by 6 to 20 kg CO_2 per tonne of clinker as a result of higher electricity demand. The net balance depends strongly on the carbon intensity of the power supply (European Cement Research Academy 2022).

Economic feasibility is mainly determined by electricity prices and investment costs. According to recent estimates, investment requirements for new installations and retrofits are in the range of €5.5 to 11 million, with operational costs varying depending on the plant's configuration and efficiency of the oxygen supply system (European Cement Research Academy 2022).

Table 2. 5 Key facts of measure – Oxygen Enrichment Technology

Sources: (ALLPLAN GmbH, 2021),updated: (European Cement Research Academy, Ed, 2022)

Key Facts of Measure – Oxygen Enrichment Technology	
Investment Cost:	€5.5–11 million / Operational Costs**:** increase of 0.4–1.9 EURO/t_{cem}[2] Viet Nam price (depending on the country of origin of the equipment): + From Germany: € 7 million + From China: € 3-4 million
Energy Savings: (Thermal and Electricity)	100 - 170 MJ/$t_{clinker}$ (27 - 47 kWh/$t_{clinker}$) decrease of thermal energy demand 10 - 35 kWh/ $t_{clinker}$ increase of electrical energy demand
CO_2 Mitigation: (direct)	9-15 kgCO_2/$t_{clinker}$
Advantage:	• Energy saving • Maximizing alternative fuel use • Improving the stability of combustion
Disadvantage:	• High investment cost • Air separation plants are needed • Increase in electricity demand • Increase in indirect emissions due to increase in electricity use
TRL/international use	TRL 2022: 9
Current use in Vietnam	Not yet applied

2.2.5 Waste heat recovery

2.2.5.1 Description of Baseline Situation and Energy Consumption

In cement production, large quantities of medium-temperature waste heat (200–400°C) are released via kiln flue gases and clinker cooler exhaust air. In dry-process plants, this waste heat can account for nearly 40% of the total kiln energy input, with preheater exhaust gases contributing approximately 750–1,050 MJ/t clinker and clinker cooler exhaust gases providing an additional 330–540 MJ/t clinker (IFC 2017a), (European Cement Research Academy 2022).

Under conventional operating conditions, a substantial share of this energy remains unused and is discharged into the atmosphere, resulting in significant losses of recoverable energy. Although part of the exhaust gas heat is already utilized for drying raw materials or coal, a considerable amount of residual heat remains untapped.

Currently, the absence or limited application of waste heat recovery (WHR) systems restricts overall plant energy efficiency. This unused thermal energy could otherwise be harnessed to generate electricity, supply process heat, or contribute to district heating. The efficiency gap is especially evident in plants with stable kiln operation and large exhaust gas volumes, where unrecovered heat translates directly into increased fuel demand and avoidable CO_2 emissions (Marmier 2023), (IFC 2017a).

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[2] In “over-the-fence” agreements, oxygen is supplied by an external provider who erects, owns and operates the unit. This reduces CAPEX for the cement plant but increases OPEX due to monthly service fees (European Cement Research Academy, Ed, 2022).

2.2.5.2 Suggested Measures of Improvement

To harness the significant waste heat potential in cement plants, several WHR technologies using waste heat for electricity generation can be applied. The most relevant options include the Steam Rankine Cycle (SRC), the Organic Rankine Cycle (ORC), and the Kalina Cycle.

Steam Rankine Cycle (SRC):

The Steam Rankine Cycle is the most established technology for WHR in cement plants. It uses water as the working fluid, which is vaporized in a waste heat recovery boiler by hot exhaust gases from the kiln and clinker cooler. The generated high-pressure steam drives a turbine to produce electricity before being condensed and recirculated in a closed loop.

SRC systems are widely applied because they rely on mature, proven power plant technology that is well-known in the cement industry. They are relatively simple to operate, available from a broad range of suppliers, and comparatively cost-effective.

For optimal operation, SRC requires sufficiently high waste gas temperatures (typically above 260°C). The technology is best suited for large kilns with stable operation and significant exhaust heat availability. However, it also comes with technical requirements: conditioning of feedwater is necessary, water-cooled condensers are generally preferred over air-cooled ones, and continuous operator supervision may be required. At lower operating temperatures, partial condensation of steam in the turbine can occur, which may lead to blade erosion.

Error! Reference source not found. illustrates a typical waste heat recovery system using the Steam Rankine Cycle in a cement plant. Exhaust gases from the preheater and clinker cooler are directed to boilers, where steam is generated and then expanded in a turbine generator to produce electricity. The cycle is completed as the steam is condensed and fed back into the system (Marmier, A., 2023), (International Finance Corporation, 2017).

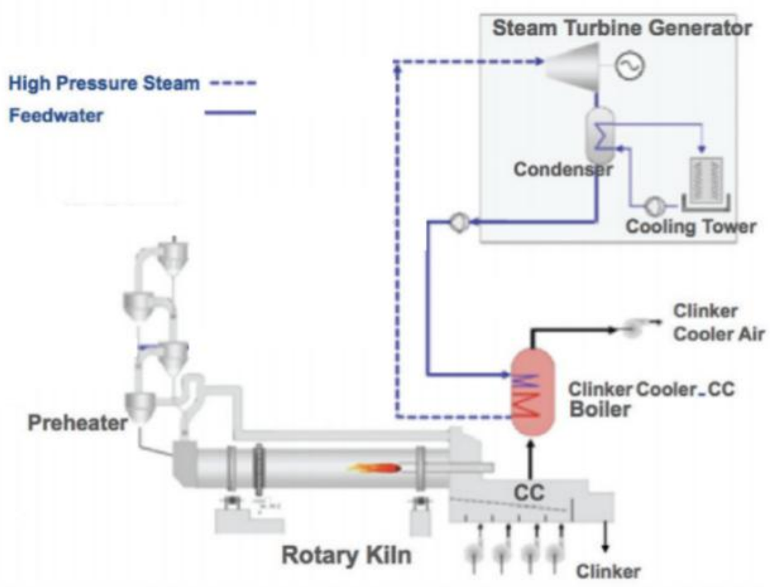

Figure 2. 10 Waste heat recovery system using Steam Rankine Cycle (SRC),

Source: (International Finance Corporation, 2017)

Organic Rankine Cycle (ORC):

The ORC is a waste heat recovery technology designed to utilize low-temperature waste heat streams that cannot be effectively exploited by conventional steam cycles. Instead of water, ORC systems use organic working fluids such as pentane, toluene, or butane, which have lower boiling points and higher vapor pressures. This enables energy recovery from sources in the range of 150–350°C, such as clinker cooler exhaust gases (European Cement Research Academy 2022).

ORC units are usually configured with two heat transfer stages: heat is first transferred from the waste gases to an intermediate fluid (e.g., thermal oil), and then from this fluid to the organic working fluid. The vaporized organic fluid drives a turbine connected to a generator, producing electricity, before being condensed and recirculated (ALLPLAN GmbH. 2021).

Because of their lower pressure operation and absence of superheaters, ORC systems are mechanically simpler, less prone to turbine blade erosion, and can run fully automated. They are especially suitable for small- and medium-sized cement plants (1,500–3,000 tpd) or for kilns with high raw material moisture, where lower-temperature waste heat is abundant (European Cement Research Academy, Ed, 2022).

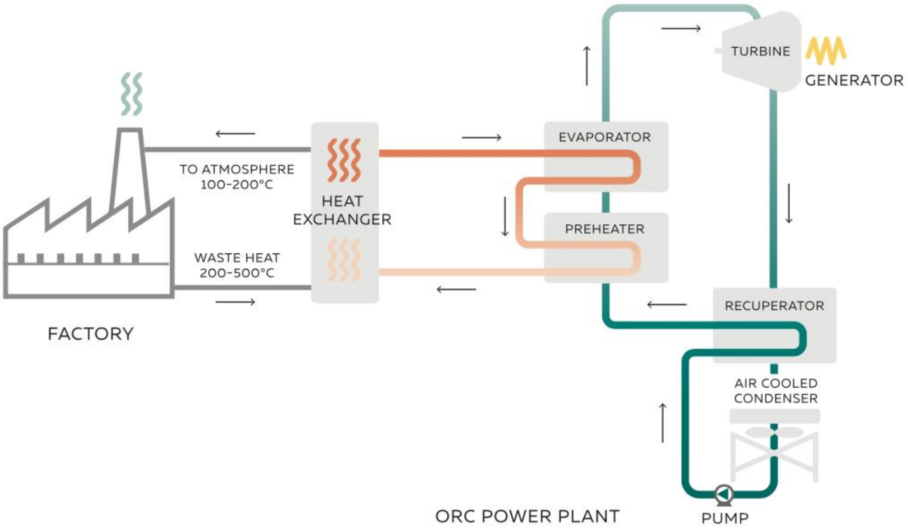

Figure 2. 11 Waste heat recovery system using Organic Rankine Cycle (ORC)

Source: (EXERGY 2022)

Kalina Cycle:

The Kalina Cycle is a modified Rankine process that uses a mixture of water and ammonia as the working fluid. Thanks to its variable boiling point, it can recover waste heat more effectively at lower temperatures (200–400°C) than conventional steam systems. This makes it suitable for cement kiln exhaust gases, where standard steam turbines are inefficient.

Typical efficiencies range between 20–25%, but installation costs are higher due to the corrosive properties of ammonia. Despite this, the cycle offers better heat utilization and reduced exergy losses, especially in low-temperature applications (European Cement Research Academy 2022).

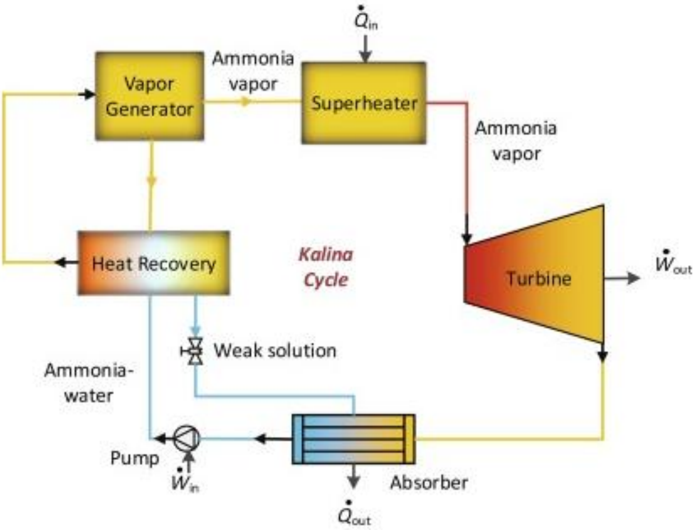

Figure 2. 12 Waste heat recovery system using Kalina Cycle

Source:(Dincer and Bicer 2020)

2.2.5.3 Potential Energy Savings and Greenhouse Gas Emission Reduction

Regarding energy performance, optimized WHR systems in cement plants can achieve electricity savings of 8 to 24 kWh/t clinker, depending on the technology applied (SRC, ORC, or Kalina). This corresponds to a net decrease in power demand, as the additional consumption of boilers and turbines is outweighed by the electricity produced from recovered heat. No direct thermal fuel savings are realized, since only residual heat is utilized.

In terms of GHG emissions, WHR does not directly reduce CO_2 emissions at plant level but contributes to indirect reductions of 5 to 14 kg CO_2/t clinker, depending on the carbon intensity of displaced grid electricity.

From an economic perspective, investment costs range from €15 to 30 million for both new installations and retrofits, with operational cost reductions of 0.5 to 1.7 €/t cement expected. These savings result mainly from avoided electricity purchases. Costs vary with site-specific parameters such as raw material moisture, cooler configuration, and the quality of available waste heat (European Cement Research Academy 2022).

Table 2. 6 Key Facts of Measure – Optimized waste heat recovery

Sources: (ALLPLAN GmbH, 2021), updated: (European Cement Research Academy, Ed, 2022)

Key Facts of Measure – Optimized waste heat recovery	
Investment Cost:	€15–30 million / Operational Costs: decrease of 0.5–1.7 EURO/t cem[3]

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[3] The cost estimation assumes a clinker production capacity of 2 million t/a and includes the construction of a boiler/steam turbine cycle. Specific costs are considered constant over time, while operating cost savings mainly result from reduced electricity demand.

	VIET NAM price: 1 MW using WHR: $1-1.5mil. (€0.85-1.28 mil.)
Energy Savings: (Thermal and Electricity)	8 - 24 kWh/ $t_{clinker}$ decrease of electrical energy demand
CO_2 Mitigation: (indirect)	5 - 14 $kgCO_2/t_{clinker}$
Advantage:	• Uses waste heat, improving plant efficiency. • Reduces grid electricity demand (indirect CO_2 savings). • Proven, available technologies. • Lowers operating costs without extra fuel.
Disadvantage:	• High investment costs. • Efficiency depends on site and temperature levels. • Requires space, maintenance, and skilled operation. • Special working fluids may raise safety/environmental issues.
TRL/international use	TRL 2022: 9
Current use in Vietnam	Installed in 38/64 production lines

2.2.5.4 Current status of deployment of WHR in Viet Nam's cement industry

With the current cement production technology in Viet Nam, all clinker lines use dry-process rotary kilns with 5-stage preheaters, calciners, and grade coolers. These lines have two high-temperature waste-gas streams from the clinker kiln system: (i) preheater exit gas at approximately 300-360°C; and (ii) clinker cooler gas at approximately 250-400°C. The heat content of these gases is substantial and is often used to dry raw materials for the raw mill. Calculations indicate that, on average, waste gas from producing 1,000 t clinker/day can supply heat for a boiler-turbine power system of about 1.5 MW. Practical WHR installations show that a kiln of 4,000 t clinker/day can provide sufficient and surplus heat for a 6 MW power system; similarly, 6,000 t clinker/day generating min. ≥ 9 MW, and 12,000 t clinker/day generating min. ≥ 18 MW.

By October 2025, a total of 38 lines had installed WHR power-generation systems with a combined capacity of 278,5 MW. In 2024, VICEM and several plants launched tenders and commenced a series of new WHR projects. There are currently around 19 WHR systems under investment, with an expected total capacity of 123.50 MW. List of cement plants have HWR system in operating and installing shown in Table A.1- Annex

Notably, in 2025 a series of VICEM's WHR systems under investment are likely to be commissioned, such as Hoang Thach, Binh Phuoc, Tam Diep. In addition, some non-VICEM plants are also expected to complete the investment phase, including Lien Khe, Trung Son, Hoang Long.

Thus, by October of 2025, there were 64 lines out of a total of 87 clinker production lines that are required to install WHR under the Decision No.1266/QD-TTg. The remaining four plants that may also be planning WHR installation in the near term are: Cam Pha, Fico YTL Tay Ninh, Yen Binh, and Song Thao.

Figure 2. 13 WHR system at Vicemt But Son plant

(Source: Vicem But Son)

2.2.6 Vertical roller mills for finish grinding

2.2.6.1 Description of Baseline Situation and Energy Consumption

The final step in cement production is finishing grinding, which represents one of the most electricity-intensive operations in a cement plant. It typically accounts for 50–65% of the total electricity consumption of the plant, with a specific energy demand of around 30–42 kWh per ton of cement in ball mills (European Cement Research Academy, Ed, 2022), (International Finance Corporation, 2017). Cement grinding has a direct influence on important product properties such as strength, setting behaviour, and water demand. In recent years, the shift toward higher-strength cement classes and finer product requirements has further increased the energy intensity of grinding processes (Ausfelder Florian 2018).

Clinker is usually ground either alone (with up to 5% minor additional constituents) or together with other main cement components. To regulate setting, gypsum or a gypsum-anhydrite mixture is typically added during grinding. In the case of joint fine grinding, the particle size distributions of the different components cannot be controlled separately. Therefore, separate grinding followed by mixing is sometimes applied, particularly when raw materials differ significantly in grindability.

In principle, three types of grinding systems are used in cement production:

- **Ball mills** – material is ground by impact and friction from grinding balls.
- **Material bed roller mills** (high-pressure grinding rollers, HPGRs) – the material is compressed between two counter-rotating rollers.

- **VRMs** – grinding takes place by compression and shear forces on a rotating grinding table.

(Diethelm Bosold 2017)

Ball mills remain the most widely used technology worldwide due to their robustness, operational reliability, and ability to handle a wide range of cement qualities. They provide a broad particle size distribution and allow some drying of moist raw materials by using hot process gases. Tube diameters of up to 6 m and lengths of up to 20m are common (Schorcht et al. 2013). However, compared to roller-based technologies, ball mills have higher specific energy consumption and are the least energy-efficient option.

2.2.6.2 Suggested Measures of Improvement

Energy saving potentials in cement grinding can be realized through two main pathways: process optimization (e.g., optimization of classifiers, adjustment of circulation ratios, classifier speeds, or the use of grinding aids) and the replacement of conventional ball mills with more energy-efficient technologies (ALLPLAN GmbH, 2021).

Vertical Roller Mills (VRMs)

VRMs (see Figure below) consist of two to four grinding rollers mounted on hinged arms, which press material onto a rotating grinding table. VRMs are particularly well suited for the simultaneous grinding and drying of cement raw materials or slag, as they can process feeds with high moisture content. The short residence time of material in the mill reduces the risk of clinker pre-hydration (Schorcht et al. 2013).

In earlier applications, VRMs faced operational challenges such as vibrations, roller and disc wear, and difficulties in achieving consistent particle size distribution. However, more recent evidence suggests that these issues have largely been resolved. Today, the main considerations are maintenance intensity and spare-part management (IFC 2017a). VRMs can achieve product fineness up to 5,500 Blaine, while also offering energy savings of up to 30–40% compared with ball mills.

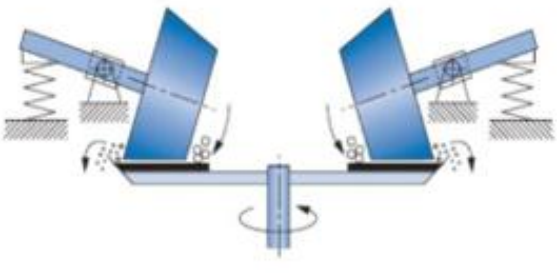

Figure 2. 14 The working principle of Vertical Roller Mill

Source: (ALLPLAN GmbH. 2021)

High-Pressure Grinding Rolls (HPGRs)

High-pressure grinding rolls (HPGRs, also known as Gutbett Roller Mills; see Figure below) expose the feed material to very high pressures, up to 3,500 bar, for a short duration. This process significantly improves grinding efficiency and allows Blaine fineness values of 4,500–5,500 cm²/g. HPGRs are commonly applied as pre-grinders to expand the capacity of existing ball mills.

Although they can deliver energy savings of up to 50% compared to ball mills, HPGRs often result in a narrower particle size distribution, which can affect water demand and strength development of cement. They also require comparatively high maintenance due to roller wear, and are therefore frequently combined with ball mills in semi-finish grinding systems (European Cement Research Academy 2022), (IFC 2017a).

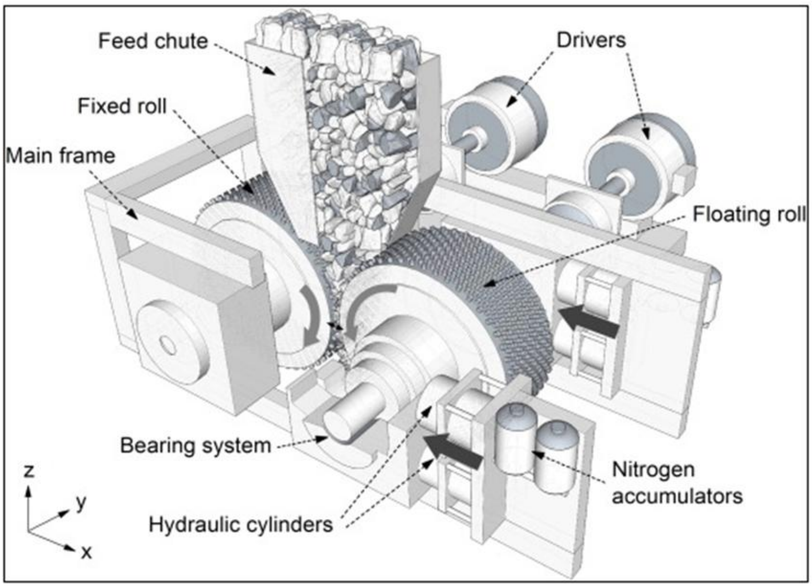

Figure 2. 15 High Pressure/Gutbett Roller Mills

Source: (Barrios Gabriel K.P. 2016)

Horomill® (Horizontal Roller Mill)

The Horomill® represents another efficient alternative for cement grinding, operating on the principle of a horizontal ring-roller mill. It combines compression and shearing forces, enabling Blaine fineness levels up to 5,000 cm²/g with relatively low power consumption. Compared to High-Pressure Grinding Rolls (HPGRs) and Vertical Roller Mills (VRMs), the Horomill® is characterized by moderate maintenance needs, lower capital costs, and greater flexibility in handling raw materials with moisture contents of up to 10% (IFC 2017a).

As shown in **Error! Reference source not found.**, the Horomill® system operates as a closed-circuit bucket elevator mill. It can be equipped with a flash dryer or aerodecantor, allowing efficient processing of raw materials and blast furnace slag with varying moisture contents. Its ability to consistently supply finished ground product, even in closed-circuit systems, makes it particularly attractive for installations requiring high outputs and flexibility.

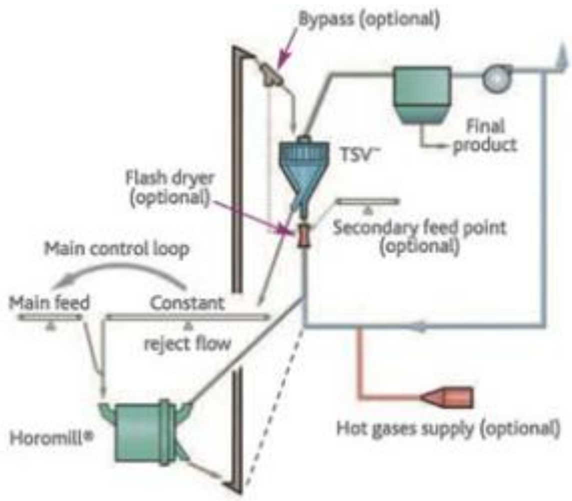

Figure 2. 16 Basic Layout of Cement Grinding Using Horomill®

Energy-Saving Configurations

Substantial energy savings can be achieved by replacing or combining ball mills with the technologies above. The most common configurations include:

- **Pre-grinding**: HPGR or roller press for pre-grinding, followed by finish grinding in a ball mill-classifier system.
- **Hybrid grinding**: Partial load shared between ball mills and VRMs.
- **Combined grinding**: Fresh feed is crushed in a roller press; fine fractions are separated, while coarse material is sent to the ball mill for final grinding.
- **Separate grinding**: Cement constituents are ground in dedicated mills according to their grindability, then blended. This is particularly relevant for blast-furnace slag cements (CEM III).(ALLPLAN GmbH. 2021)

2.2.6.3 Potential Energy Savings and Greenhouse Gas Emission Reduction

Modern grinding technologies offer clear advantages over conventional ball mills in terms of electricity demand. Depending on the configuration, VRMs typically require 25–30 kWh/t cement, while ball mills consume 30–42 kWh/t. HPGR-based semi-finish systems can further reduce consumption, with reported savings of 6–18 kWh/t cement (European Cement Research Academy 2022). Horomill® installations show similarly favourable performance, achieving power use as low as 23–30 kWh/t depending on cement type (IFC 2017a).

As illustrated in **Error! Reference source not found.**, the specific energy consumption of VRMs rises moderately with higher Blaine values, while ball mills show a much steeper increase. At a fineness of ≈4000 cm²/g Blaine, VRMs typically require 25–30 kWh/t for the main drive (increasing slightly with roller/table wear), and about 40 kWh/t when auxiliary drives (fans, classifiers) are included. In contrast, ball mills consume 60–75 kWh/t under comparable conditions.

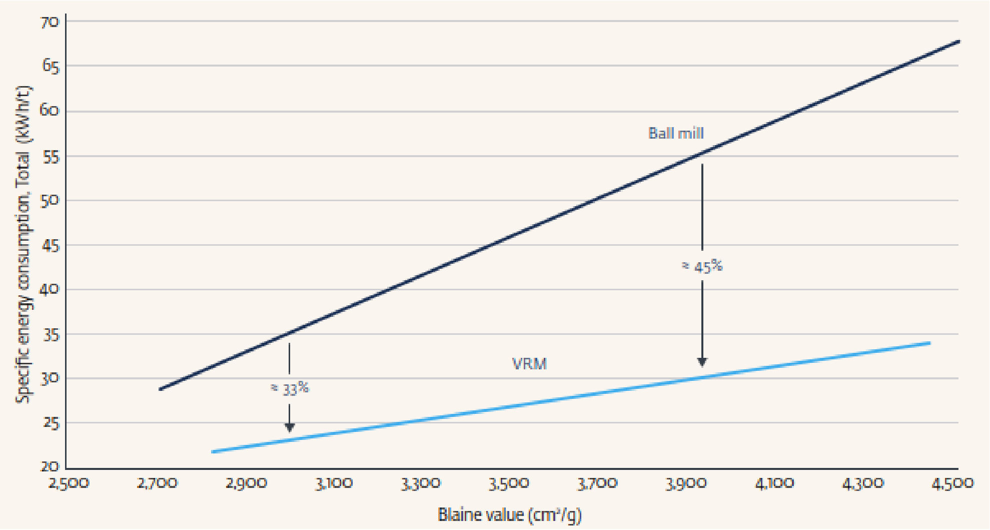

Figure 2. 17 Energy Savings Potential of Vertical Roller Mills versus Ball Mills

Source: (IFC 2017c)

The reduction in electrical energy translates into indirect CO_2 savings of 3.8–10.1 kg CO_2 per ton of cement, depending on the carbon intensity of the regional electricity grid (European Cement Research Academy 2022). Since the clinker process itself remains unchanged, no direct CO_2 reductions are realized.

In terms of costs, investment for new VRM or HPGR systems is estimated at 20–30 million € for a 2 Mt/a clinker plant, while retrofits using roller presses or semi-finish circuits range between 4–15 million €. Operational savings of about 1.0–1.7 €/t cement can be expected for new installations, and up to 1 €/t for retrofit projects, primarily due to lower power consumption.

Overall, upgrading to advanced grinding systems is among the most effective measures for lowering electricity demand in cement plants, delivering both economic and environmental benefits.

Table 2. 7 Key Facts of Measure – Vertical Roller Mills for Finish Grinding

Sources: (ALLPLAN GmbH, 2021), updated: (European Cement Research Academy, Ed, 2022)

Key Facts of Measure – Vertical Roller Mills for Finish Grinding	
Investment Cost:	€20–30 million new installation/ Operational Costs**:** decrease of 1.0–1.7 EURO/t $_{cem}$ €4–15 million retrofit/ Operational Costs**:** decrease of up to 1.0 EURO/t $_{cem}$ [4] VIET NAM price: 350–450 t/h + From China: $6-10 mil. (€ 5.12- 8.5 million) + From Loesche (Germany): $10-18 mil. (€ 8.5-15.4 million)
Energy Savings: (Thermal and Electricity)	6 - 18 kWh/ $t_{clinker}$ decrease of electrical energy demand

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[4] According to ECRA (2022), cost estimates for a clinker capacity of 2 Mt/a range from €20–30 million for new VRM or roller press installations (up to €40 million for complex semi-finish systems) and €4–15 million for retrofits. Operational savings are €0.9–1.8 per ton of cement, while additional costs from maintenance, drying energy, and system complexity are not included.

CO_2 Mitigation: (indirect)	5 - 14 $kgCO_2/t_{clinker}$
Advantage:	• Significant energy savings • Suitable for slag and moist feed materials due to simultaneous grinding and drying. • Higher fineness achievable.
Disadvantage:	• High investment costs. • Maintenance-intensive (rollers, grinding disc, classifiers). • Operational complexity compared to ball mills. • Past issues: vibration, wear, and particle size distribution control (largely improved in modern systems).
TRL/international use	TRL 2022: 9
Current use in Vietnam	Many cement plants in Viet Nam use vertical roller mills for grinding cement, or use of a combination of vertical roller mills and ball mills.

2.2.6.4 Current status of deployment of Vertical roller mills for finish grinding in Viet Nam's cement industry

Survey results from cement plants during 2022–2025 by VIBM (Hoan NV 2025) show that Viet Nam currently employs three main cement grinding technologies: (i) traditional ball mills without pre-grinding, (ii) ball mills with pre-grinding systems (roller press or high-pressure grinding rolls), and (iii) VRM. Most production lines commissioned after 2010 have shifted toward VRM due to their superior energy efficiency and operational stability.

Regarding electricity consumption, there is a clear difference among the technologies. The traditional ball mill without pre-grinding has the highest consumption, averaging 38.0 kWh/t, reflecting its lower grinding efficiency and high dependence on achieving fine product requirements. Ball mills with pre-grinding perform noticeably better, averaging 36.6 kWh/t, as the pre-grinding unit significantly reduces the load on the main mill. Vertical roller mills exhibit the best energy performance, with an average consumption of only 35.3 kWh/t and show stable performance across all survey years.

The distribution of technologies also varies according to plant scale and equipment age. Large and very large production lines (>4,000 t clinker/day) predominantly use VRM, which helps reduce the sector's overall electricity intensity and brings it closer to the energy-saving targets set by the Building Materials Development Strategy (Decision No. 1266/QD-TTg). In contrast, many smaller and older lines (≤ 2,500 t/day) still rely on traditional ball mills, which raises the industry's average consumption and highlights the urgent need for modernization and retrofitting.

On the energy consumption in clinker production of has improved to some extent; however, significant disparities remain across different kiln-line segments. The average thermal energy consumption of the sector is 827.1 kcal/kg clinker (3460 MJ/t), while the average electricity consumption is 62.6 kWh/ton clinker.

Large and very large production lines (≥ 4,000 t/day) demonstrate noticeably higher energy efficiency. The 4,000 to 6,000 t/day group has already achieved an electricity consumption level of 59.5 kWh/t, surpassing the target of 65 kWh/t clinker set by Decision No. 1266/QD-TTg. Lines with capacities above 6,000 t/day perform even better, benefiting from modernized equipment, more advanced process control, and higher levels of automation.

In contrast, smaller production lines (≤ 2,500 t/day) continue to exhibit high energy consumption-both thermal and electrical-thereby driving up the sector-wide average. This indicates that the overall energy efficiency of Viet Nam's cement industry is strongly dependent on the capacity structure of production lines and the degree of equipment modernization.

Overall, the sector's energy-consumption trends during the survey period remain relatively stable but have not yet met the energy targets outlined in the Building Materials Development Strategy (Decision No. 1266/QD-TTg), especially with respect to thermal energy consumption.

2.3 Alternative Fuels

2.3.1 Description of Baseline Situation and Energy Consumption

On a global average in cement production, only around 6% of fossil fuels are currently substituted by alternative fuels/alternative raw materials, about two thirds of this share are fossil based. In some countries/regions the substitution rate is considerable higher, e.g. some countries in the European Union use substitution rates of more than 70%. (European Cement Research Academy 2022)

The use of waste materials as fuel for cement production has two-fold positive impact on emissions – lower emissions in cement production and avoided emissions from waste incineration or landfilling.

2.3.2 Suggested Measures of Improvement

Potential alternative fuels comprise:

RDF (refuse derived fuel)

- waste tyres, waste oil and solvents
- pre-treated industrial and domestic wastes
- plastic, textile and paper wastes

other alternatives:

- **pure biomass biomass:** waste wood, sawdust, animal meal
- **other organic material**: currently limited availability/only regional relevance e.g. wood, certain grass types, cultivated green algae.
- Also **hydrogen** is considered a potential option to reduce CO_2 emissions, which only releases water instead of carbon oxides and shows high efficiency in cement industry as no process-related compression of the gas is required. However, the availability of green hydrogen, produced with renewable energy, currently is still limited with almost no application in in the cement industry. It is expected that in future, a share of 10% hydrogen use in cement industry could be feasible. (European Cement Research Academy 2022)

2.3.3 Potential Energy Savings and Greenhouse Gas Emission

Fuel related CO_2 emissions make up for about one third of overall emissions from cement production (two thirds process-related), which could theoretically fully be replaced by alternative fuels.

Technical limitations for applicability of fuel relate to their chemical composition, the moisture content and their content of trace elements or chlorine. For most organic material the calorific value of is comparatively low (10 to 18 GJ/t). In the precalciner of modern cement kilns (up to 65% of the fuel input) the lower process temperature also allows the use of low calorific fuels (approximately 13 GJ/t). For the main firing of the cement kiln, however, an average calorific value of at least 20 to 22 GJ/t is required. Although the energy input of alternative fuels might be higher than using fossil fuels, this is by far outweighed by lower emissions. (European Cement Research Academy 2022)

Additionally, **pre-treatment of alternative fuels** is often required to secure combustion efficiency and to minimise problematic substances (e. g. high concentration of chlorine or other trace substances or management of metals). This pre-treatment means additional process steps (grinding, drying) which also lead to additional energy consumption and costs. These factors have to be weighed against the savings resulting from the use of alternative fuels.

High substitution rates of alternative fuels (65% and more) might lead to **operational problems** in the kiln system. Fuels with high concentrations of chlorine and sulphur might lead to increased coating formation in the kiln inlet, gas riser duct and the lower cyclone stages. This may require additional cleaning efforts or the installation of a bypass in the kiln inlet (ALLPLAN GmbH. 2021).

In addition, the use of alternative fuels also requires adequate framework conditions, such as:

- Waste management legislation that promotes waste recovery instead of disposal
- Availability of controlled waste collection, treatment and processing including local waste collection (including monitoring)
- Reduced bureaucracy when obtaining a permit for the use of alternative fuels
- Social acceptance of co-processing waste fuels in cement plants (requires clear information and emission monitoring) (IEA 2018a)
- CO_2 legislation and CO_2 pricing
- Technical and operational experience in using alternative fuels
- If used: availability of adequate agricultural areas for growing of biomass crops and sufficient carbon neutral electricity for production of green hydrogen. (European Cement Research Academy 2022)

The cost estimation is based on a clinker capacity of 2 Mio. t/a. Investment costs cover handling, storing, feeding and dosing facilities; operational cost savings relate only to fuel cost savings as main factor.

Table 2. 8 Key facts of measure – Alternative Fuels Co-Processing

Sources: (ALLPLAN GmbH, 2021), updated: (European Cement Research Academy, Ed, 2022)

Key facts of measure – Alternative Fuels Co-Processing	
Investment Cost:	€5-15 million (retrofit; clinker capacity 2 Mio. t/a) reduction of operational cost by 3-4 EURO /$t_{clinker}$ [5] VIET NAM price: + \$5-10 million (€4,3-8,5 million) (includes: investment in storage facilities, feed conveyors, and auxiliary combustion chambers). + an auxiliary combustion chamber 400 tpd: \$2-\$5 million USD.
Energy Savings: (thermal and electricity)	Reduction of fossil fuel consumption[6] Increase of overall thermal energy demand: by 200-300MJ/$t_{clinker}$ Increase of overall electric energy demand: by 2-4 kWh/ $t_{clinker}$
CO_2 mitigation:	30-50 kg CO_2/$t_{clinker}$, indirect increase 1-2 kg CO_2/$t_{clinker}$
Advantage:	• Reduction of fossil fuel consumption • Higher material efficiency, less waste disposal
Disadvantage:	• partly higher thermal energy demand compared to fossil fuels • additional process steps for fuel preparation (drying, grinding) • potential operational problems at high substitution rates • hard to implement when framework conditions are not yet in place (legislation, waste collection/availability and monitoring, social acceptance)
TRL/international use	• TRL 2022: 9
Current use in Vietnam	TSR: 5-7% on average + 5-6 cement plants that regularly use waste as an alternative fuel (operating year-round). +4 plants have auxiliary combustion chambers.

2.3.4 Current status of use of Alternative Fuels in Viet Nam's cement industry

Initial steps have been taken to replace coal in the calciner with industrial waste, hazardous waste, sludge, and RDF from municipal solid waste. INSEE is the pioneering plant in this area, achieving a fuel substitution rate of approximately 40%. Other plants such as Vicem Bút Sơn, Yên Bái Cement, and Lam Thạch Cement have reached 20–30% substitution rates.

Most cement plants in Viet Nam have favourable technical and operational conditions to utilize alternative fuels. However, co-processing waste materials in cement kilns requires an official waste treatment license. The common method of alternative fuel use in Viet Nam is direct combustion, by feeding the material into the calciner.

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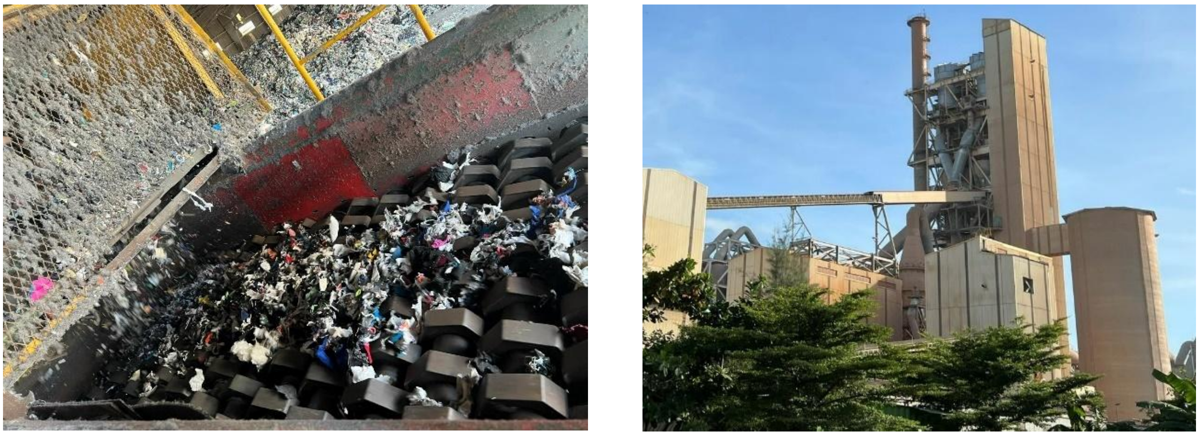
[5] Original source refers to price per tcement. Is expected to be per tclinker.

[6] Reduction fossil fuel 0.07 t/tclinker, increase alternative fuel mix 0.1 t/tclinker (European Cement Research Academy 2022)



Waste sorting equipment

Conveyor for feeding into the calciner

Figure 2. 18 Industrial waste incineration system provides heat at Viet Nam cement factory

(Source: Adapted from (Châm TT 2022)

By the end of 2024, the cement plants listed in the table have begun deploying alternative fuels and waste-derived inputs - mainly industrial waste - at varying levels. Reported thermal substitution rates (TSR) range from negligible/small quantities at some sites (e.g., Tam Diep, Tay Ninh, Binh Phuoc) to moderate levels of about 13–20% (Quang Phuc ~13%, Song Gianh ~16%, Ha Tien ~20%), and higher levels of around 25–30% at several plants (Song Thao 25%—fed to the calciner; Lam Thach 30%; Yen Bai ~30%). Two facilities stand out with particularly high substitution: But Son and Insee reached 40% coal replacement in 2024 (fed to the calciner), Tan Thang has reached 32% when applied, but the usage is not consistent (at times the replacement rate peaked at 32%, but for most of the remaining time, the RDF usage rate was only around 10-15%).

Overall, the data indicate that adoption is uneven: a few plants have achieved high TSR, while many others are still at early-stage or low-volume use—suggesting substantial headroom to scale up alternative fuel utilization across Viet Nam's cement industry. List of cement plants with waste co-processing systems as alternative fuel in cement production in Viet Nam shown in Table A.2 - Annex 1.

2.4 Change in Raw Materials: Blended Cement Alternatives

2.4.1 Description of Baseline Situation and Energy Consumption

The **clinker to cement ratio** describes the share of clinker in cement on a mass basis. Clinker hardens the cement when it is mixed with water and is the main constituent of most cement types. Due to process emissions from the clinker production process and (thermal) energy related emissions from its production, switching partially from clinker to less CO_2 intensive – components is one of the key levers to reduce CO_2 emissions arising from cement production (IEA 2018a).

Specific clinker to cement ratios are defined for specific types of cement, depending on the mechanical and durability requirements of the respective final products or applications. Portland cement typically contains 90% clinker, together with gypsum and fine limestone. Blended cement alternatives have a lower clinker share and thus a lower CO_2 footprint.

Potential alternative sources, also called **supplementary cementitious materials (SCM)** are:

- **Granulated Blast Furnace Slag** (GBFS, generated in the production of pig iron): cement shows lower early strength, higher long-term strength and improved chemical resistance.
- **Fly ash** (from coal fired power plants): cement shows lower early strength, lower water demand, improved workability, higher long-term strength and increased resistance against sulphate attack.
- **Natural pozzolanic materials/pozzolanas** (materials of volcanic origin or sedimentary rocks): early strength of pozzolana-containing cements decreases with the increasing proportion of pozzolana.
- **Limestone**: in order to reach similar strength cements have to be ground to higher fineness, shows synergetic effects when used to together with **calcined clay.**
- **Recycled fines from mineral construction waste** (recycled concrete fines) can be used in Portland composite cements as cement constituent (5 -20%).(European Cement Research Academy 2022)

Following the European Norm DIN EN 197-1, five main types of cement are defined (Diethelm Bosold 2017): Portland cement CEM I, Portland composite cement CEM II, Blast furnace cement CEM III ,Pozzolan cement CEM IV ,Composite cement CEM V. Viet Nam has also drafted a Vietnamese standard based on BS EN 197-1, adding several other mineral additives in the local appendix.

Based on latest data (GCCA Roadmap) the clinker-to-cement ratio on a global level was 72%, in Europe 77% and in China 66%. (European Cement Research Academy 2022)

2.4.2 Suggested Measures of Improvement

The suggested measure of improvement concerns the substitution of clinker with other input materials. Resulting cement properties (especially the calcium content and content of other main elements) need to be **suitable for the specific application** in terms of durability and strength. Further factors to be considered are the possibilities and cost of further treatment of the alternative raw materials and their local or regional availability.

Given the overall aim of decarbonizing industrial and energy processes, we can expect that the **availability** of blast furnace slag or fly ash from coal power plants will decrease within the next decades. It is assumed that the iron and steel sector will move from blast furnace processes to more efficient electric arc furnaces and that coal power plants will be substituted by other ways of power production.

The availability of natural pozzolanic materials (from volcanic compounds or sedimentary rocks; ash from agricultural residues and silica fumes) depends on local conditions as well as competition with other industrial applications.

Moreover, the following restrictions should be considered (IEA 2018a):

- **Granulated blast furnace slag** can be integrated at high portions (95% on a mass basis).

- **Fly ash** can be used up to 25-30%, while considering rather varying quality worldwide; both types require higher electricity consumption compared to Portland cement due to additional process steps. However, these efforts are by far offset by thermal energy savings.
- The extent of using **limestone** instead of clinker typically reaches 25-35% of mass content but could be extended to up to 50%.
- Using **calcined clay** has a long history dating back to bridge constructions in the 1930s in San Francisco. Current applications point at optimized combinations of calcined clay and limestone which can displace clinker by up to 50% without changing cement properties. (ALLPLAN GmbH. 2021)

2.4.3 Potential Energy Savings and Greenhouse Gas Emission

Substituting clinker by other, alternative calcium-containing and thus less CO_2 intensive raw materials reduces overall energy consumption and CO_2 emissions (both in terms of process emissions and thermal energy for the calcination process). However, it requires additional process steps (grinding, mixing) which lead to a (slight) increase in electricity consumption. (ALLPLAN GmbH. 2021)

Main influencing factors on savings potentials comprise:

- Composition of available raw materials at the considered plants
- Local/regional availability
- Calcium content and other main elements of the alternative materials
- Decarbonated portion of calcium content
- Possibilities to improve the material by further treatment (European Cement Research Academy 2022).

Table 2. 9 Key facts of measure – Blended Cement Alternatives

Sources: (ALLPLAN GmbH, 2021), updated: (European Cement Research Academy, Ed, 2022)

Key Facts of Measure – Blended Cement Alternatives	
Investment Cost:	0-6 million EURO /$t_{clinker}$; Operational costs decrease[7] by 0-1 EURO /$t_{clinker}$ VIET NAM price: No data
Energy Savings: (Thermal and Electricity)	100-400 MJ/$t_{clinker}$ (30-110 kWh/$t_{clinker}$) decrease of thermal energy demand 0-3 kWh/ $t_{clinker}$ increase of electrical energy demand
CO_2 Mitigation: (direct)	100 kg CO_2/$t_{clinker}$ (10-15% replacement of raw material by GBPS)
Advantage:	• Considerable reduction of thermal energy demand and process emissions • Partly use of waste materials
Disadvantage:	• Not all types of cement are suitable for all types of applications • Additional process steps required (grinding, blending), additional quality assurance

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[7] Investment cost incl. storage and handling of additional raw material; operational costs inc. cost for alternative raw material, fuel saving, saving of replaced raw materials and additional power needed. Can be negative when using waste materials and cement company is paid for them; potential wear and tear on the system is not considered.

	- Difference in local availability of alternative raw materials (quality/ quantity) - Reduced availability of GBFS and fly ash in the future due to expected production changes
TRL/international use	TRL 2022: 9
Current use in Vietnam	Already Implemented at all of the cement plants.

2.4.4 Current status of use of Blended Cement Alternatives in Viet Nam

At present, the use of clinker-substituting materials in Viet Nam's cement industry has been implemented at the sectoral scale, primarily through the production of Portland blended cements (PCB). The main supplementary cementitious materials (SCMs) ground together with clinker include ground limestone, basalt, coal-combustion by-products from thermal power plants (fly ash and bottom ash), granulated blast-furnace slag, and natural pozzolan (Mai CT 2023). Among these, limestone and coal ash are the most widely used due to their relatively stable availability and good compatibility with existing grinding technologies.

In terms of cement product structure, the Vietnamese market is currently dominated by PCB40, PCB30, PC40, and masonry cements. Because these cement types account for the majority of total production, the average clinker substitution rate across the industry remains at approximately 17–20%, corresponding to an average clinker factor of about 0.80–0.83 (Mai CT 2023). This level indicates that clinker reduction has already been achieved to a certain extent; however, it remains below the technical potential offered by available SCMs and below the levels observed in countries with more advanced CO_2-reduction pathways.

Domestic research and industrial trials demonstrate that the technical potential for further clinker substitution is substantial. Fly ash and bottom ash can replace clinker at levels of up to 30% while still meeting the requirements for PCB30 cement; finely ground limestone can typically substitute 10–15% of clinker; natural pozzolan can replace 15–20%, depending on its reactivity; while ground granulated blast-furnace slag can achieve very high clinker replacement rates, reaching 60–70% in specialised cement systems. These findings highlight the significant opportunity to further reduce the clinker factor and associated CO_2 emissions through expanded SCM utilisation.

In commercial production, PCB40 cement in accordance with TCVN 6260:2020 remains the most widely produced cement type in Viet Nam. The standard allows a total SCM content of up to 40%, and in cases where granulated blast-furnace slag is used at levels ≥10%, the permitted SCM content may reach 50%. In practice, however, the average SCM content across the industry is estimated at around 25–30%, corresponding to a clinker content of approximately 65–70% in PCB40 cement. This gap between regulatory limits and actual practice suggests that there is considerable room for further clinker reduction through both technical optimisation and supportive policy and market measures.

2.5 Other measures

In the following chapter, measures for decarbonizing processes outside the core cement production are described. On the one hand these measures focus on options for alternative solutions/materials which serve the same/similar purpose as cement-based materials (chapter □). On the other hand, measures trying to reduce carbon content outside the core production process are described (chapters 2.5.2.- 2.5.3).

2.5.1 Carbon capture and storage

Although roadmaps and contribution shares of different mitigation options vary among different authors, it is a common denominator that additional measures such as carbon capture will be needed for decarbonization of the cement industry on an international level.

The Oxford Institute for Energy Studies compared different pathways to reach carbon neutrality from Material Economics and the IEA as shown below:

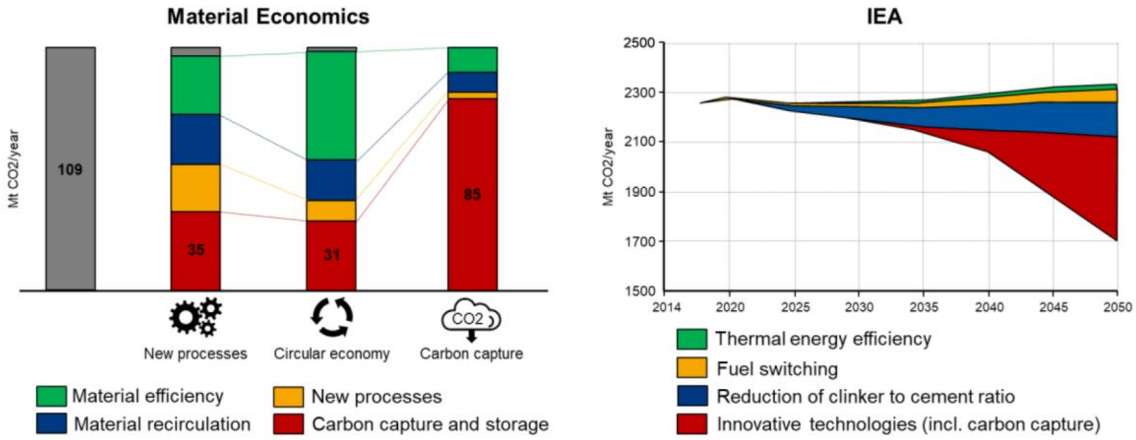


Figure 2. 19 Comparison of scenario analysis and roadmaps for the cement industry,

Source: (Studies. 2022)

The scenario analysis from Material Economics study evaluates different scenarios for the cement industry in Europe: a) electrifying the production process, b) more efficient production and material efficiency and c) more focus on CCS. IEA roadmap shows the clear and gradually increasing share of innovative technologies such as carbon capture. (ILO. 2024)

CO_2 can be captured directly from the flue gases of rotary kilns, either for permanent storage (CCS) or subsequent use (CCU, see below) .Two major technologies are currently being investigated: post- combustion and oxy-fuel technology (ALLPLAN GmbH. 2021).

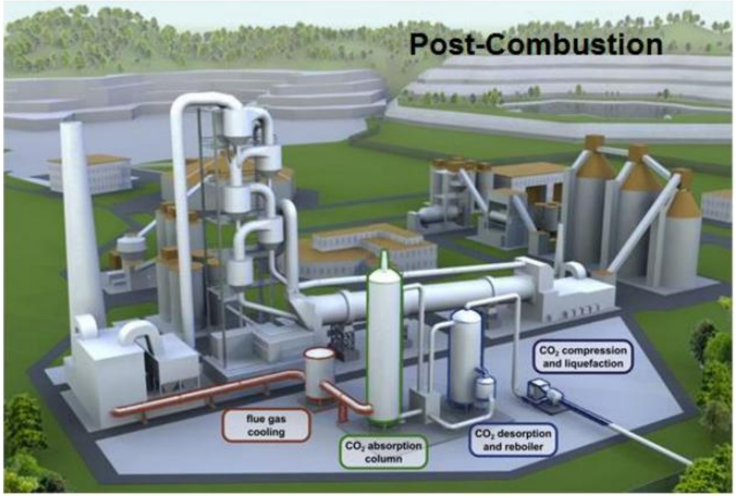


Figure 2. 20 Scheme of CO_2-Post Combustion

Source: (Schneider 2018)

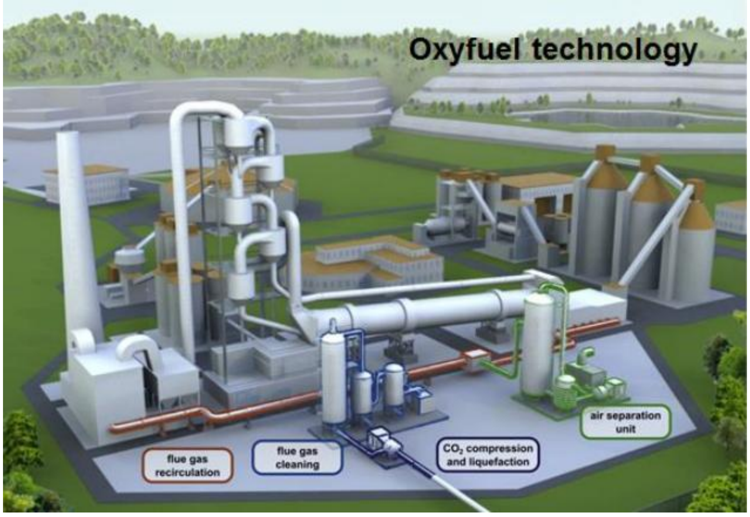


Figure 2. 21 Scheme of Oxyfuel Technology

Source: (Schneider 2018)

The major characteristics are:

Post-Combustion: (see e. g. Norcem Brevig Project, Heidelberg Cement)

- Tail-end separation of CO_2 from flue gas by e.g. chemical absorption, adsorption, membranes or Ca-looping
- Very energy-intensive technology.

Oxy-fuel Technology (see e. g. pilot project Lafarge Retznei in Austria):

- Combustion with pure oxygen instead of air in combination with flue gas recirculation to increase the CO_2 concentration.
- Requires process and design adaptations.(Schneider 2018)

On a general level, carbon capture and utilization or storage (CCUS) sequesters generated process emissions and requires the four stages:

- CO_2 capture/separation from flue gas (CO_2 concentration in flue gas appr. 18-20%)

- CO_2 purification and compression (depending on the transport system)
- Transportation (high costs for gaseous state; mostly liquid or super-critical); selection of transportation mode depends on distance and quantity
- CO_2 geological storage or utilization.

There are many different technologies available for carbon capture, which can be classified by

- Mechanism used (e.g. absorption, adsorption, membranes)
- Substances used (liquid solvent or solid adsorbent)
- Technical approach (depending on where the capturing process takes place: pre-combustion, post-combustion, oxy-fuel (during combustion) or direct separation).

For direct separation, a recent project can be cited, LEILAC (https://www.leilac.com/) pilot plant in Lixhe, Belgium with about 8-10 t/h. Steel tubes indirectly heat the calcination reaction and deliver a pure stream of CO_2 process emissions that is kept separate from any furnace exhaust gases or air (unlike separation gases from gases for other technologies). During the trial runs in 2019/20 the calcination process was successful, LEILAC 2 project was initiated in 2024. For an animated description on how it works, refer to: https://www.leilac.com/technology/#how-it-works

Technology readiness levels vary considerably among technologies but are highest for various liquid solvents, pressure solving adsorption or oxy-fuel technology. Carbon Capturing costs show a wide range between 20 and 140 €/t CO_2. Additionally, the technologies vary concerning OPEX, reliability, maintenance, flexibility or retrofitting possibilities and lowest carbon capturing costs are not necessarily the best options. (Studies. 2022).

Typical transportation costs depend on distance, quantity and state of CO_2. Transporting CO_2 has high TRLs due to experience in other applications (LNG or LPG shipping).

CO_2 geological storage means permanent storage and costs range between 1 and 22 €/t CO_2. Potential sinks are depleted oil/gas fields or saline aquifers. Offshore storage is more expensive but socially more accepted.

CC utilisation offers various options such as mineralization and carbonation which is reached by fixing captured CO_2 into certain minerals and cementitious materials via reactions with the oxides. TRL for typical CCU technologies are given below:

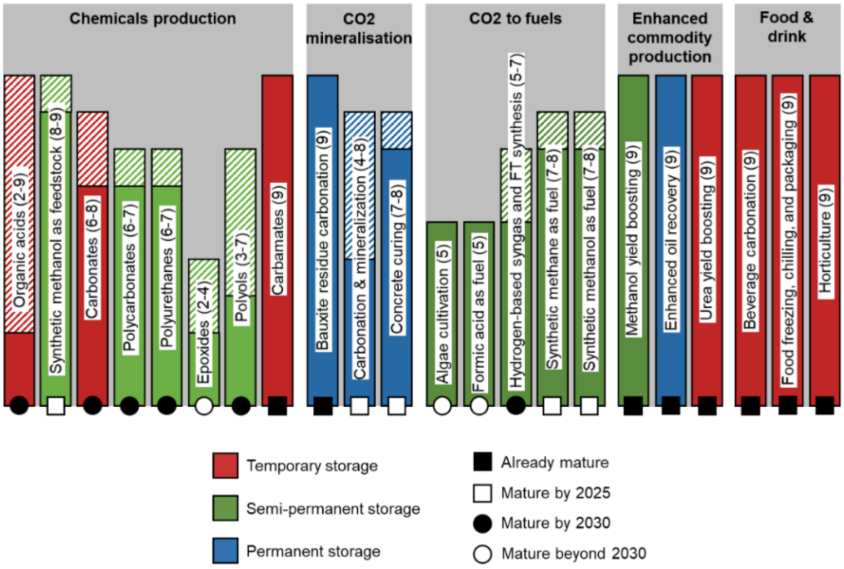


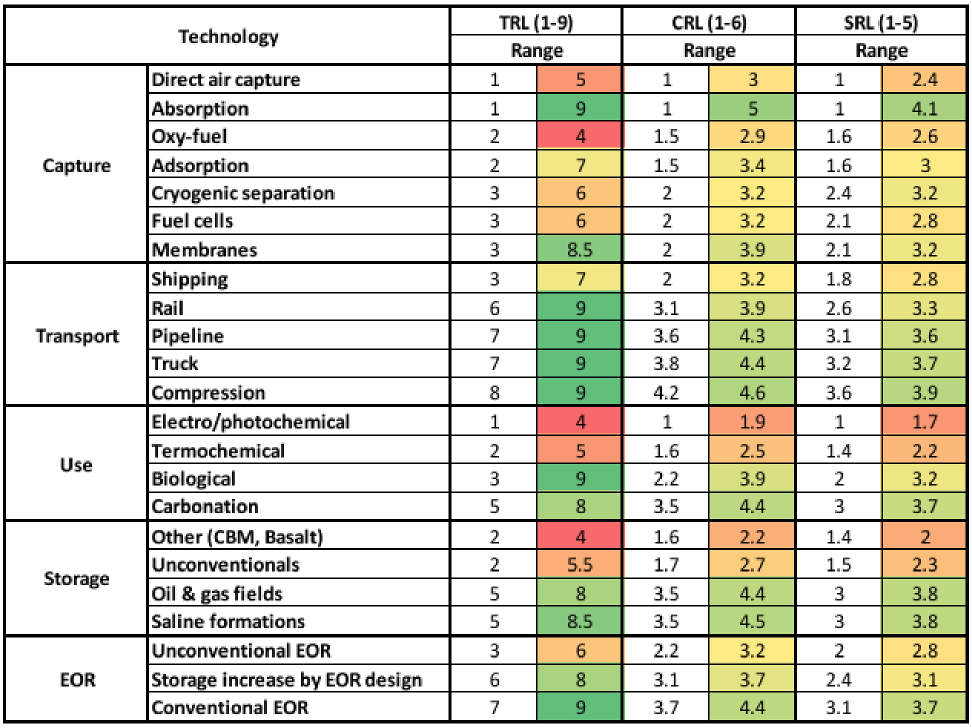
Figure 2. 22 TRLs of CCU technologies

Source: (Studies. 2022)

One important issue with the application of whatever CCU technology is that it is not sufficient to only look at technology readiness but also consider commercial readiness (CRL) (commercial maturity in 6 levels) and social readiness (SRL) which depicts how much society is willing to accept/use a technology. The following table summarizes the concepts for various technologies:

Table 2. 10 Comparison between CCU technologies

Source: (Studies. 2022)



Technology		TRL (1-9)		CRL (1-6)		SRL (1-5)	
		Range		Range		Range	
Capture	Direct air capture	1	5	1	3	1	2.4
	Absorption	1	9	1	5	1	4.1
	Oxy-fuel	2	4	1.5	2.9	1.6	2.6
	Adsorption	2	7	1.5	3.4	1.6	3
	Cryogenic separation	3	6	2	3.2	2.4	3.2
	Fuel cells	3	6	2	3.2	2.1	2.8
	Membranes	3	8.5	2	3.9	2.1	3.2
Transport	Shipping	3	7	2	3.2	1.8	2.8
	Rail	6	9	3.1	3.9	2.6	3.3
	Pipeline	7	9	3.6	4.3	3.1	3.6
	Truck	7	9	3.8	4.4	3.2	3.7
	Compression	8	9	4.2	4.6	3.6	3.9
Use	Electro/photochemical	1	4	1	1.9	1	1.7
	Termochemical	2	5	1.6	2.5	1.4	2.2
	Biological	3	9	2.2	3.9	2	3.2
	Carbonation	5	8	3.5	4.4	3	3.7
Storage	Other (CBM, Basalt)	2	4	1.6	2.2	1.4	2
	Unconventionals	2	5.5	1.7	2.7	1.5	2.3
	Oil & gas fields	5	8	3.5	4.4	3	3.8
	Saline formations	5	8.5	3.5	4.5	3	3.8
EOR	Unconventional EOR	3	6	2.2	3.2	2	2.8
	Storage increase by EOR design	6	8	3.1	3.7	2.4	3.1
	Conventional EOR	7	9	3.7	4.4	3.1	3.7

2.5.2 Recarbonation/circular economy approaches

Recarbonation approaches constitute a specific option of carbon capture and utilisation. This approach makes use of the fact that **concrete itself reintegrates CO_2** in a natural and slow way (over decades). It is assumed that with this natural carbonation around 20% of the CO_2 emitted from limestone during clinker production is carbonated, which means that appr. 80% of the hardened cement paste in concrete elements is not carbonated at the end of its lifetime. Thus, the share offers a potential for further re-integration of CO_2 in cement.

By exposing the material to CO_2 at 40–60 °C and moisture treatment (5-10 mass %) rapid carbonation can be reached, which is further enhanced by pressure. Typical flue gas compositions from cement plants provide a good basis for such conditions.

With **enforced carbonation** on the one hand further CO_2 can be incorporated and on the other hand a material (hardened cement paste) is produced which could be used as cement constituent to reduce the clinker factor.

For one tonne of hardened cement past around 5 tonnes of crushed concrete are necessary. Measures for separation of crushed concrete during demolition and the separation of hardened past from the aggregate are necessary. It would be advisable to have similar high throughputs for CO_2 treatment like cement kilns. If concrete has to be transported to the cement plant for crushing, separating and treatment, high transportation costs occur.

Circular approaches require the existence of selective demolition of concrete structures, collecting and processing. Details on potential savings and investment costs are not yet available.

Currently, technologies for processing of waste such as crushing and separating are available (TRL:9); however industrial systems for the enforced carbonation are not yet in place (TRL:6). (European Cement Research Academy 2022)

2.5.3 Use of Artificial Intelligence in Cement Production

Despite significant progress in alternative fuel use and classical energy efficiency measures, process- and energy-related emissions remain a key lever for further reduction potential in cement production.

Today’s cement plants primarily rely on Distributed Control Systems (DCS) which employ conventional PID control loops and programmed logics (Åström and Hägglund 2006), (Siemens 2025), (ABB 2025). These are often complemented by Advanced Process Control (APC) solutions, including Model Predictive Control (MPC) or Fuzzy Logic. While these tools are widely established, they face limitations when dealing with high-dimensional, nonlinear optimization problems and real-time decision-making under strict operational constraints (Wurzinger et al. 2019).

To overcome these challenges, data-driven methods, particularly machine learning (ML), are gaining importance in cement production. One of the main applications is the use of soft sensors, i.e., ML models that estimate difficult-to-measure process variables based on easily available data. In cement production, soft sensors are applied to predict clinker phases or strength development, which are otherwise only measurable in the laboratory with significant delay (Stöhr and Zielke 2023), (Lawrence 2024). Another promising field is predictive maintenance, where ML models analyse sensor data such as vibration and temperature signals from mills or conveyors to predict equipment failures and calculate the “remaining useful lifetime” of components (Achouch et al. 2022).

Quality prediction is another active research area, with approaches using ML to forecast cement properties based on raw material and process data. Some solutions aim to optimize concrete recipes by reducing clinker content while maintaining strength (OptimiX 2025). Start-ups like Alcemy (Alcemy 2025) have already developed AI-based systems for process and quality optimization, focusing on cement grinding and strength development, with pilot implementations in German plants. Similarly, ABB has partnered with the AI start-up Carbon Re to integrate its Delta Zero platform into cement and lime production, targeting energy- and emission-intensive operations such as kiln control (ABB 2024).

Beyond current applications, Deep Reinforcement Learning (DRL) is emerging as a dynamic research field. DRL allows agents to learn optimal control policies through interaction with their environment, guided by reward functions. Initially successful in domains such as gaming (AlphaGo 2025), robotics, and autonomous driving, DRL is now being explored for industrial optimization, including chemical processes (Nian, Liu, and Huang 2020), (Yoo et al. 2021). Pilot studies indicate its potential for optimizing energy use in batch operations and process heating. A striking demonstration of DRL’s capabilities was the real-time control of plasma equilibrium in a fusion reactor by DeepMind (Degrave et al. 2022), showing that DRL can reliably manage highly complex physical systems.

In summary, AI and ML methods are already being applied in pilot projects in the cement industry, particularly for soft sensing, predictive maintenance, and process optimization. The rapid development of DRL and other advanced ML approaches highlights the potential of AI to become a central enabler for future emission reduction, energy efficiency, and quality improvement in cement production.

2.6 Framework Conditions

2.6.1 Policy and market drivers (international perspective)

In general, policy options can be categorized into “carrots” (incentives which make the desired action more attractive, in this case increasing energy efficiency) and “sticks” (penalties for companies not complying with relevant targets). These policy options can take the form of regulatory measures, fiscal/financial policies and information/capacity building (Fawkes et al. 2016). In the industrial sector in Europe, the most important tools and measures are the definition of benchmarks (Best Available Technologies), the European Emission Trading scheme and the obligation to apply energy auditing.

There are different energy consumption/energy efficiency figures in the same industry’s different production sites, depending on the applied technologies, the size of the plant and its operation. One of the most powerful methods of examining different production sites is to compare their actual consumption with sectoral energy benchmarks and – more globally – their respective distance to Best Available Technologies (BAT).

In Europe, for example, there are reference documents describing Best Available Technologies for industrial sub-sectors, called BREFs, which follow the requirements of the EU Industrial Emission Directive. The results, cover not only the energy consumption performance, but also the emissions to air, water and soil as well as resource efficiency. They are derived from discussions between industry representatives, NGOs, the EU member states and the European Commission and are published on the website of the European IPPC Bureau under https://eippcb.jrc.ec.europa.eu/reference. According to these results, new installations have to comply with BAT standard and corresponding emission levels from the start of operation. Existing installations have to be adapted within four years after publication of BAT conclusions. (ALLPLAN GmbH. 2021)

Another application of benchmarking against the most efficient industrial plants can be found within the European Union Emission Trading scheme, which has been operating since 2005. Designed as a cap-and-trade system, this market-based mechanism aims to reduce overall GHG emission in the most cost-effective way. This means that a specific cap is defined for all covered installations (currently about 11,000 heavy energy-using installations including power stations & industrial plants and airlines operating between these countries) which together are responsible for about 40 % of overall emissions of the participating countries. This cap defines the total amount of GHG which can be emitted by all installations covered by the system. The “emission allowances” have to be surrendered each year by the companies to fully cover their actual emissions. Some of the allowances are allocated to companies via a mechanism that takes into account historical emissions of the respective sector and emission levels of the best 10% of participating companies (benchmarking), among other factors. The difference (either surplus or lack) can be traded on the market. (ALLPLAN GmbH. 2021)

Preliminary results show that the scheme reaches its targets. Emissions of the covered installations were reduced by about 47.6 % between 2005 and 2023. Most of the reduction was attributable to the power sector with the switch from fossil-fuelled plants to solar and wind power and gas replacing coal in power generation. This was also supported by sustained average carbon prices in 2023 of over 80 €/t CO_2. In the energy-intensive industry sectors, a reduction of emissions of 7.5% compared to 2022 was observed, due to a combination of a reduced output and efficiency gains. (Commission. 2024)

What is important for any saving project is the application of monitoring and verification, as this sets the basis for verifying the actually achieved savings. For those companies wishing to extend their knowledge base and integrate energy management in their overall quality/environmental processes, the application of established management tools and processes in the Standard ISO 50001 can be an option.

In Europe, large enterprises, for the first time not defined by turnover or employees, but in terms of energy consumption, either have to apply such energy (or environmental) management systems or regularly conduct energy audits in every four years following the requirements of the Energy Efficiency Directive, version III (Directive 2023/1791). This directive also obliges the public sector to take the lead in energy efficiency and sets binding targets for public procurement e.g. reduction of overall energy consumption of public buildings or obligatory renovation targets (ALLPLAN GmbH. 2021), updated.

The decarbonization of cement production is further supported by a large number of standards, norms and certifications which cover ecological criteria, CO_2 balances, alternative materials or production processes. They cover – among others:

- **EN 197-1 / EN 197-5 European Cement Norm (see chapter 0)**
- **EN 15804 - Sustainability of buildings –** basis for EPD (Environmental Product Declarations): Basic rules for the product category construction: Product declarations which cover the whole life cycle of (e.g) a cement product relating to CO_2, energy, resources etc.
- **Product Labels: e**.g. various Environmental labels such as the European Environmental Label, or “Blauer Engel” in Germany, e.g. low emission building materials
- **International Green Building Certificates** such as LEED, BREEAM or HQE which prefer low carbon products.

Further, there are initiatives from cement organization to reduce carbon emissions:

- Cembureau Roadmap 2050 (target climate neutrality 2050)
- Global Cement and Concrete Association: Global initiative to support low-carbon technologies
- Low-carbon Concrete Codes e.g. in Switzerland or UK: reduction of cement related emissions via material-based requirements.

As an example, the Cembureau 2050 roadmap scheme is presented here:

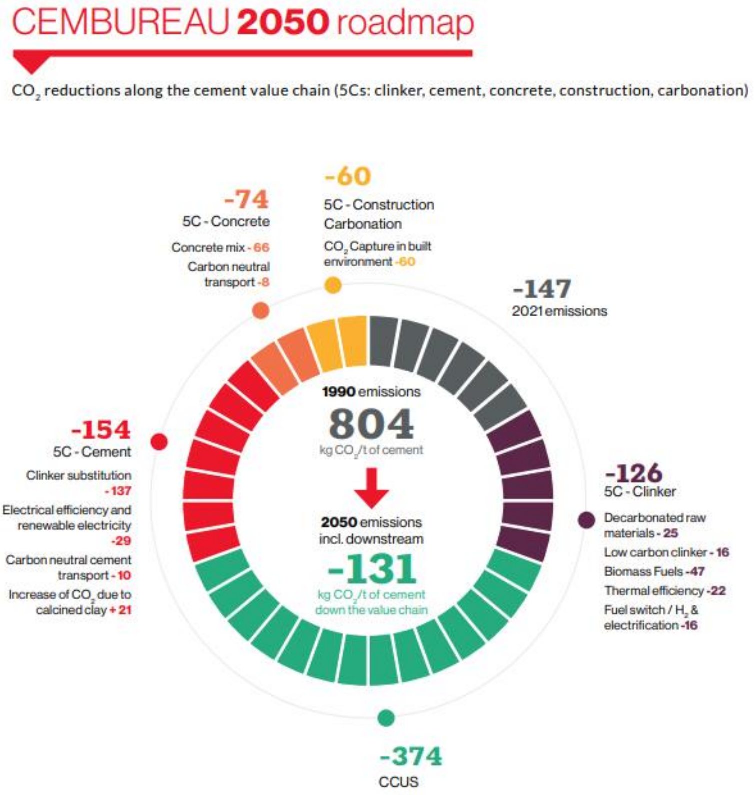


Table 2. 11 Cembureau 2050 Roadmap

Source: (Cembureau 2024a)

In 2024, the net zero roadmap was updated and now also includes targets for 2040 (-78% reduction cement, 93% downstream) and 2030 (-37% reduction cement, 50% downstream), respectively[8]. From Cembureau perspective, the following key policy measures are important to reach the goals:

- a functioning CBAM[9]
- financial support to support decarbonisation investments
- guaranteed access to affordable decarbonised energy, infrastructure and raw materials
- creation of lead markets for low carbon, circular products.

2.6.2 Cement-Based Materials Market Trends

In addition to the technology and cement production point of view used in previous chapters, this sub-chapter focuses on the other perspective: looking at building market trends linked to cement-based materials (or their alternatives). For details on specific technologies mentioned, we refer to the specific sub-chapters under 2.2,0,2.3.4 and 0.

2.6.2.1 Concrete

At the time being, Cement/concrete is still the dominant building material worldwide (>70% of construction materials), widely used because of its abundance, easy operation, durability and versatility. Major cement producers worldwide are China, (more than 2000 millions of tonnes), followed by India and Viet Nam. (ILO. 2024)

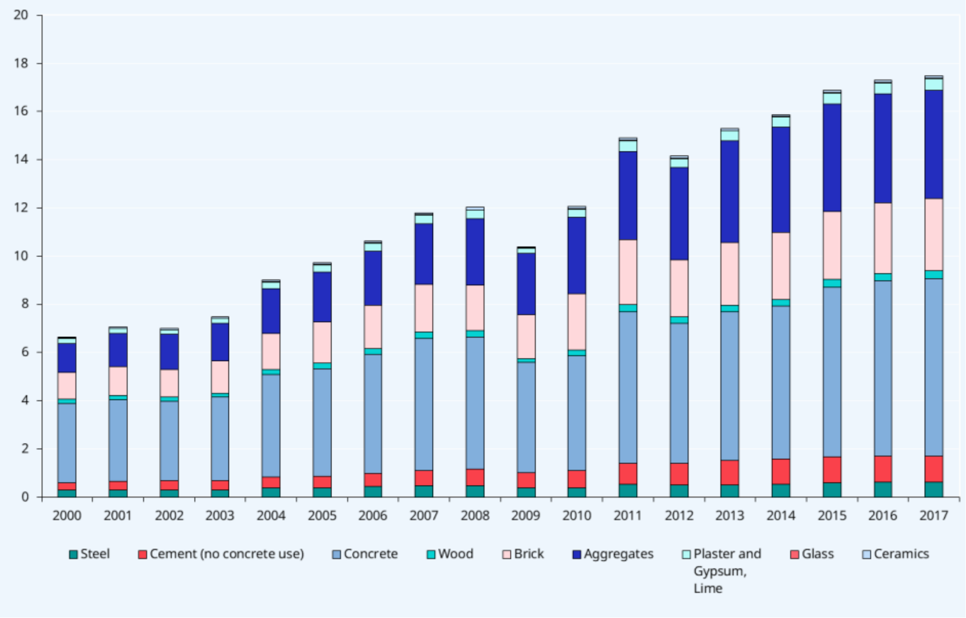


Table 2. 12 Historical trends in global building materials use (billion tonnes)

Source: (ILO. 2024)

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[8] https://cembureau.eu/library/reports/cembureau-s-net-zero-roadmap/

[9] The Carbon Border Adjustment Mechanism (CBAM) is the EU's tool to put a fair price on carbon emitted during the production of carbon-intensive goods that are entering the EU, and to encourage cleaner industrial production in non-EU countries. CBAM will apply in its definitive regime from 2026, with a transitional phase of 2023 to 2025. This gradual introduction is aligned with the phase-out of free allowances under the EU Emissions Trading System (ETS) to support the decarbonisation of EU industry.(https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en)

The production of cement, as outlined above an energy-intensive process including chemical processes with inherent process emissions is also closely linked to the following environmental challenges:

- depletion of natural resources such as sand
- erosion of ecosystems
- consumption of water in concrete production (about 9% of global industrial water withdrawals in 2012. By 2050, appr. 75% of the water required for concrete production is projected to be used in regions facing water stress). (ILO. 2024)
- Growth areas: urbanisation in Asia & Africa, infrastructure spending.

Global trends include:

- More long-lasting materials
- Volatility in energy markets has a great impact on the industry
- Environmental regulations and rising costs of imported raw material leads to the use of sustainable technologies and alternative forms of cement
- Use of prefabricated concrete sections has increased (offsite construction)
- Rise of population, urbanization and economic growth accelerates the demand of building material in development countries. Construction sector will double until 2060 (ILO. 2024)
- Shift to ready-mix concrete (RMC) in urban construction (Insights. 2025).
- Use of supplementary cementitious materials (SCMs) (fly ash, slag, silica fume, calcined clays) (Amadi and Mahachi 2025).
- Low-carbon concrete (carbon-cured, geopolymer, alkali-activated) (Barbhuiya et al. 2025).
- Circular economy approaches: recycled aggregates, demolition waste reuse (Krajewska and Siewczynska 2025).

2.6.2.2 Non-Fired Bricks

Unfired, unburnt or non-fired bricks, sun-dried bricks, adobe bricks can be made from natural materials such as clay, sand and straw. Other sources are fly ash, industrial waste, lime or soil. As the name says, these types of bricks are not baked in a kiln but are dry naturally in the sun. Due to lower energy requirements and potential use of alternative/waste inputs they lead to lower GHG emissions than “traditional” bricks and are becoming more popular due to sustainability reasons.

Recent studies show that unfired bricks require 10-15 times less energy than fired clay bricks of similar size which also means considerable reduction of GHG emissions. Actual environmental impacts depend on regional factors such as electricity mix and transportation distances. Main issues are strength and moisture exposure. When properly stabilized, unfired bricks (based on waste) can attain comparable strength ranges, though the mechanism is different (cementitious binding instead of ceramic bonding). Main applications comprise: (e.g., compressed stabilised earth blocks) in low-rise construction, infill masonry, partition walls, and rural building projects; rather not in high-rise load-bearing structures or highly aggressive environments: Due to their higher porosity, unfired bricks often have better insulation properties (lower thermal conductivity) than dense-fired bricks. The comparison of CO_2 emissions and energy consumption is shown in the following charts:

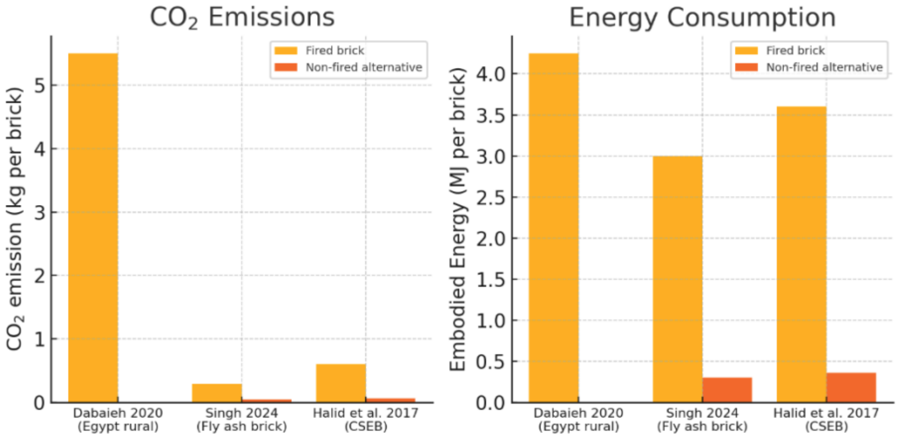

Figure 2. 23 Comparison Fired and Unfired Bricks in Terms of CO_2 and Energy Consumption

Source: (Wang Yuxin 2025)

Different stabilizers are used to increase performance of unfired bricks, such as cement, geopolymer, lime, bio-stabilizer/MICP or ceramic waste.

The following chart compares strength and water absorption properties of different types of unfired bricks (with cement-, lime-, geopolymer- or bio-stabilizers) with fired bricks.

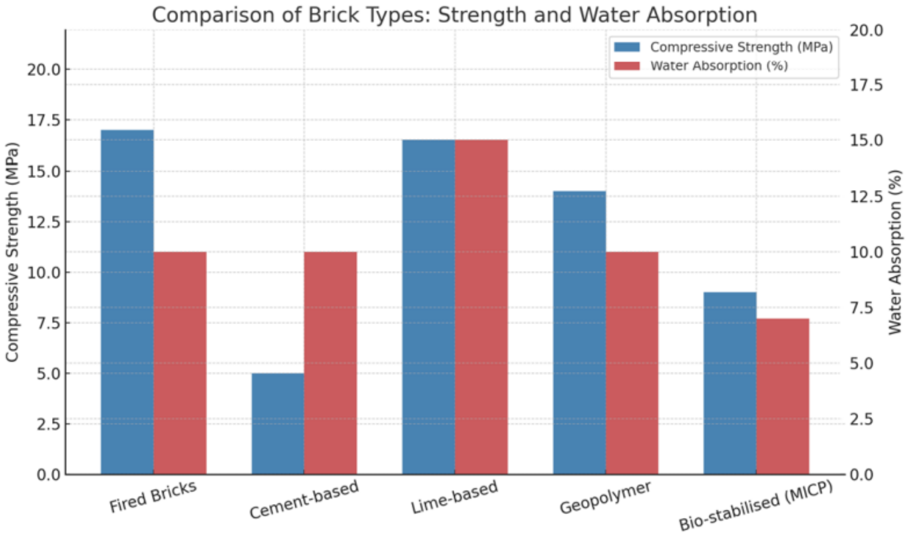

Figure 2. 24 Comparison Fired and Different Types Unfired Bricks: Strength and Water Absorption

Source: (Wang Yuxin 2025)

Comparative assessments of unfired masonry units (soil blocks, fly ash bricks, cement–slag blocks, geopolymer blocks, etc.). show that, with proper mix design, their compressive strength and water absorption can be equivalent to or even better than fired clay bricks while reducing emissions by up to ~60% compared with conventional concrete, particularly when used for precast elements. India has mandated the use of fly ash bricks for public construction projects within a 300 km radius of coal power plants, which has rapidly accelerated the market development of fly ash bricks, concrete blocks, and AAC products.

International studies show that CO_2 curing can simultaneously enhance early-age strength and permanently “lock in” CO_2 within the concrete matrix.

2.6.2.3 Alternative Binders

The ECRA Technology Papers (European Cement Research Academy 2022) highlight several alternative binders with potential to further reduce CO_2 emissions in cement production. In contrast to established Portland cement composite cement types (which still require a considerable share of Portland cement clinker with its high process emissions) alternative binding materials are investigated which should assure the required strength and quality requirements. The aim is to identify binding systems which work completely without Portland cement.

Alternative binder systems to Portland cement at the clinker level can be divided into four main categories, all aiming to reduce process-related CO_2 emissions while maintaining applicability in conventional concrete. The first is Reactive Belite-rich Portland Cement (RBPC), in which the C_3S content is reduced and highly reactive C_2S is increased. This approach retains the “Portland family,” ensuring strong compatibility with existing standards and allowing production on current rotary kiln lines. CO_2 reduction comes mainly from lower alite content and slightly lower burning temperatures. The main limitation is reduced early strength, making RBPC more suitable for mass concrete and applications where rapid formwork removal is not required (Gartner 2018).

The second is belite–ye’elimite–ferrite (BYF) clinker, developed from sulfoaluminate cement (CSA) technology. This clinker contains substantial belite, ye’elimite, and aluminoferrite phases, and is burned at around 1,250–1,350 °C - lower than Portland cement, thus significantly reducing heat consumption, improving grindability, and potentially increasing kiln throughput. Calculations show that belite-rich BYF systems can substantially reduce CO_2 emissions compared with OPC and allow better utilization of sulphur-rich raw materials and fuels.(Gartner 2018).

The third is Carbonatable Calcium Silicate Clinkers (CCSC), based on phases such as wollastonite. These systems require far less energy and generate much lower CO_2 emissions during clinkering compared with OPC. They are then cured in a CO_2 environment to reabsorb a significant portion of emitted CO_2, creating “CO_2-cured binder systems” particularly suitable for precast concrete and prefabricated elements.

The fourth is Magnesium Oxides from Magnesium Silicates (MOMS) clinker, where MgO is produced from magnesium silicate minerals instead of $MgCO_3$. In theory, this process produces nearly no CO_2 from raw materials and requires much less energy than Portland clinker production. Because MgO hardens mainly through carbonation, MOMS systems have the potential to become “carbon-negative binders,” i.e., achieving net CO_2 uptake.

These include alkali-activated binders, which use fly ash, slag or metakaolin activated by alkaline solutions to produce high-strength concretes, but face safety and cost challenges. According to (Juenger et al. 2011), alkali-activated materials (AAM)/geopolymers-using fly ash, slag, metakaolin, and alkaline activators-can reduce CO_2 emissions by more than 80% compared with OPC concrete when waste sources and energy use are optimized. These technologies are regarded by (ECRA 2022) as “long-term levers” that require strengthened research, standardization, and testing before large-scale market deployment.

Carbonation-based cements harden through CO_2 curing, offering up to 60 % emission savings and suitability for precast products. Pre-hydrated calcium-silicate and belite-rich cements can be produced at lower temperatures, reducing energy demand but showing slower strength development. Belite–calcium-sulphoaluminate cements combine early and late strength benefits but remain limited to niche use. Overall, these binders show strong potential for regional or specialised applications, though large-scale replacement of Portland cement is not yet feasible.

Overall, these clinker systems demonstrate the potential to reduce CO_2 emissions by about 20–40% compared with OPC, and even more when combined with CO_2-curing strategies. In addition, most of them can leverage or adapt existing rotary kiln technologies in the cement industry.

2.6.2.4 Bio-based materials and engineered wood

LCA studies on mass timber (CLT, glulam) demonstrate that timber structures have significantly lower embodied emissions than reinforced concrete or steel structures for the same functional performance. For example, the Stockholm Wood City project is widely cited as a model for urban-scale emission reduction through increased adoption of timber construction.

In the context of Viet Nam, mass timber may serve as a partial substitute for concrete–steel systems in low-rise housing, resort buildings, and community structures-provided that it is accompanied by sustainable forest management practices and improved fire and structural standards.

Thus, “alternative materials” in this context extend far beyond a few specialty cements; they represent a portfolio of material and design solutions that collectively reduce dependence on high-carbon construction materials in Viet Nam’s built environment.

Many net-zero roadmaps emphasize material efficiency, such as designing slimmer structural systems, using UHPC or voided slabs to reduce concrete–steel consumption by 20–30%; increasing modularity, prefabrication, and off-site construction to reduce waste and enable component reuse; and expanding concrete recycling.

2.6.2.5 Regional Trends

In the following we summarize the major trends with Viet Nams major trade Partners.

China

- China remains the world’s largest producer and consumer of cement and concrete, accounting for more than half of global cement output (Statista 2024).

- In addition, prefabricated and modular concrete construction is expanding rapidly, supported by national targets for green and energy-efficient buildings (Qiushi 2022).
- Recent pilot projects also explore carbon-cured concrete using captured CO_2 as a curing agent in industrial demonstrations in central China (Wang et al. 2022).

India

- India has implemented national mandates requiring the use of fly-ash bricks in all public projects located within 300 km of coal-based power plants (Forests. 2016)
- The Pradhan Mantri Awas Yojana and other affordable-housing schemes have accelerated adoption of resource-efficient materials such as fly-ash and autoclaved aerated concrete (AAC) blocks (India. 2024)

ASEAN (Thailand, Indonesia, Malaysia)

- The ASEAN region is undergoing an infrastructure-led construction boom, driving strong demand for concrete and cement (Ltd. 2024).
- Countries such as Thailand have introduced green-building codes and sustainability standards for public construction, encouraging use of recycled and low-emission materials (Energy 2018)
- The ASEAN Federation of Cement Manufacturers (AFCM) launched its 2035 Roadmap aiming for a 38 Mt CO_2 reduction by promoting low-carbon cement, expanding the use of SCMs like fly ash and slag to cut clinker content, advancing the energy transition, and adopting deep decarbonisation technologies under a unified emissions reporting system (Energy 2025).

European Union

- The European Union maintains a strong decarbonisation agenda for construction materials, promoting low-clinker cements, recycled aggregates, and circular building practices (Institute. 2020), (Pacheco, Brito, and Lamperti 2023).
- EU producers target a 30% CO_2 reduction by 2030 through clinker substitution and alternative binders (Global. 2023).
- For Vietnam, the EU's CBAM and evolving environmental standards will likely exert trade pressure on energy-intensive exports such as cement and clinker (Center. 2024).

Japan & South Korea

- Japan and South Korea are leaders in research and development of advanced, low-carbon construction materials. In Japan, for example, the CO_2-SUICOM concrete absorbs more CO_2 than it emits (Japan. 2022). In South Korea, innovations such as nanobubble-based 'carbon eating concrete' and low-carbon precast systems using CarbonCure technology are being commercialised (KICT. 2024), (GPC. 2024).

Chapter 3. Discussion of Energy Transition Options and Emission Reduction Pathways for the Cement and Concrete Sector in Viet Nam

3.1 Market Potential for Low-Carbon Cement and Concrete Products

The market potential of low-carbon cement and concrete products in Viet Nam is shaped by two primary factors: the global trend towards decarbonised construction materials, and the domestic momentum driven by the net-zero by 2050 commitment, construction industry growth, and emerging regulatory and export considerations.

Globally, the market for low-carbon construction materials is rapidly transitioning from a “niche pilot segment” to a high-growth sector. Market assessments indicate that the low-carbon concrete market was valued at around USD 15 billion (EUR 12.7 billion, VND 395 trillion) in 2023 and could reach USD 45 billion (EUR 38.2 billion, VND 1.184 quadrillion) by 2032, growing at approximately 13% per year due to tightening emission regulations and accelerated technological innovation (Sharma 2024).

The wider low-carbon construction materials market, including low-carbon cement, concrete, steel, and alternative binders, is estimated at EUR 253 billion (VND 7.754 quadrillion) in 2025 and projected to exceed EUR 490 billion (VND 15.018 quadrillion) by 2034 (CAGR ~8–9%) (Insightaceanalytic 2025). The low-carbon cement segment alone is expected to grow at over 11% annually between 2025 and 2031, driven by increasing demand for sustainable construction materials and the adoption of green building requirements (Lucintel 2025).

In Viet Nam, the market potential for low-carbon cement and concrete is closely tied to the expansion of green buildings and sustainable urban development. According to the Viet Nam Cement Association (VNCA, 2024), 163 buildings received green certification in 2024-double the previous year-raising the total to approximately 559 certified green buildings, far exceeding the earlier national targets (80 by 2025 and 160 by 2030). Viet Nam is also preparing to issue its first national green building standard, linking urban development with Net Zero objectives. These trends indicate a structural increase in demand for low-carbon cement and concrete as green criteria become embedded in design and procurement practices.

3.1.1 Key market segments for low-carbon cement and concrete products

Based on international studies on the low-carbon concrete market (Insightaceanalytic 2025), several high-potential market segments can be identified as follows:

Material-specific market segments particularly suitable for decarbonisation

- **Low-carbon cement for ready-mixed concrete (RMC) and urban precast components**: The shift from on-site concrete mixing to RMC and precast production in urban construction enables standardised mix designs, tighter quality control, and easier adoption of “low-carbon cement/concrete” standards and Environmental Product Declarations (EPDs). This segment is well-suited for blended cements such as CEM II/CEM IV, slag cement, LC3, and high-SCM concrete without requiring major changes in construction practices.

- **Alternative materials and specialised products**: non-fired bricks, CO_2-cured concrete, geopolymer concrete: ECRA lists several alternative binder systems, such as alkali-activated binders, supersulphated cement, CAC/CSA cement, and CO_2-cured concrete, which can reduce emissions by 40–60% compared to traditional Portland cement and are particularly suitable for precast components, non-fired masonry products, and concrete blocks. However, as emphasised by Scrivener et al., new binder systems still face challenges related to market acceptance and the lack of standardised technical specifications. Therefore, in the near term, they are better positioned in niche markets with stringent environmental requirements (e.g., demonstration projects, eco-cities, CSR-driven developments).

Client-specific market segments that could create pilot markets

- **Green public procurement policies in public infrastructure, transportation, and government-funded projects**: This segment is strongly influenced by green public procurement requirements and emerging "low-carbon procurement" policies currently adopted in the EU and several OECD countries. International experience shows that the public sector can act as a "first mover" for low-carbon cement and concrete. In Viet Nam, with the ongoing expansion of public investment in transportation, seaports, and new urban areas, integrating embodied-carbon criteria into tender documents could create a stable, high-volume market for low-carbon cement and concrete.
- **Green buildings and mid- to high-end commercial/residential real estate**: Developers pursuing LEED, EDGE or LOTUS certification have a direct incentive to adopt low-carbon concrete and green construction materials to gain credits related to energy, materials, and embodied carbon.
- **Industrial zones, logistics facilities, FDI manufacturing, and indirect exports**: Many multinational corporations have publicly committed to reducing embodied carbon across their supply chains (MeticulousMarketResearch 2025). As a result, factories, warehouses, and logistics centres in Viet Nam increasingly prioritise low-carbon concrete solutions accompanied by green certifications. Given Viet Nam's role as a key node in global supply chains, industrial parks could become "hotspots" for demand for low-carbon cement and concrete if such criteria are integrated into planning and investment-attraction policies.

3.1.2 *Conditions for realising market potential*

Although the opportunities are substantial, international studies on alternative binders and the low-carbon concrete market consistently emphasise that technical potential alone is insufficient; market-enabling conditions must be activated in parallel.

- **Standards, regulations, and environmental labelling**: to enable customers to compare products based on embodied emissions, national standards for low-carbon cement/concrete, LC3, high-SCM concrete, and CO_2-cured concrete, together with an Environmental Product Declaration (EPD) mechanism aligned with EN 15804 need to be developed and implemented.

- **Lead-market policies:** Drawing on CEMBUREAU and EU experience (CEMBUREAU 2024b, 2025), Viet Nam can use green public procurement, life-cycle-cost-based tendering, and prioritisation of low-carbon materials in publicly funded projects to "create the initial demand" at a sufficiently large scale.
- **Linkage with green finance and the carbon market**: Integrating criteria on the use of low-carbon building materials into green credit programs, green bonds, and participation in the domestic carbon market will help convert environmental benefits into concrete financial incentives for producers and project developers (Insightaceanalytic 2025).
- **Research–piloting–performance validation under Vietnamese conditions**: Technical literature (ECRA 2022) and Chapter 2 of this report highlight that deploying new technologies and products requires pilots and long-term testing on durability, standard compatibility, and life-cycle assessment (LCA). For Vietnam, this calls for leadership from research institutes, universities, and pioneering cement plants/testing units to demonstrate the technical and economic feasibility of each product line.

In summary, the market potential for low-carbon cement–concrete in Viet Nam is significant, driven by the convergence of: (i) construction growth and the rise of green buildings, (ii) international climate-policy and trade pressures, (iii) the shift of green capital and climate finance, and (iv) existing technical foundations for SCM, LC3, non-fired materials, and low-carbon concrete as demonstrated by both international studies and domestic projects. The question is not whether a market exists, but how ambitious, fast, and well-designed Viet Nam's policy, standards, and financial mechanisms will be in capturing this market segment during 2025–2050.

3.2 Future product portfolio and demand scenarios

3.2.1 Future product portfolio

Based on global energy transition trends, Viet Nam's Net Zero 2050 commitment, and the current oversupply in the cement sector, the future portfolio of cement–concrete products can be grouped into three main categories:

1) Optimised Portland cement and conventional concrete with reduced clinker factor and increased SCM use;
2) Alternative cementitious binder systems with lower carbon intensity; and
3) Alternate material solutions that partially substitute concrete, steel, and fired clay bricks in specific building segments.

These product groups will develop at different speeds under three demand scenarios: (1) Business-as-usual (BAU); (2) Gradual transition/low-carbon scenario; and (3) Accelerated green cement / deep transition – net-zero 2050 scenario.

(1) Low-carbon Portland Cement and Concrete Products:

Portland-clinker–based cements are expected to remain dominant in the medium to long term. This is primarily due to their well-established advantages: economies of scale and highly optimised production processes (with benefits for both cost and energy use), widespread availability of raw materials, ease of use enabled by adequate workability before setting, and proven long-term durability supported by extensive, decades-long application (Scrivener, John, and Gartner 2018). Against this backdrop, one of the most effective near- to mid-term decarbonisation strategies is to reduce the clinker factor by substituting a portion of Portland clinker with supplementary cementitious materials (SCMs**).** In Viet Nam, SCM resources (slag, fly ash, limestone, natural pozzolan, suitable clay for LC3, rice husk ash, and various industrial by-products) are relatively abundant. Energy efficiency improvements, and increased use of alternative raw materials could be low-cost short-term measures to partially decarbonise existing plants. Under all scenarios, low-carbon Portland cement will remain the backbone of Viet Nam's cement–concrete market through 2030 and continue to hold a substantial share up to 2050.

Optimised Portland cement and conventional concrete with reduced clinker factor are expected to represent the largest share of total cement demand across all scenarios, particularly in the short to medium term. Under a BAU scenario, this group may account for 70–80% of total cement output by 2030, gradually declining thereafter. In the gradual transition scenario, its share is likely to decrease to 50–60% by 2040, while in the accelerated Net Zero scenario, it could fall to 40–45% by 2050 as deeper decarbonisation options scale up. The achievable scale of this product group is primarily influenced by availability and logistics of SCMs (fly ash, slag, limestone, pozzolan), cement standards (e.g. TCVN 6260), market acceptance of lower-strength classes, and procurement practices in public infrastructure projects.

(2) Alternative Binder Systems:

In Vietnam, alternative binders, including high-slag cements, LC3, calcined clay-based binders, calcium aluminate cement (CAC), calcium sulfoaluminate cement (CSA), supersulphated cement (SSC), and alkali-activated materials (AAM/geopolymers) have potential applications in precast construction, specialized infrastructure, highly aggressive environments (chemically and physically aggressive) exposure conditions, such as marine and coastal structures (chloride and sulphate ingress with wet–dry cycling), sulphate-rich soils and groundwater, wastewater and sewer systems subject to biogenic acid attack, and industrial facilities exposed to acids, chlorides, and other corrosive, and pilot green or net-zero building projects, provided they are supported by appropriate regulatory frameworks (TCVN/QCVN) and access to green financing mechanisms.

Alternative low-carbon cementitious binder systems currently remain at a pilot to early-commercial stage in Viet Nam but offer a medium- to long-term abatement potential. Their market penetration is expected to be limited to 5–10% by 2030, increasing to 15–25% by 2040, and potentially 30–40% by 2050 under an accelerated transition scenario, provided that regulatory approval, standardisation, and supply-chain readiness are achieved. Key influencing factors include capital investment requirements, calcined clay and slag supply, revision of national standards and design codes, carbon pricing or incentives, and risk perception among contractors and developers.

(3) Material and design solutions that substitute high-carbon concrete and fired bricks

While not necessarily eliminating cement use, material and design solutions can reduces dependence on conventional cement-based concrete:

(i) expanding the use of engineered timber (CLT, LVL) for low- and mid-rise buildings;

(ii) adopting lightweight walls, roofs, and floor systems (lightweight concrete panels, gypsum boards, fibre–cement sheets, insulation materials);

(iii) scaling up unfired bricks, concrete blocks, hollow blocks, fly ash–slag bricks; and

(iv) promoting material-efficient design solutions, such as voided or optimised structural systems, precast elements, and modular construction.

A wide range of LCA studies indicate that engineered timber and certain lightweight panel systems have significantly lower CO_2 intensity per m² of usable floor area compared with traditional reinforced concrete and fired clay brick construction, especially when considering the carbon storage potential of bio-based materials.

Alternate material solutions substituting concrete, steel, and fired clay bricks are expected to remain niche in volume terms, but strategically important in specific building segments. Their overall substitution effect is estimated at 5–10% of total material demand by 2040–2050, with higher penetration in low-rise residential, non-structural elements, and interior applications. The scale of deployment is strongly influenced by building codes, urbanisation patterns, construction industrialisation, cost competitiveness, and consumer acceptance, rather than cement-sector dynamics alone.

3.2.2 Future Scenarios for Cement Product Demand

Based on the product groups identified above, three indicative, orientation-level scenarios can be proposed. The future demand for cement and concrete in Viet Nam will depend on factors such as GDP growth, urbanisation rate, infrastructure needs, energy transition, housing programmes, and global trends toward green materials. According to the Nationally Determined Contribution (NDC 2022), Viet Nam targets a conditional 43.5% emissions reduction by 2030. At the same time, Power Development Plan VIII and the Prime Minister’s decisions on emission reduction in hard-to-abate industries require the cement sector to follow a low-carbon transition pathway.

Based on these drivers, three demand scenarios for cement–concrete towards 2030, with outlook to 2050, are developed as follows (1266/QĐ-TTg 2020; Mai 2024; Long 9/2025).

Table 3. 1 Cement Demand and Product Scenarios to 2030, with Vision to 2050

Scenario	BAU	Transition (Low-Carbon)	Deep Decarb/Net-Zero
Key Characteristics	- Maintain cement consumption growth at 1.5–2%/year. - Domestic demand increases slightly, driven by public investment and urbanization. - Export volumes of clinker and cement remain largely unchanged. - Production technologies remain at current levels (NSP kilns + VRM), with low SCM usage (20–25%). - Alternative fuel substitution (AFR) increases only marginally (<10% by 2030).	- Substantive implementation of NDC measures and green materials programs. - SCM proportion increases to 30–40% (fly ash, slag, limestone powder, LC3). - AFR reaches 20–30% by 2030, in line with QCVN 19:2024 guidelines. - Accelerated WHR deployment: 8–10 new WHR projects by 2030 (current examples: Nghi Sơn 15 MW, INSEE 6.27 MW, Thăng Long 8.9 MW).	- Fuel substitution rate (FR) ≥ 50–60%, aligned with EU Best Practice. - WHR installed at 100% of cement plants. - Optimized energy performance: Thermal ≤ 680 kcal/kg clinker, Electricity ≤ 60 kWh/t cement (EU BAT). - Adoption of CO_2 curing, CCUS, oxy-fuel combustion, and carbon mineralization. - Next-generation concretes (UHPC, geopolymer, alkali-activated binders, super sulfate cement, CAC/CSA, BYF cement), or mass timber, bio-based building materials, reduce cement demand by 20–30% per m³
Cement demand to 2030/2050	126.170/130 Mt (FiinGroup 2024)	90–100 Mt (The research team 2025)	70–60 Mt (The research team 2025)
Domestic cement demand	70–75 Mt	65–70 Mt	50–55 Mt
AFR[10]	<10%	20%/30% TSR in 2030/2050, respectively	80%/90% TSR in 2030/2050, respectively
WHR	70% of total plants	80%/90% of total plants in 2030/2050, respectively	90%/100% of total plants in 2030/2050, respectively
Clinker factor	0.8–0.83	0.68–0.70	0.55–0.60 (1266/QĐ-TTg. 2020)
CCUS	not applied	not applied	5%/36% in 2030/2050(GCCA 2020)

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[10] BAU: based on sector-wide baseline assumptions for Viet Nam. Transition and Deep Decarbonization scenarios follow the trajectories defined in CEMBUREAU's Net Zero Roadmap (2024)

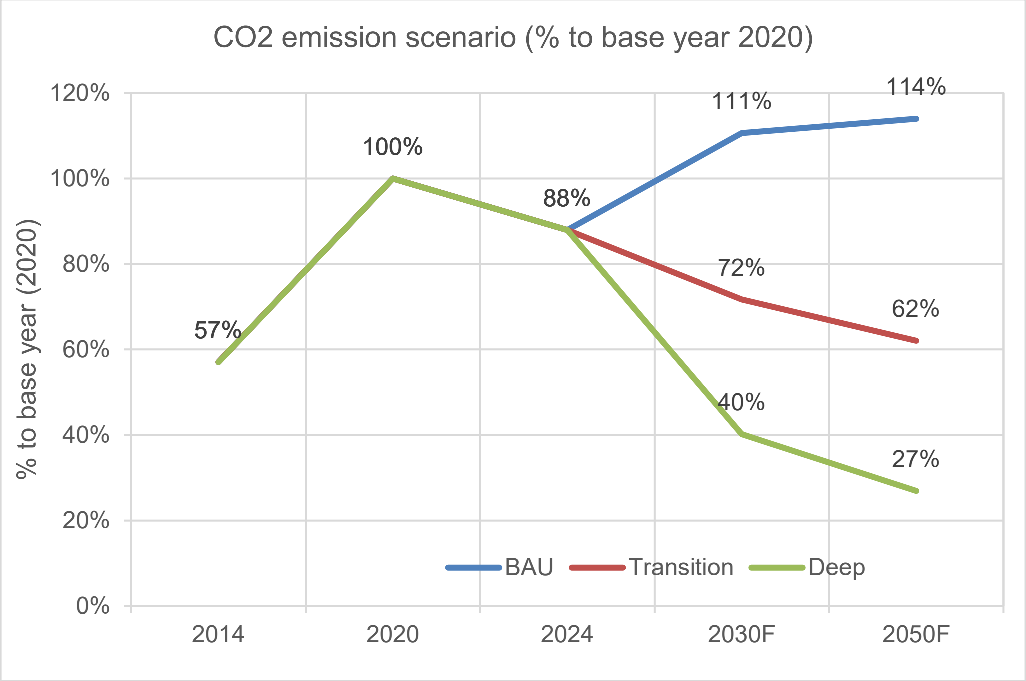

Table 3. 2 CO2 emission scenarios of Vietnamese cement sector to 2050 (compared to base year 2020)

(Source: Authors' analysis based on data collected for the report)

Note: The total CO_2 emissions of the cement sector in 2020 were 77.04 Mil.ton (Mai 2025).

From the scenario table above, it is evident that under Viet Nam's conditions, energy-efficiency measures, WHR, AFR, increased SCM/LC3 use, and digitalisation are the most suitable technology groups and should be prioritised for immediate large-scale deployment. New binder systems and CO_2-cured concrete are more appropriate for the pilot and standardization phase, while CCUS should be considered a long-term option, dependent on the development of national institutions, infrastructure, and the carbon market.

3.2.3 International Lessons and Applicability to Viet Nam

International experience, particularly from Thailand, shows that the low-carbon transition in the cement–concrete sector is most effective when it is guided by a sectoral roadmap, an integrated policy toolbox, and "lead markets":

- **A dedicated Net Zero roadmap for the cement–concrete sector**: The Thailand Cement Manufacturers Association (TCMA) has developed the "Thailand 2050 Net Zero Cement & Concrete Roadmap," which is integrated into the Thailand Taxonomy – Manufacturing, with specific criteria for green cement and concrete. This provides long-term signals for businesses and aligns corporate actions with the national carbon-neutrality target (Khammuang 2024). In parallel, India provides another strong roadmap example: GCCA India and TERI have developed a national "Decarbonization Roadmap for the Indian Cement Sector" aligned with India's net-zero 2070 goal and interim milestones. The roadmap explicitly structures decarbonisation through quantified levers (e.g., clinker efficiency, alternative fuels, SCMs/new binders such as LC3/PLC, decarbonised electricity, cement-use efficiency, recarbonation, and CCUS), clarifying that deep decarbonisation requires a staged pathway that combines near-term deployment measures with longer-term breakthrough technologies and enabling infrastructure (India-TERI 2025). At EU level, the roadmap function is supported by a system-wide regulatory trajectory: Europe’s industrial decarbonisation pathway is anchored by strengthened supply-side signals (notably the EU ETS revision and CBAM), which are increasingly complemented by demand-side lead-market instruments to accelerate adoption of climate-friendly basic materials, including cement and concrete (Industry 2024).

- **Strong integration of technology, economic instruments, and market mechanisms**: Thailand accelerated low-carbon cement adoption through product innovation by the producer SCG and other major producers. The first generation of low-carbon cement achieved 15–20% emission reductions compared with OPC (for every ton of cement, approximately 0.7 tons of CO2 are emitted, with a clinker factor of 0.76 (Mai 2024)), while the next generation targets 40–50% reductions. By the end of 2023, low-carbon cement penetration reached ~81% of the market, with a target of 100% in 2024. At the same time, Thailand mainstreamed WHR and AFR in cement plants and developed the T-VER methodology for WHR projects, enabling the issuance and trading of emission-reduction credits on the voluntary carbon market (Khammuang 2024). India’s roadmap reinforces this “technology + enabling framework” logic: it highlights that scaling alternative fuels depends on building an organised supply chain (e.g., RDF/biomass/waste-derived fuels), and that CCUS readiness requires legal certainty, monitoring–verification frameworks, and shared CO_2 transport and storage infrastructure—paired with strategic green financing that supports pilots (e.g., hydrogen, kiln electrification, CCUS) and later-stage scale-up (India-TERI 2025). EU experience adds another layer: a balanced supply–demand policy mix**.** While carbon pricing and border adjustment improve the economics of low-carbon production, EU practice emphasises that these instruments must be complemented by demand-side measures (standards, labels/certification, procurement requirements, quotas/embodied-carbon approaches) to create predictable early demand and reduce risk for first movers (Industry 2024).
- **Green public procurement and international support create “pull markets**”: The “Decarbonization of the Cement and Concrete Sectors in Thailand” project, funded by UNIDO/ECCC, focuses on emission standards, green public procurement (GPP) for cement–concrete, investment mobilisation, and regional knowledge sharing. Thailand introduced the Green Industry Label and green credit schemes linked to emission-reduction criteria in industrial production (Khammuang 2024). In the EU, GPP is positioned as a core lead-market instrument within a broader toolkit that typically also includes standards (preferably performance-based), carbon accounting and reporting (e.g., EPD/LCA-based requirements), labels/certification, and embodied-carbon limits all intended to create early demand for climate-friendly basic materials and reduce risk for first movers (Industry 2024)

These lessons align closely with the general recommendations of the IEA (IEA 2018b) and GCCA (GCCA 2020), which emphasises four pillars: energy efficiency, low-carbon fuels/AFR, clinker-factor reduction, and deployment of breakthrough technologies (CCUS/CO_2 curing).

For Viet Nam, Thailand's experience suggests several directly relevant pathways:

- Develop a national net-zero roadmap for the cement–concrete sector, integrated with the Strategy for Building Materials Development, the NDC/net-zero commitments-similar to the "Thailand 2050 Net Zero Cement & Concrete Roadmap"-to create a unified action framework for the whole sector.
- Design an integrated technology–market policy package: Require WHR for large lines; incentivize AFR and SCM/LC3; and simultaneously develop MRV methodologies and carbon-credit mechanisms for WHR, AFR, and low-carbon cement, mirroring the Thailand Voluntary Emission Reduction (T-VER) model/mechanism. In the Vietnamese context, incentivising the deployment of alternative fuels (AFR) and low-clinker cement systems such as SCM- and LC3-based products requires a combination of regulatory, economic, and institutional measures rather than technology mandates alone. For AFR, the primary constraint is not kiln readiness but the absence of a formalised waste-to-fuel supply chain. This can be addressed by introducing technical standards for RDF/SRF quality, integrating cement kilns into national and provincial waste-management master plans, and allowing long-term offtake contracts between waste operators and cement plants. In parallel, simplified permitting procedures and clear environmental guidelines for co-processing would reduce transaction costs and regulatory uncertainty for cement producers. Economic incentives could be introduced through differentiated waste treatment fees, tax reductions for fossil-fuel substitution, and the eligibility of AFR projects for domestic carbon-crediting mechanisms under the emerging carbon market framework. Similar to Thailand's T-VER model for WHR, methodologies for AFR-based emission reductions could be developed, enabling cement plants to monetise verified CO_2 savings. For SCM and LC3, incentives should focus on demand-side pull and standardisation. This includes updating cement and concrete standards to explicitly recognise blended and LC3-type cements, incorporating clinker-factor or embodied-carbon criteria into public procurement, and allowing performance-based specifications in infrastructure projects rather than prescriptive OPC requirements. Such measures would lower market-entry barriers for low-clinker products without compromising structural performance.
- Pilot green public procurement (GPP) for low-carbon cement/concrete in infrastructure, urban development, and public buildings, following the GPP model used in the UNIDO–Thailand project. Vie Nnam has issued a legal and policy framework for GPP through the National Action Program on Sustainable Production and Consumption for the period 2021-2030 (Decision No. 889/QD-TTg dated June 24, 2020). However, the implementation of GPP is still in its early stages. Current regulations mainly encourage or prioritize environmentally friendly

products and services, rather than imposing mandatory green procurement requirements on all public procurement packages.

If combined with Viet Nam's strong SCM potential, WHR and AFR opportunities, and the growing domestic green-building market, these approaches could significantly shorten the transition time and help Viet Nam align with regional net-zero pathways for the cement–concrete sector. However, translating these international lessons into the Vietnamese context requires addressing several country-specific structural and institutional challenges through targeted auxiliary measures.

(i) Tackling the lack of alternative fuel (AFR) supply chains

Unlike Thailand, Viet Nam currently lacks a mature system for waste segregation, quality control, and regulatory standards for waste-derived fuels suitable for cement kilns. To overcome this bottleneck, complementary policies are required beyond the cement sector itself, including mandatory source separation of municipal solid waste, technical standards for RDF/SRF quality, and contractual frameworks linking waste management operators with cement plants. Without such upstream interventions, AFR deployment in cement plants will remain constrained regardless of kiln readiness.

(ii) Decarbonising private building projects through standards and demand-side measures

While public procurement can act as an initial "lead market," the decarbonisation of private construction remains a critical gap in Viet Nam. The absence of mandatory building energy or embodied-carbon standards limits demand for low-carbon cement and concrete in the private sector. International experience suggests that gradually introducing building codes, green building certification, and disclosure requirements for embodied carbon can extend low-carbon demand beyond public projects and avoid over-reliance on state-led procurement

(iii) Incentivising non-cement-based and low-clinker building materials

In a context of cement overcapacity, a comprehensive transition strategy should not focus exclusively on decarbonising cement production, but also on diversifying the building materials mix. Incentives for non-cement-based materials, prefabrication, and material-efficient construction systems can reduce structural demand for clinker while supporting circular economy objectives. This approach complements clinker-factor reduction strategies and helps moderate long-term cement demand growth.

(iv) Integrating circular economy policies beyond the plant boundary

The circular economy dimension in Viet Nam remains fragmented, with limited coordination between industrial symbiosis, waste regulation, and construction material standards. Aligning cement-sector decarbonisation with broader circular economy policies-covering industrial by-products, demolition waste recycling, and material reuse-would enhance system-wide emission reductions while reducing reliance on primary raw materials.

(v) Using oversupply as a lever for structural transition

Viet Nam's persistent cement overcapacity should be treated not only as a market challenge but also as a transition lever. Similar to Thailand's focus on upgrading existing assets rather than expanding clinker capacity, Viet Nam could accelerate the retirement or conversion of inefficient lines, prioritise retrofitting over new investments, and channel capital towards low-carbon product differentiation instead of volume-based competition.

Taken together, Thailand's experience highlights that successful low-carbon transition in the cement-concrete sector requires not only technology deployment, but also coordinated waste, building, market, and industrial restructuring policies. For Viet Nam, embedding these auxiliary measures into a sectoral net-zero roadmap would strengthen the credibility, feasibility, and speed of the transition while simultaneously addressing structural oversupply and long-term competitiveness.

3.2.4 Preliminary CAPEX Assessment by Technology and Plant Group

A preliminary assessment of investment costs (CAPEX) serves three main purposes:

1) prioritising technology options (digitalisation/efficiency first, then SCM/LC3, AFR, WHR, and only later CCS or kiln rebuilds);
2) linking technologies to specific plant groups to form phased investment roadmaps;
3) providing a basis for cost–benefit analysis and financial planning.

Based on the technologies summarised in the previous sections, **Error! Reference source not found.** provides indicative, order-of-magnitude CAPEX ranges for key CO_2-reduction technologies, categorised according to the plant groups defined in Section 3.3.1. These figures are based on literature and international benchmark data and should not be interpreted as detailed project-level cost estimates. Actual investment costs may vary depending on plant size, existing equipment configuration, local conditions, supplier origin, import costs, retrofit requirements, and project boundaries. Therefore, plant-specific feasibility studies would be required for more accurate cost assessment before investment decisions are made.

Table 3. 3 Preliminary CAPEX Estimates for Key CO_2-Reduction Technologies

Technology / Plant Group	CAPEX, million USD			Specific cost estimates /ranges	Source
	Group A Large	Group B medium	Group C small		
WHR (steam-based, 5–15 MW)	11–30	6–20	3–10	1.100–2.000 USD/kW (based on benchmark data from Asia)	(IFC 2017a)
AFR / Co-processing	20–120	10–80	5–40	10–40 USD/t cement/year	(Beguedou 2023)
SCM / LC3 (low-clinker cement)	10–30	5–20	3–10	3–10 USD/t capacity/year +	(Mittal 2025)

Technology / Plant Group	CAPEX, million USD			Specific cost estimates /ranges	Source
	Group A Large	Group B medium	Group C small		
				CAPEX calciner/retrofit	
Digitalisation & Energy Efficiency	2–5	1–3	0.5–2	Additional Fans, Variable Speed Drive (VSD), Advanced Process Control (APC), AI… (0,03–1 USD/t cement/y)	(IFC 2017a)
CCS / CCUS (post-combustion)	200–300	100–200	>100 (often uneconomic)	≈100 USD/t capacity/year, OPEX +28–60 USD/t cement	(Gardarsdottir 2019)
Major kiln upgrade / new clinker line	250–400 (2–3 Mt/year)	150–250	80–150	≈150 USD/t per annual production capacity for a new plant	(CEMBUREAU 2025)

3.3 Impacts on Related Sectors

3.3.1 Impacts of Low-Carbon Measures on Energy Use and CO_2 Emissions

IEA's technology roadmap (IEA 2018b) indicates that, if energy efficiency, alternative fuels, clinker-factor reduction, and new technologies (including CCUS) are deployed in an integrated manner, the global cement sector could reduce cumulative emissions by approximately 7.7 Gt CO_2 by 2050, with clinker-factor reduction contributing about 37% of the total reduction. This implies that Vietnamese cement plants, when adopting the measures discussed above (WHR, AFR, SCM/LC3, energy optimization, CCUS), will not only reduce on-site emission intensity but also significantly contribute to lowering carbon intensity across the entire construction value chain.

• WHR: Installing WHR with appropriate capacity can reduce electricity purchased from the grid-thereby reducing indirect fossil-based emissions (Scope 2), especially when the grid is not yet fully decarbonized. Technical assessments show WHR can supply 5–30% of a plant's electricity demand, resulting in equivalent reductions in Scope 2 emissions. (Gorbatenko et al. 2014). WHR systems in cement plants can, according to the IEA (IEA 2018b), supply 20–30% of a plant's electricity demand, equivalent to several tens of kWh per tonne of clinker, reducing dependence on grid electricity, reducing the need for new power-generation investments. For Viet Nam, scaling up WHR in Group A/B plants (as identified in Section 3.3.1) will reduce electricity demand from coal-fired power plants and support the restructuring of the national power mix in line with the Viet Nam National Energy Development Strategy to 2030, with a Vision to 2045 (Decision No. 2171/QĐ-TTg 2021)

• Alternative Fuels (AFR: RDF/Biomass): Replacing 10–40% of fossil fuels leads to proportional reductions in direct (Scope 1) emissions. Case studies indicate that substituting ~15% RDF can generate substantial fuel savings and CO_2 reductions (case-specific). For Viet Nam, RDF deployment should not focus only on increasing the thermal substitution rate, but also on developing a stable RDF supply chain, pre-treatment standards, and quality control mechanisms because chlorine and heavy metal content in RDF to negative impacts on clinker quality and stack emissions (Hemidat et al. 2019). CEMBUREAU reports that using waste as fuel reduces coal consumption, minimizes landfilling, strengthens energy security, and allows the mineral fraction of RDF to be incorporated into clinker. Recent reviews also highlight the role of AFR, concrete recycling, and the use of recycled aggregates in reducing raw-material consumption and lifecycle emissions of concrete (CEMBUREAU 2024b). Vietnamese plants such as INSEE, Bút Sơn and Vicem Kiên Lương demonstrate potential emissions reductions of 0.05–0.15 tCO_2/t clinker, while simultaneously processing hundreds of thousands of tonnes of waste annually (Châm 2022). Assuming Viet Nam's clinker production is approximately 80–85 million tonnes/year, scaling up AFR deployment to achieve average emissions reductions of 0.05–0.15 tCO_2 per tonne of clinker would translate into national savings of roughly 4–12 $MtCO_2$ per year. Even at the lower bound (0.05 tCO_2/t clinker), this corresponds to emissions reductions comparable to those of a medium-sized coal-fired power plant. In addition, nationwide AFR deployment could enable the co-processing of several million tonnes of municipal and industrial waste annually, substantially reducing landfill demand while strengthening the circular economy role of the cement sector. Concrete recycling and the use of recycled aggregates reduce demand for virgin raw materials, lower quarrying and transport-related emissions, and thus decrease the embodied carbon of concrete. When combined with low-clinker cements (SCM/LC3), recycled aggregates can deliver additional lifecycle CO_2 reductions without significant performance penalties in many applications. Life-cycle assessments show that material recycling typically reduces cradle-to-gate concrete emissions by around 5–15%, depending on replacement rates and logistics (CEMBUREAU 2024b). This reinforces the role of cement plants as key nodes in a circular economy, linking AFR, material recovery, and low-carbon construction systems.

- Supplementary Cementitious Materials (SCM): Increasing SCM use reduces process emissions by lowering the clinker factor. For example, a 10–20% reduction in clinker factor typically results in a 10–20% reduction in process-related CO_2 emissions-subject to SCM availability and compliance with technical standards (Worrell 2008). In Viet Nam, clinker emissions are 897 kg CO2/ton of clinker, and if 76% clinker and 20% SCM are used in cement, the emissions would only be about 718 kg CO2/ton of cement. For SCM/LC3 and low-carbon concrete systems, recent LCA studies show that combining LC3 or high-SCM cements with recycled concrete aggregates and/or biomass ash can reduce climate-change impacts by 36–46% compared with conventional OPC concrete, while lowering lifecycle costs by 9–26%, depending on mix design and application context (Haverkamp 2025). According to Viet Nam's 2022 NDC, by 2030, compared to the BAU emissions scenario, Viet Nam will reduce emissions by 15.8% (146.3 MtCO2e). With international support, Viet Nam will reduce emissions by an additional 27.7% (257.4 MtCO2e) or a total reduction of 43.5% (403.7 MtCO2e). To achieve this goal, the use of SCM in cement is extremely important. LC3 assessments indicate that LC3 mixes using recycled concrete aggregates can reduce climate-change impacts by up to ~42% and lifecycle costs by ~26%, whereas concrete mixes using recycled aggregates plus biomass ash show 12–25% CO_2 reductions and 13.8–20% cost reductions compared with OPC reference mixtures (Agrela 2024). LC3, in particular, using kaolinitic clay and low-grade limestone-including limestone/dolomite fractions unsuitable for clinker-combined with recycled materials, is regarded as a solution that effectively integrates decarbonization with material circularity (Díaz 2017). When combined with selected recycled or secondary materials, LC3 can support both clinker reduction and material circularity, thereby contributing to lower CO_2 emissions and more efficient use of domestic mineral resources.

- Carbon Capture, Utilization and Storage (CCUS): CCUS can capture 50–90% of CO_2 in the flue gas stream. (Reuters 2025). On the other hand, CCUS and several electrification-related technologies (e.g., electric grinding using clean power, CO_2 compression and pumping, electrolysis for e-fuels) significantly increase electricity demand in cement production. IEA modelling shows that in a clean-technology scenario, CCUS accounts for around 15% of the total emissions reductions required for the cement and steel sectors, but it also demands a commensurate increase in electricity consumption to operate CO_2 capture, compression, and conditioning systems (IEA 2018). For Viet Nam, CCUS should be assessed not only as an emission-reduction option, but also in terms of electricity demand, cost, infrastructure readiness, and access to CO_2 transport and storage solutions. In the near term, CO_2 mineralization technologies (CO_2 curing, recarbonation of recycled aggregates) create opportunities to convert CO_2 emissions from kilns into feedstock for precast concrete, effectively closing the carbon loop within the cement–concrete value chain (Quang 2025). Reviews of circular-economy strategies in concrete highlight CO_2 mineralization as a key pillar of "circular carbon".

3.3.2 Linkages with the Construction, Transport, and Material Supply Chains

3.3.2.1 Impacts on the Construction and Real Estate Sectors

Recent international reports show that the buildings and construction sector, by far the largest user of cement and concrete, is under intensifying pressure to reduce embodied carbon.

Analyses of upfront carbon indicate that emissions generated before a building begins operation (primarily from materials) may represent up to half of the carbon footprint of new buildings between now and 2050 (NZGBC 2023). Against this backdrop, deploying low-carbon cement and concrete (SCM, LC3, optimized mix designs, recycled aggregates) at the plant level (Sections 3.1–3.3) will directly help the construction sector reduce embodied carbon without necessarily increasing lifecycle costs. Guidance on embodied carbon in concrete (ARUP & IStructE 2023) emphasizes that although concrete has a lower cost and carbon intensity per kilogram than steel, its massive volume of use means that decarbonizing cement–concrete has system-wide impacts across the building value chain. From an economic standpoint, decarbonising cement and concrete is generally more cost-effective than substituting concrete with alternative materials such as green steel, which currently carries a significant cost premium. Low-carbon cement and concrete can deliver meaningful embodied-carbon reductions at relatively low or even negative marginal abatement costs. Given the very large volumes of concrete used in buildings and infrastructure, these incremental reductions translate into substantial system-wide emission and cost benefits.

In Viet Nam's broader energy transition, low-carbon cement and concrete are tightly linked to the decarbonization pathway of the buildings sector. Viet Nam's NDC (2022) (NDC 2022) explicitly identifies buildings as a pillar for meeting NDC and Net Zero targets, including both operational and embodied carbon. This demonstrates that without reducing the emission intensity of cement–concrete, it will be extremely difficult for the building sector in Viet Nam to meet its committed decarbonization pathway.

3.3.2.2 Linkages with the Material Supply Chain, Transport and Infrastructure Sectors

Transitioning to SCM/LC3, AFR, and increased material recycling reshapes the logistics and supply chain for building materials. It involves increasing flows of slag, fly ash, clays, low-grade limestone, recycled aggregates, RDF, and biomass to cement plants or grinding stations. Concurrently, traditional transport flows of coal and conventional clinker are expected to diminish.

This necessitates reorganising material logistics networks (including ports, transfer hubs, and rail or waterway transport for bulk materials) around integrated **cement–power–steel industrial clusters** (WorldGBC 2023, WEF 2016, and the Ellen MacArthur Foundation 2019). Integrating low-carbon and circularity requirements into the supply chains of large-scale infrastructure projects will significantly reduce transport-related emissions and material losses.

3.3.2.3 *Circularity in Transport and Infrastructure*

Viet Nam's infrastructure projects generate enormous demand for cement and concrete (highways, bridges, ports, airports, metro systems), while producing large volumes of construction and demolition (C&D) waste. In Viet Nam, C&D waste already represents a significant and growing waste stream, accounting for an estimated 10–15% of total municipal solid waste generation, equivalent to roughly 70,000 t/day nationwide. In major metropolitan areas such as Hà Nội and Ho Chi Minh City, this share is considerably higher, reaching approximately 20–25% due to intensive urban redevelopment and infrastructure construction. For Hà Nội, official statistics report more than 2,000 t/day of collected C&D waste during 2015–2020; however, estimates based on demolition intensity (0.22–0.41 t/m² of floor area) indicate that actual generation reached around 4,200 t/day in 2021 and could exceed 9,400 t/day by 2025. When excavated soil and slurry from foundation works are included, total C&D-related waste flows in Hà Nội are estimated at 8,000–9,000 t/day. These figures highlight a substantial, yet largely underutilized, potential for recycled aggregates and circular infrastructure practices, with direct implications for reducing raw material demand, transport emissions, and embodied carbon in the cement–concrete value chain. This waste can be reintegrated into the cement–concrete cycle as recycled aggregates. Studies on circular infrastructure show that circular practices-material reuse, design for deconstruction, concrete and steel recycling, reducing pavement thickness-could mitigate up to 19% of total infrastructure emissions if deployed at scale (Altermind and Vauban IP 2023).

The Building Materials Strategy (1266/QĐ-TTg, 2020) and VIBM's 2023 research consistently promote the use of industrial by-products and recycled aggregates in cement–concrete. This aligns with Viet Nam’s circular-economy framework institutionalised under the Law on Environmental Protection 2020 and Decision 687/QĐ-TTg (June 2022), which identifies the building materials sector as a cornerstone for reducing landfilling and enabling resource recovery.

3.3.2.4 Implications for Policy and Green-Building Markets:

Low-carbon cement–concrete solutions (SCM, LC3, AFR, recycled aggregates, CO_2-cured concrete, etc.) not only reduce emissions at the plant level but also play a critical role in meeting the NDC pathway for buildings, the national green-building program, transport and infrastructure planning, and the national circular-economy strategy.

Embedding low-carbon material requirements into public-investment projects, especially transport infrastructure and public buildings, Viet Nam can support the industry modernisation to reach the net-zero by 2050 objectives. When coupled with emerging policies such as the amended Law on Efficient Energy Use (2025), the national green-taxonomy decision (21/2025/QĐ-TTg), and the carbon-market scheme (232/QĐ-TTg 2025), the cement–concrete sector can be positioned to become the core of green-building value chains, provided it aligns with embodied-carbon standards.

3.4 Market Drivers and Barriers for Low-Carbon Cement and Concrete Products

In the context of structural overcapacity, price-driven competition, and rising pressure from the net-zero by 2050 commitment, the market for low-carbon cement and concrete in Viet Nam is beginning to emerge but still faces significant supply-side and demand-side barriers. At the same time, a series of new instruments-ETS/carbon markets, CBAM, green finance, LCA/EPD requirements-are becoming long-term drivers that will eventually push the market to shift.

3.4.1 Supply-Side Barriers (Investment, Technology Risks, Clinker-Based Regulations)

(a) Overcapacity, thin profit margins, and limited investment space for new technology

Due to prolonged state of overcapacity, many producers have been operating at a loss; 42 out of 92 kiln lines were temporarily shut down due to weak demand and rising coal and electricity costs (Ximang.vn 2025). This results in extremely thin profit margins, making producers reluctant to commit large CAPEX for WHR, AFR, LC3 upgrades, or CCUS (see Section 3.3.2).

(b) Technology risks and fixed-asset “lock-in”

Many low-carbon technologies-especially LC3, alternative binders, CO_2 curing, and CCUS-are still at pilot or pre-commercial stages and not yet fully covered by Vietnamese standards (TCVN), leading to:

- Concerns from producers that products may not be accepted in major infrastructure projects without clear official guidance.
- Lock-in of existing assets: current kiln lines, grinding systems, and storage facilities are optimized for high-clinker OPC. Transitioning to LC3/high-SCM cement

requires additional investments in calciner upgrades, SCM storage and dosing systems, etc., raising fears of stranded assets if the policy environment changes or remains unclear.

(c) Technical standards and regulations still largely centred on clinker/OPC

The TCVN/QCVN system allows blended cements and SCMs, but in practice, many construction norms, unit price frameworks, and technical specifications still implicitly favour PC/OPC, using cement strength and clinker content as the main reference, rather than performance-based criteria. The lack of a dedicated standard or guideline for LC3, CAC, CSA, AAM/geopolymer cement, or CO_2-cured concrete results in a lack of a formal basis ("legal acceptance pathway") for designers, contractors, and regulators to approve large-scale applications.

(d) Lack of risk-sharing and cost-sharing mechanisms for AFR and CCUS

For AFR: Investing in alternative-fuel systems (handling, storage, pre-processing RDF, environmental monitoring) requires substantial CAPEX, while waste collection, segregation, and pre-treatment systems in Viet Nam remain fragmented and cost-sharing responsibilities among municipalities, waste-treatment operators, and cement plants are unclear, causing cement producers to shoulder most of the CAPEX/OPEX burden, reducing incentives for AFR adoption. As a result, cement producers may have to bear a large share of both CAPEX and OPEX, which reduces the financial attractiveness of AFR adoption and slows down wider deployment.

For CCUS: CCUS involves extremely high investment and operational costs (Section 3.3.2), while Viet Nam currently lacks: a domestic carbon price; CO_2 transport and storage infrastructure, and a clear legal framework. This creates very high financial risks for any producer attempting to deploy CCUS independently.

(e) Limited financial capacity and constrained access to green finance
In addition to thin profit margins, many Vietnamese cement producers face constrained balance sheets and high leverage following years of overcapacity and weak domestic demand. This limits their creditworthiness and access to long-term bank loans for capital-intensive low-carbon investments such as WHR upgrades, AFR systems. While green finance instruments are emerging in Viet Nam, most banks still perceive low-carbon cement technologies as high-risk due to uncertain payback periods, lack of standardized LCA/EPD benchmarks, and unclear policy signals. As a result, financing conditions (interest rates, loan tenors, collateral requirements) remain misaligned with the long investment horizons required for deep decarbonization technologies.

3.4.2 Demand-Side Barriers (Price Sensitivity, Public Procurement, Technical Standards)

(a) Price-driven market dynamics and limited willingness to pay for "green premiums"

Surveys by VIBM (Tâm NT 2023) show that developers and contractors rarely accept higher material prices solely for environmental benefits, unless required by green building certification (LEED, LOTUS, EDGE) or by international financiers. As a result, cement and concrete producers do not want to invest in LC3, high-SCM products, AFR systems, or CO_2 curing, also considering the overcapacity on the market. This slows down market uptake of low-carbon cement/concrete despite technical viability.

(b) Public procurement and infrastructure projects not yet aligned with low-carbon criteria

Despite the Building Materials Development Strategy (Decision 1266/QĐ-TTg, 2020), green building programmes, and the NDC are emphasising decarbonisation. Current public procurement regulations focus on operational energy efficiency and do not yet mandate LCA/EPD, embodied carbon limits, or low-carbon cement/concrete criteria in tender documents. In Thailand, criteria for green cement/concrete in public procurement (GPP) let the low-carbon cement penetration rise rapidly to ≈81% of the market in 2023–2024.

(c) Lack of reliable information on performance, durability, and long-term benefits

For many developers, consultants, and contractors, low-carbon cement/concrete remains a relatively new concept. In Viet Nam, there are few large-scale demonstration projects meaning that long-term data on durability, lifecycle cost (LCC), and verified carbon reductions are limited, particularly in easily usable formats (e.g., catalogues, standardised EPDs). Due to the lack of domestic evidence, the Vietnamese market remains cautious about whether international experience with LC3 concrete and mixes incorporating recycled aggregates or biomass ash can deliver the same 36–46% climate impacts and 9–26% reductions in lifecycle costs (Jin et al. 2024; Haverkamp 2025).

(d) Barriers from technical standards and entrenched design practices

Most structural engineers, consultants, and contractors are accustomed to traditional strength-class-based design and conventional cement types. Transitioning to performance-based design, using new materials (LC3, high-SCM concrete, UHPC, lightweight concrete, etc.), requires updated design guidelines and technical manuals; adjustments to TCVN/QCVN codes and construction norms; time for training and market familiarisation. Until such changes occur, status quo design habits and risk-aversion will continue to limit acceptance of low-carbon cement and concrete.

3.4.3 Market Drivers (ETS, CBAM, Green Finance, LCA/EPD Standards)

Despite the numerous barriers, strong market drivers for low-carbon products are beginning to emerge both domestically and internationally.

(a) EU CBAM and pressure from global supply chains

The EU's CBAM has entered its transitional phase for cement, steel, and fertilisers, requiring exporters to report embedded emissions from 2023 and pay carbon charges from 2026 onward. Although Viet Nam's direct cement export share to the EU is modest, CBAM sets a precedent for similar mechanisms in other markets (Japan, the United States, Korea). It also creates indirect pressure through European, Japanese, and Korean investors and contractors active in Viet Nam, who increasingly require materials with transparent EPD/LCA documentation. As a result, cement and concrete producers are being pushed to quantify and reduce emissions and prepare low-carbon product lines to maintain competitiveness in global supply chains.

(b) Domestic carbon market (ETS) and carbon pricing mechanisms

The Law on Environmental Protection (2020) and the National Carbon Market Development Scheme (QĐ 2157/QĐ-TTg 21/12/2021) specify that large emitters in industrial and energy sectors, including cement, will participate in pilot emissions trading and domestic carbon crediting between 2025–2027, moving toward a fully operational ETS by 2028. This creates direct economic incentives for cement and concrete companies to reduce emissions: lower demand for emission allowances and an opportunity to generate and sell carbon credits through WHR, AFR, LC3, CO_2 curing, and CCUS projects. For Viet Nam, this means that cement companies should begin preparing robust MRV systems, project pipelines and feasibility studies for creditable emission-reduction measures, similar to Thailand’s T-VER mechanism for cement WHR/AFR projects. The indicative carbon-price ranges are derived from international marginal abatement cost (MAC) analyses for the cement sector (IEA 2018a). For WHR, energy efficiency, and initial AFR deployment, carbon prices of ~US$10–30/$tCO_2$ are generally sufficient, as avoided electricity and fuel costs already cover a significant share of CAPEX and OPEX. For SCM/LC3, higher prices in the range of ~US$30–50/$tCO_2$ are typically required to compensate for additional costs related to calcined clay production, SCM logistics, quality control, and market acceptance (IEA 2018b). In contrast, CCUS requires carbon prices above ~US$80–120/$tCO_2$, consistent with capture, compression, and storage costs reported in global cement-sector CCUS assessments, and therefore cannot be incentivized by carbon pricing alone without complementary public support (IEA 2018a).

(c) Green finance and the expanding green building market

The State Bank of Viet Nam has issued guidelines on green credit, while Decision 21/2025/QĐ-TTg classifies “environmentally friendly building materials production” as a priority sector for green finance mobilisation. The scheme aims to mobilise green loans from international financial institutions (IFC, ADB, WB) as well as green bonds and blended finance, also for low-carbon construction materials;

The rapid growth of the green building market in Việt Nam (LEED, LOTUS, EDGE), which more than doubled from 2020 to 2024, indicates a segment of the market where developers are willing to pay for low-carbon materials to achieve higher certification ratings.

(d) LCA/EPD standards and embodied-carbon transparency

Globally, the standardisation of lifecycle assessment (LCA) and environmental product declarations (EPDs) is accelerating, which norms such as EN 15804 for construction product EPDs and ISO 14040/44 for LCA. Many countries now incorporate embodied-carbon limits directly into building codes.

For Việt Nam, UNIDO, GIZ, and IFC are supporting the development of LCA methodologies, datasets, and pilot EPDs for cement and concrete. Once LCA/EPD frameworks are institutionalised through building codes and green public procurement, they will directly translate climate objectives into measurable market signals, helping to overcome information asymmetry and shift competition from clinker-based price metrics toward verified lifecycle performance.

CBAM, the emerging domestic ETS, green finance, the growth of green buildings, and LCA/EPD standardisation are gradually forming a new set of structural drivers. For Viet Nam, these drivers may affect both export-oriented producers and domestic suppliers, as carbon performance, product transparency and life-cycle emissions become increasingly important in market access, financing and procurement decisions. These may increasingly push the market away from traditional high-carbon cement–concrete models toward the low-carbon technologies and products outlined in Sections 3.1–3.4.

3.5 Summary and Key Insights

Chapter 3 has examined the pathways for energy transition and technological adoption to reduce greenhouse gas emissions in the cement and concrete sector, drawing on global trends as well as practical conditions in Viet Nam. The analysis shows that Viet Nam is currently in a transition phase between improving energy efficiency and shifting toward low-carbon and near-zero-carbon technologies. Most plants have already reached relatively competitive levels of energy consumption; however, a substantial efficiency potential of 10–15% remains through process optimization, increased SCM use, co-processing of waste, and expanded waste-heat recovery.

Indirect emission-reduction technologies-such as clinker substitution, energy optimization, and alternative fuels-exhibit high readiness levels and are feasible for wide deployment during 2025–2035. In contrast, advanced solutions such as CCUS, electrification of kiln auxiliaries, and hydrogen-based systems will require piloting, standardization, and targeted policy support after 2035. Successful localization and large-scale adoption of these technologies hinge on cross-sectoral coordination among the materials, energy, and environmental sectors, combined with access to green finance and supportive policy instruments.

The low-carbon transition in cement will create spillover impacts across multiple sectors, including electricity supply (via WHR and electrification), waste management (via AFR and circularity pathways), emissions monitoring (MRV), and future participation in carbon markets. Importantly, the effectiveness of several mitigation options - particularly electrification, digitalisation, and CCUS - will depend on the parallel decarbonisation of the power sector, as increased electricity demand could otherwise shift emissions upstream rather than reduce them in net terms. Nevertheless, the transition is constrained by significant financial, institutional, and market barriers, including high upfront investment costs, the absence of well-defined standards for low-carbon products, and limited market awareness and acceptance.

Chapter 4 Conclusion and discussion of pathways for decarbonising Viet Nam’s cement industry

4.1 Summary of the Potential for Developing Low-Carbon Cement in Viet Nam

Based on the analyses in Chapters 1–3, the potential for developing low-carbon cement and concrete in Viet Nam can be summarised along three closely linked dimensions. First, the sector possesses a technically viable mitigation portfolio capable of significantly reducing both energy intensity and process-related CO_2 emissions. Second, market and policy drivers - including national climate commitments, green construction programmes, carbon-pricing instruments, and international supply-chain requirements - are increasingly shaping demand and investment decisions in favour of low-carbon materials. Third, structural oversupply and limited growth in domestic cement demand are weakening volume-based expansion models, while strengthening the economic rationale for value-added, low-carbon products. Together, these factors indicate that Viet Nam’s cement industry is at a pivotal transition point, where decarbonisation is no longer optional but increasingly aligned with long-term competitiveness and sectoral restructuring.

4.1.1 Emission reduction potential by technology solution clusters

Assessment across the cement–concrete value chain confirms that Viet Nam has significant mitigation potential, aligned with global decarbonisation frameworks (CEMBUREAU 2024b). This potential can be grouped into four main technology pillars:

(1) Clinker-factor reduction through expanded use of SCMs and low-clinker cements

This remains the most impactful and cost-effective measure. Viet Nam’s clinker factor (0.75–0.78) is still above global benchmarks, while domestic SCM availability, including fly ash, slag-creates strong potential for rapid scale-up. With appropriate mobilisation and market standards, the clinker factor could decline to ~0.60 by 2030 and 0.52–0.55 by 2050.

(2) Alternative fuels and circular-economy integration

AFR utilisation in Viet Nam remains low (5–7% TSR on average), despite individual plants achieving 25–35%. Scaling up co-processing of RDF/SRF, industrial waste, sludge and biomass could substantially reduce coal consumption while supporting national waste-reduction policies. Technical feasibility is clear, but sector-wide expansion requires cross-ministerial coordination.

(3) Energy efficiency, WHR deployment and digitalisation

WHR is installed in 38 lines (60,3% of ≥2,500 t/day lines), yet substantial untapped potential remains. Digital process control (APC/AI), VSDs and optimisation systems can reduce electricity use and thermal energy - an important enabler in the current oversupply environment.

(4) Long-term CCUS and CO_2 utilisation/mineralisation technologies

Residual emissions will remain significant even under ambitious clinker reduction and AFR expansion. Viet Nam’s offshore sedimentary basins offer potential CO_2 storage opportunities, enabling future CCUS clusters linking cement, power and petrochemicals. Earlier deployment options such as CO_2 curing and mineralisation in precast concrete can begin before 2035.

If implemented in a coordinated manner and supported by suitable policy instruments, these four pillars provide a robust foundation for Viet Nam’s cement sector to achieve 80–90% emission reduction by 2050. Clinker-factor reduction and AFR expansion are the most cost-effective near-term priorities; WHR and digitalisation deliver immediate efficiency gains; and CCUS is essential for completing the decarbonisation pathway in the post-2040 period.

4.1.2 Market Drivers for Low-Carbon Materials in Viet Nam

Analysis from previous chapters shows that the shift toward low-carbon construction materials in Viet Nam is driven not only by mitigation requirements but also by significant market, policy, and supply-chain pressures.

(1) Pressure from international carbon mechanisms and export-driven supply chains

Viet Nam’s cement industry is increasingly exposed to global carbon-pricing schemes, particularly the CBAM. From 2026, all cement and clinker exported to the EU must report emissions according to ISO standards and pay corresponding carbon costs under the EU ETS. With sectoral emissions estimated at ~72.5 $MtCO_2$/year (about 22% of national emissions), cement is a priority sector for compliance in international trade (Tâm NT 2023; Tâm NT 2024). Other major markets-including Japan, Korea, and the United States-are also tightening embodied-carbon requirements, with several multinational contractors already requesting EPDs for materials sourced in Viet Nam. This creates strong incentives for domestic producers to transition to low-carbon cement products.

(2) Rapid growth of the domestic green-building and sustainable-materials market

Viet Nam is one of the fastest-growing green-building markets in Southeast Asia, with EDGE-certified floor area increasing 20–25% annually. Large commercial, FDI and industrial/logistics projects increasingly require low-CO_2 concrete with transparent LCA/EPD documentation.

(3) Strong national policy framework supporting low-carbon materials

Key policies, including the National Strategy for Building Materials (1266/QĐ-TTg 2020), QCVN 19:2024 on industrial emissions, clearly mandate clinker reduction, increased SCM use, AFR expansion and improved energy efficiency. Viet Nam’s updated NDC (2022) targets 15.8% unconditional and 43.5% conditional emissions reduction by 2030, while Decree 06/2022/NĐ-CP requires the construction sector to cut at least 74.3 $MtCO_2$ by 2030. Cement is therefore classified as a “mandatory transition” sector in all net-zero scenarios.

(4) Abundant SCM resources and cost advantages

Viet Nam has substantial domestic availability of fly ash, slag, fine limestone and high-kaolinite clays suitable for LC3 production. International assessments (JRC 2023; GCCA 2022) confirm that LC3 can reduce CO_2 emissions by up to 40% compared with OPC, with production costs equal to or lower than CEM II, giving Viet Nam a competitive advantage, especially in a price-sensitive market.

(5) Emergence of a domestic low-carbon concrete market

Recent studies show strong global growth in low-carbon concrete, driven by mix optimisation, expanded use of SCM, LC3, CO_2 curing, and alternative binders. Major Vietnamese contractors have begun piloting slag-based, fly-ash-based and CO_2-mineralised concrete, indicating clear and growing market demand.

Together, these drivers create a strong foundation for scaling low-carbon cement and concrete in Viet Nam over the next 10–15 years, supporting the sector's broader decarbonisation pathway.

4.1.3 Main Barriers to the Development of Low-Carbon Cement

Although Viet Nam holds strong potential for low-carbon cement and concrete, the transition remains constrained by several structural, technical, regulatory and market barriers. These limitations slow technology adoption and reduce the sector's ability to mobilise investment and commercialise low-carbon products in the coming decade.

(1) Structural barriers: persistent overcapacity and low profit margins

Prolonged oversupply suppresses prices and limits capital accumulation, constraining investment in medium- and high-CAPEX decarbonisation measures such as WHR, AFR and CCUS.

(2) Standards, regulations and legal framework gaps

Many Vietnamese building standards remain oriented toward traditional Portland cement and do not sufficiently enable blended cements (e.g., slag cement, limestone–pozzolan cements such as CEM II/C-M), low-clinker cements (LC3, supersulfated cement), or low-carbon concrete (Mai CT 2023). Existing TCVN standards are not fully aligned with international low-carbon material trends and do not adequately accommodate SCMs with variable quality.

For AFR, despite QCVN 19:2024 providing a regulatory basis, gaps persist in waste-classification systems, dedicated material standards, and licensing processes, leading to inconsistent co-processing practices.

(3) SCM and AFR supply and logistics constraints in cement production

Although SCM availability is generally abundant, constraints include variable quality of fly ash, limited slag grinding and transport infrastructure, and the need to identify and permit kaolinite-rich clay deposits for LC3. For AFR, the primary barriers lie in the lack of industrial-scale waste sorting and pre-processing (RDF/SRF) and absence of unified standards and conditions identified by IFC (IFC 2017a) as critical for successful AFR adoption.

(4) Technology-readiness limitations

Many decarbonisation technologies remain at low TRL/MRL levels. WHR has been installed in only 43 lines; AFR substitution averages just 5–7% (Long 2025), far below the EU average (53%) (CEMBUREAU 2025). LC3 has not undergone pilot-scale deployment, and CCUS remains conceptual. Low readiness increases perceived technology risk and reduces investor confidence.

(5) Limited carbon data, LCA/EPD systems and MRV capacity

Viet Nam lacks a national LCA database for construction materials, and most cement producers do not yet issue EPDs meeting ISO 14025/EN 15804 standards, limiting compliance with CBAM and international contractor requirements. Literature indicates that transparent product-level carbon data is essential for low-carbon market formation.

(6) Financial constraints and high CAPEX requirements

High investment costs, such as CCUS (USD 70–120/tCO_2) and WHR (USD 1,100–1,400/kW) (IFC 2017a) exceed the financial capacity of many producers, particularly small plants (<1 Mt clinker/year). Persistent oversupply, coal and electricity price volatility further weaken financial resilience.

(7) Low market awareness and slow demand pull

Stakeholders in the construction value chain continue to prefer OPC and conventional blends, expressing concerns about technical risks when adopting LC3 or high-SCM cements. Low demand from developers, limited EPD/LCA requirements in procurement, and batching plants' unfamiliarity with low-carbon mix designs reinforce slow market uptake, consistent with international findings that value-chain awareness is the top barrier to low-carbon materials.

These barriers must be systematically addressed through targeted policies, investment mechanisms and coordinated roadmaps, as outlined in subsequent sections of this report.

4.2 Policy Options and Enabling Conditions for Energy Transition and Emission Reduction

The transition toward low-carbon cement in Viet Nam requires a comprehensive policy package that includes technology-support instruments at the plant level, market-creating mechanisms for low-carbon products, and cross-sector enabling conditions to ensure long-term feasibility.

(i) Standards, regulations and technical roadmaps for low-carbon technologies

Accelerating low-carbon cement requires a modernised standards framework focused on clinker reduction and expanded SCM use. Priority actions include:

- Developing national standards (TCVN) for LC3, low-clinker eco-cement, and low-carbon concrete (e.g., geopolymer, alkali-activated).
- Transitioning to performance-based design and construction codes instead of prescriptive OPC/PC requirements.
- Setting maximum clinker-factor limits, aligned with EU and India's policies.

- Issuing a national AFR roadmap targeting ≥30% by 2030 and 50–60% by 2050

These tools provide technological clarity and reduce investment risks.

(ii) Financial tools: green credit, tax incentives and innovation support

Many low-carbon technologies-such as WHR, full-line AFR systems, high-efficiency separators and CCUS-require medium- to high-CAPEX. Key financial mechanisms include:

- Preferential green credit lines for technologies with verified CO_2 reductions (based on LCA).
- Incentives for WHR equipment, waste pre-processing, LC3 grinding and APC/AI systems.
- A national carbon fund to bridge the cost gap between low-carbon and conventional cement by providing targeted financial support for early-stage investments. The fund could be capitalised from ETS revenues, state climate budgets, and international climate finance, and disburse support through investment grants or results-based payments per tonne of verified CO_2 reduction. By improving project bankability and reducing investment risks, the carbon fund would accelerate deployment of WHR, AFR, LC3, and CCUS before carbon pricing mechanisms become fully effective.
- Blended finance for CCUS, as exercised by the MoC–MOIT–WB–JICA collaboration (following Korea's ESR Fund model).

Financial instruments are essential to accelerate deployment during 2025–2035.

(iii) MRV systems, carbon reporting and data transparency tools

To overcome current data gaps, Viet Nam needs:

- A mandatory national MRV system for cement aligned with IPCC 2006 and ISO 14064.
- A national LCA database (Viet NamLCI) compatible with EN 15804 for EPD development.
- A national EPD tool for cement and concrete (ISO 14025).
- Plant-level carbon inventories as required by Decree 06/2022/NĐ-CP.

These tools enable compliance with CBAM and FDI procurement requirements.

4.3 Stakeholder Perspectives on the Emission Reduction Roadmap

Stakeholder views play a critical role in assessing the feasibility of proposed solutions and the overall decarbonisation pathway. The following synthesis reflects inputs from cement producers, ready-mix concrete suppliers, regulatory agencies, and developers/design consultants gathered through project consultations.

4.3.1 Perspectives of Cement Producers

Cement companies clearly recognise the pressures posed by CBAM, rising coal and electricity prices, and the growing shift toward green buildings. They strongly support low-cost measures such as the use of SCM, digitalisation, energy optimisation, and WHR. However, they also express concerns about high CAPEX requirements for CCUS and advanced AFR; absence of standards for LC3 and emerging binders; lack of stable market demand for low-carbon cement; difficulties in accessing green finance.

4.3.2 Perspectives of Ready-Mix Concrete Companies

Major ready-mix producers report that they are willing to adopt SCM/LC3 if clear standards and stable supply are ensured; CCUS does not directly affect concrete mix design but influences cement costs; Cement producers must provide EPDs to support green-building certifications (LEED, LOTUS, EDGE).

4.3.3 Perspectives of Developers, Design Consultants and Contractors

This group emphasises three points:

- Initial construction cost remains the primary decision factor.
- They support low-carbon concrete if certified, accompanied by EPDs, and without compromising project timelines.
- Foreign investors increasingly require LCA/EPD disclosure, putting pressure on the supply chain

4.3.4 Perspectives of Regulatory Agencies

Government agencies (MoC, MONRE, MOST) strongly support the transition to low-carbon materials and highlight:

- Material standards are the most significant barrier;
- The need for a national ETS to create long-term incentives.
- AFR and CCUS development requires coordinated action across environment, energy, transport and industry sectors.

4.4 Structural Changes Required for a Net-Zero Cement Sector

Analysis of technical data and international experience shows that achieving net-zero by 2050 in Viet Nam's cement sector requires not only technological upgrading but also deep structural adjustments across capacity planning, product portfolios, market mechanisms, fuel–material supply chains and emissions infrastructure. Without these structural reforms, low-carbon technologies (SCM/LC3, AFR, WHR, CCUS) cannot reach full effectiveness. Six major structural changes are identified:

(1) Capacity restructuring and phase-out of outdated, low-efficiency production lines

Viet Nam's current capacity of over 122 Mt/year exceeds domestic demand by ~50%, weakening profitability and limiting capital for decarbonisation. In response, policy priorities should focus on maintaining the moratorium on new project licensing (Decision 1266/QĐ-TTg, 2020), progressively phasing out small and inefficient clinker lines (<2,500 t/day; e.g. through capacity buy-back schemes, merger and acquisition incentives, or mandatory efficiency benchmarks), and promoting production consolidation into larger industrial clusters to enable cost-effective deployment of AFR, WHR, and, in the longer term, CCUS.

(2) Shifting the product structure from OPC to low-clinker cements (LC3, CEM II/C-M, CEM III)

Despite high OPC dependency, Viet Nam has strong LC3 potential due to abundant kaolinitic clays and limestone. Expanding 30–50% SCM substitution could reduce sectoral CO_2 by 35–40%. This requires new TCVN standards aligned with EN 197-5, performance-based design codes, and development of national SCM hubs and satellite grinding centres to pivot away from clinker-intensive production.

(3) Developing a national AFR and solid-waste ecosystem

To reach 50–60% AFR by 2050, Viet Nam must implement structural reforms: build 10–12 regional RDF/SRF hubs, integrate waste sorting–preprocessing systems to cement standards, allow regional co-processing models (as in Thailand and Japan), and phase out outdated landfills. Reaching this target requires a mix of regulatory and economic policies, including mandatory waste sorting, landfill taxes or bans on combustible waste, and clear technical standards recognising RDF/SRF as approved fuels for cement kilns. These should be supported by tipping-fee mechanisms and public–private investment support for regional RDF/SRF hubs to secure stable supply chains and reduce investment risks. Without this structural changes, AFR cannot scale to net-zero requirements.

(4) Making WHR and digitalisation mandatory across the sector

To reach Net Zero, WHR should be mandatory for all lines by 2030. Likewise, sector-wide deployment of digital systems-APC/AI, EMS, and high-efficiency process optimisation without requiring major changes to the existing production structure -is needed to reduce 10–15% CO_2. Compared with deep retrofit options, digitalization and process optimization are relatively easier to implement, have shorter payback periods, and can provide early emission reductions while preparing plants for more advanced decarbonisation technologies. This requires binding regulatory mandates, such as making WHR a licensing or operating condition for cement kilns above a defined capacity, combined with minimum energy-efficiency benchmarks. These mandates should be supported by preferential grid-connection rules, feed-in or self-consumption incentives for recovered power, and recognition of verified efficiency gains within the ETS/MRV framework to accelerate digitalisation uptake.

(5) Building CO_2 collection–transport–storage (CCUS) infrastructure

CCUS will account for 20–30% of total CO_2 reduction (GCCA 2020). Yet Viet Nam lacks legal frameworks, safety standards and CO_2 transport/storage infrastructure; offshore basins remain under-assessed. The sector needs government support to plan CCUS clusters, build CO_2 pipelines/transport systems, and implement financial mechanisms (blended finance, carbon CfDs).

(6) Creating a low-carbon cement–concrete market through standards reform and ETS implementation

A structural shift is required from trading based on cement grades to trading based on CO_2 intensity. This includes mandatory EPDs for cement and concrete by 2030, LCA requirements in public procurement, implementation of a national ETS (ximang.vn 2/2025) with cement as a compulsory sector, and a national carbon label for building materials. Clear carbon pricing will drive investment in high-cost technologies. On the demand side, public procurement rules should introduce embodied-carbon thresholds for public buildings and infrastructure, alongside preferential purchasing of low-carbon cement and concrete, similar to Thailand's Green Procurement and T-VER framework. On the financial side, revenues from the ETS should be recycled into targeted subsidies, tax rebates, or results-based payments for verified low-carbon products to offset their initial cost premium. Combining standards, carbon pricing, demand-pull instruments, and recycling of carbon revenues would create a coherent market package that accelerates uptake while maintaining competitiveness.

4.5 Implementation roadmap and responsibilities of relevant parties

Based on technology readiness levels (TRLs), sector-specific applicability, and the prevailing policy and market context, this report proposes a phased roadmap for deploying CO_2-reduction measures in Viet Nam's cement and concrete sector. Table 4.1 summarises the roadmap by milestone periods (to 2030, 2040, and 2050), highlighting a sequenced approach in which near-term, commercially available measures are prioritised first, while enabling conditions for advanced technologies are progressively established for large-scale adoption after 2040.

Table 4. 1 Roadmap for CO_2-reduction technology deployment for Viet Nam cement industry

Phase	Application roadmap	
	Objectives	Technologies / Measures
To 2030	Achieve significant reductions in energy consumption and CO_2 per tonne of cement, without relying on breakthrough technologies	- Install WHR systems on **90%** of production lines ≥ 2,500 t clinker/day. - Increase AFR to **10–20%**. - Reduce clinker factor to **0.65**. - Deploy energy optimisation, advanced process control, and digitalisation (APC, energy monitoring, "smart plant") at major facilities. - Establish standards, technical regulations, carbon labeling, and initial green public procurement for low-carbon cement/concrete to create **structural demand** in public projects.
To 2040	Prepare for Net Zero through new technologies and CCUS	- Complete WHR installation for 100% of production lines ≥ 2,500 t clinker/day. - Increase AFR to **30–40%** across the industry. - Reduce clinker factor to **0.60**. - Conduct industrial-scale pilots of alternative binders (CAC, CSA, SSC, AAM) for precast concrete and green demonstration projects; develop corresponding TCVN/QCVN standards and technical guidelines. - Deploy **CO_2-cured concrete / recarbonation** at selected unfired brick, concrete block, and precast plants, accompanied by MRV systems to quantify mineralized CO_2, preparing for integration with the carbon market.

		- Develop a national CCUS roadmap for the cement sector at the policy level.
To 2050	Achieve deep absolute emission reductions, aligned with Net Zero 2050 and GCCA/IEA pathways	- Increase AFR to 50–60%. - Low-carbon cement–concrete becomes the dominant product; traditional OPC is used only in special applications or in combination with CCUS. - Alternative binders account for **20–30%** of total demand. - Commercial operation of CCUS. - Coordinate with the construction sector to reduce demand for high-carbon materials and shift toward low-carbon materials.

This 2030–2040–2050 roadmap allows Viet Nam to prioritise the measures during 2025–2035 while gradually preparing the technical, institutional, and infrastructural foundations needed to scale near-zero-carbon technologies, including CCUS, after 2040. This approach aligns with the national net-zero 2050 target and global decarbonization trajectories for the cement–concrete sector.

To implement a low-carbon transition pathway at the plant level, technologies must be matched to specific plant types, rather than applying a single template to the entire sector. This allows grouping plants and recommending tailored technology packages as follows.

Table 4. 2 Plant Typology and Priority Technologies

Plant Category	**Key Characteristics**	**Priority Technologies**
Group A – Large, modern plants (≥ 5,000 t clinker/day, new-generation technology)	- Modern dry-process rotary kilns with multi-stage preheaters and precalciners; many already equipped with WHR and initial AFR co-processing. - Typically belong to VICEM or large cement groups; located in coastal regions or major transport corridors, with good access to SCMs (slag, fly ash, limestone) and waste streams for AFR.	- Optimise and expand WHR (increase capacity and operational efficiency), targeting **25–35% onsite electricity supply**. - Rapid AFR expansion, achieving **TSR 20–40%** within 5–10 years, following INSEE Hòn Chông's benchmark (TSR ≈ 38–40%). - Reduce clinker factor. - Digitalisation, advanced process control, "smart plant". - Priority candidates for **CCUS pilots** and **CO_2-cured concrete** after 2035 due to scale, coastal location, and proximity to energy–petrochemical clusters.
Group B – Medium-scale plants, partially modernized (≈ 2,500–5,000 t clinker/day)	- Dry-process with precalciner, but may lack WHR or have low AFR; many lines commissioned 2005–2015. - Distributed nationwide; face strong competition and oversupply, resulting in thin profit margins.	- Invest in WHR. - Increase AFR use, raising TSR to **10–20%**. - Lower the clinker factor. - Operational optimization, energy audits, APC deployment.
Group C – Small plants, older technology (< 2,500 t	- Some small/old lines operate unstably with high energy intensity. - Limited ability to invest in large-scale WHR or AFR;	- Prioritise low-cost measures: operational improvement, grinding-circuit optimisation, fan upgrades, insulation and heat-loss reduction, partial equipment renewal; adopt reasonable SCM substitution. - Combined with sectoral policies: mergers,

Plant Category	Key Characteristics	Priority Technologies
clinker/day, low efficiency)	location may not allow access to high-quality SCM.	restructuring, or phased retirement of obsolete lines.
Grinding stations	- Typically located near consumption centres or ports; do not generate process emissions from clinker production. - Role is to serve as **technology distribution hubs**, producing high-SCM cement, LC3, and specialty cements (for precast, green buildings).	- Flexible blending of clinker + SCM; high-efficiency grinding systems.

Tailoring a “priority technology package” for each plant group ensures that the technology roadmap reflects practical conditions, reduces investment risk, and maximises the advantages of each plant cluster as Viet Nam transitions toward low-carbon cement and concrete by 2050.

Building on the phased deployment pathway in Table 4.1 and the plant-group technology packages in Table 4.2, the assumptions are translated into the wedge-based CO_2-reduction roadmap presented in Figure 4.1, which illustrates the sequencing and relative contribution of key mitigation levers over time toward the national net-zero 2050 target.

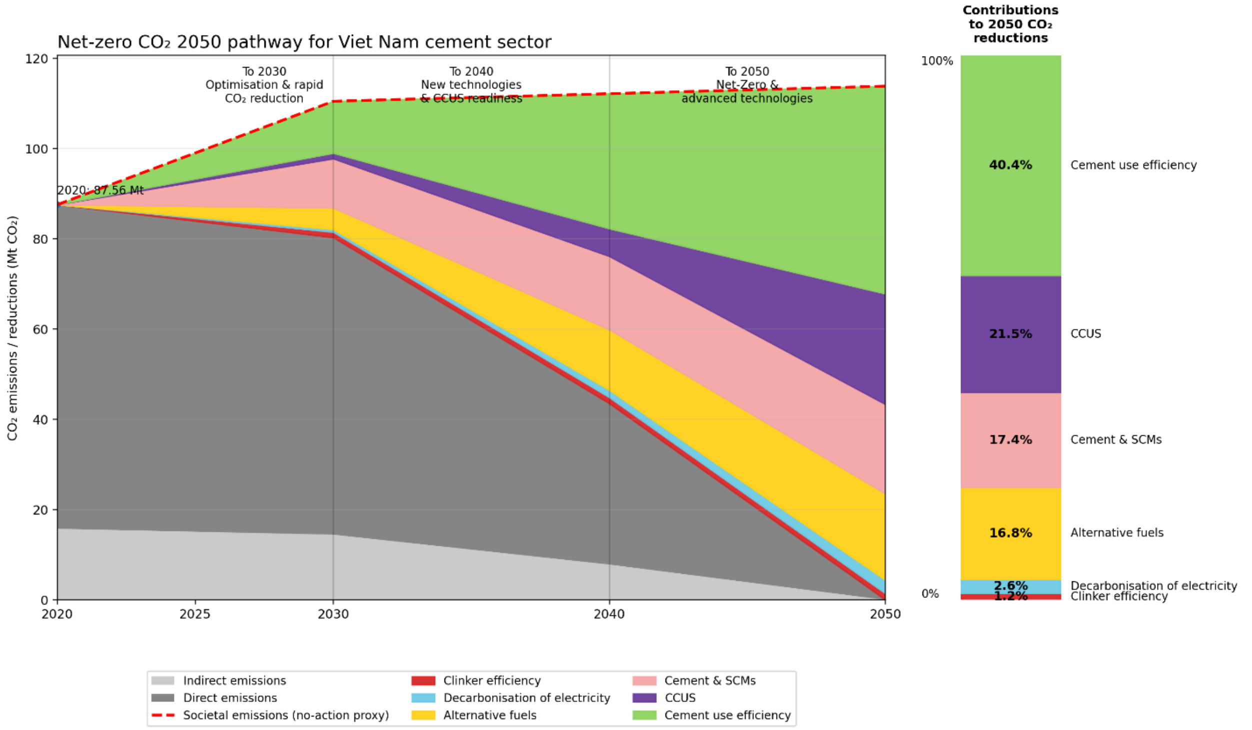

Figure 4. 1 Decarbonisation Roadmap of cement Viet Nam (Research team, 2025)

Table 4.3 then assigns roles and responsibilities to the main stakeholder groups—ministries, cement enterprises, technology providers, financiers, local governments, and research institutes—to support coordinated implementation, standardisation

(TCVN/QCVN), MRV/ETS readiness, and the mobilisation of finance and technical assistance.

Table 4. 3 Responsibilities of Key Stakeholders in the Energy Transition and CO_2 Reduction Roadmap

Stakeholder	Primary Responsibilities
Ministry of Construction (MOC)	- Issue low-carbon cement standards (CCR, blended cements) - Develop TCVN for SCM, AFR, calcined clay
Ministry of Industry and Trade (MOIT)	-Renewable energy & DPPA policies - Manage pilot and full ETS implementation
Ministry of Agriculture & Environment (MOAE)	- Develop national MRV system - Integrate cement sector into ETS/Net-Zero targets
Cement Enterprises	- Plan investments in WHR, VRM, AFR, AI - Deploy energy-management systems (EMS) - Report emissions via MRV
Insee, Nghi Sơn, Vicem, Thành Thắng, Xuân Thành, Long Sơn etc.	- Invest in new technologies, operate AI pilots - Share data and best practices
Technology Providers (FLSmidth, KHD, Sinoma, ABB, Yokogawa)	- Supply VRM, WHR, DCS, AI technologies - Deliver operator training and maintenance support
Financial Institutions (ADB, WB, JICA, JETP)	- Provide concessional finance for WHR, AFR, SCM, CCUS - Technical assistance for project preparation
Local Governments	- Plan ash/slag/waste management as SCM sources - Permit AFR and co-processing facilities
Research Institutes (VIBM, IBST, universities)	- Technical advisory - R&D on SCM, LC3 and CCUS technologies

4.6 Conclusion

This report provides an assessment of energy consumption, greenhouse gas emissions, and the current level of technological adoption within Viet Nam’s cement industry and proposes a phased roadmap for energy transition and CO_2 reduction through 2050. The analysis demonstrates that the sector faces an urgent need to shift toward a lower-carbon production model to meet national net-zero commitments, comply with emerging global climate regulations, and respond to new market mechanisms such as the CBAM.

In the near term (until 2030), the industry has significant potential to implement cost-effective measures that deliver immediate reductions in energy use and CO_2 intensity. These include equipment efficiency upgrades, improved grinding technologies, expanded WHR, increased use of AFR, and the establishment of modern energy-management and MRV systems aligned with upcoming ETS. Collectively, these actions can reduce emission intensity by 15–20% without requiring substantial structural changes.

Over the medium term (2030-2040), sustained decarbonization will depend on broader deployment of clinker substitutes (SCMs), accelerated digitalisation and AI-based process optimisation, and a gradual shift toward renewable electricity through mechanisms such as direct power purchase agreements (DPPA). These measures form the foundation for medium- to deep-level emission reductions and enhance operational efficiency and stability across the sector.

In the long term (2040-2050), achieving deep decarbonisation will require large-scale investment in breakthrough technologies, including CCUS, green hydrogen and other non-fossil fuels, and a transition to 100% renewable power. These transformative solutions are essential for the sector to achieve a 90% or greater reduction in direct emissions and ultimately reach net-zero by 2050.

Successful implementation of this roadmap will rely on early and consistent planning of concrete measures and policy mechanisms so that the industry can react, founded on strong coordination among government ministries, cement producers, research institutions, and international financial partners. Supportive policies, clear and strict technical standards, transparent carbon accounting, and access to concessional financing will be critical enablers for technological upgrading and industry-wide transformation.

In addition, the roadmap highlights the strategic importance of spatial and industrial clustering as a core enabler of deep decarbonisation. Consolidating production into regional cement–power–steel–waste clusters will allow shared infrastructure for AFR supply, WHR optimisation, CO_2 transport and storage, and bulk SCM logistics, thereby significantly reducing unit costs and investment risks. Beyond carbon-market instruments, the transition will require complementary financial mechanisms, including concessional green loans from state-owned banks, blended finance with multilateral development banks, sovereign-backed guarantees, and targeted public co-investment in shared infrastructure such as RDF hubs, rail and waterway logistics, and CO_2 transport networks. These non-ETS financial tools are essential to unlock large-scale capital investment, particularly during the 2025–2035 period before carbon prices alone become sufficiently strong to drive high-cost technologies.

In summary, Viet Nam’s cement industry possesses the technical potential and strategic opportunity to undertake a comprehensive low-carbon transition. If the proposed measures are implemented in a timely and coordinated manner, the sector will not only meet its emissions reduction obligations but also strengthen its competitiveness, ensure long-term operational resilience, and make a substantial contribution to the country’s net-zero goal for 2050.

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Annexes

Annex 1. Data tables

Table A. 1 Summary table of indicators of Vietnamese cement sector from 2014 to 2024 and forecasted for 2025 and 2050

(Source: adapted from (Ximang.vn 2025), (VNCA 2024))

Indicator	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025F	2030F
Designed capacity (Mil. t/y)	87.86	87.86	87.86	97.64	97.64	101.74	104.04	106.34	110.94	117.1	121.7	131.84	150
Total production output (Mil. t/y)	64.6	72	75.6	81.5	96.2	99.2	100.2	108.6	100.1	89.4	100.29	112.064	126.17
Ultilization rate	0.52	0.63	0.68	0.62	0.65	0.64	0.60	0.59	0.61	0.48	0.54	0.51	0.50
Total cement consumption (Mil. t/y)	64.4	71.9	75.4	81.3	96	99	100.1	108.4	99.4	87.9	95.04	92.623	102.16
Domestic cement consumption (Mil. t/y)	46.1	55.7	59.9	60.2	63.9	64.8	62.1	62.7	67.8	56.6	65.19	66.75	75.16
Total exports (Mil. t/y)	18.3	16.2	15.5	21.1	32.1	33.9	38	45.7	31.7	31.2	29.85	30.837	27.00
Total cement export (Mil. t/y)	6.3	8	5.5	5	9.1	11.2	14.8	16.8	16.4	20.3	20.29	-	-
Total clinker export (Mil. t/y)	12	8.2	10	16.1	23	22.7	23.2	28.9	15.3	10.9	9.56	-	-
Inventory	1.8	1.9	2.1	2.3	2.5	2.7	2.8	2.6	3.3	4.8	0	-	-
Population (x1000 person)	90,730	91,700	92,700	93,700	94,670	96,481	97,580	98,510	99,460	100,300	101,300	101,600	104,160

Cement consumption per capita (kg/person.year)	508	607	646	642	675	672	636	636	682	564	644	657	722

Table A. 2 Lines that have installed or are installing waste heat power generation

(Source: adapted VNCA Oct. 2025)

No.	Line name	Location	Kiln capacity, t clinker/day	Power capacity, MW	Commissioning time
I	**WHR lines in operation**				
1	Đồng Bành	Lạng Sơn	3.000	5.00	2023
2	Chinfon 1	Hải Phòng	4.000	12.85	2014
3	Chinfon 2	Hải Phòng	4.000		
4	Nam Sơn	Hà Nội	3.300	5.00	2018
5	Xuân Thành 1	Hà Nam	2.500	24.80	2018
6	Xuân Thành 2	Hà Nam	12.000		
7	Xuân Thành 3	Hà Nam	12.500	20.00	2023
8	Long Thành	Hà Nam	6.000	7.50	2023
9	Bút Sơn 1	Hà Nam	4.000	6.00	2023
10	Bút Sơn 2	Hà Nam	4.000	6.00	2023
11	Vissai 3	Hà Nam	2.500	4.00	2016
12	Vissai 4	Hà Nam	3.300	5.00	2017
13	Thành Thắng 2	Hà Nam	6.000	7.50	2017
14	Thành Thắng 3	Hà Nam	6.000	7.50	2019
15	Thành Thắng 4	Hà Nam	6.000	7.50	2021
16	Thành Thắng 5	Hà Nam	6.000	7.50	2024
17	Vissai 1	Ninh Bình	2.500	4.00	2017
18	Vissai 2	Ninh Bình	6.000	7.50	2017
19	Hướng Dương 1	Ninh Bình	2.500	5.00	2021
20	Hướng Dương 2	Ninh Bình	2.500	5.00	2021
21	Long Sơn 1	Thanh Hóa	6.000	7.50	2014
22	Long Sơn 2	Thanh Hóa	6.000	7.50	2016
23	Long Sơn 3	Thanh Hóa	6.000	7.50	2021
24	Long Sơn 4	Thanh Hóa	6.000	7.50	2022
25	Công Thanh 1	Thanh Hóa	2.500	3.00	2009
26	Công Thanh 2	Thanh Hóa	10.000	12.50	2017
27	Đại Dương 1	Thanh Hóa	6.000	7.50	2022
28	Đại Dương 2	Thanh Hóa	6.000	7.50	2023

No.	Line name	Location	Kiln capacity, t clinker/day	Power capacity, MW	Commissioning time
29	Sông Lam 1	Nghệ An	6.000	7.00	2016
30	Sông Lam 2	Nghệ An	6.000	7.00	2016
31	Tân Thắng	Nghệ An	4.000	6.50	2024
32	Sông Gianh	Quảng Bình	4.000	7.50	2018
33	Quảng Phúc	Quảng Bình	5.000	6.50	2018
34	Thành Mỹ	Quảng Nam	3.300	5.00	2022
35	Hà Tiên 2	Kiên Giang	3.000	2.95	2002
36	INSEE	Kiên Giang	4.000	6.30	2012
	Total			256.40	
II	**Plants currently installing waste-heat power generation (WHR) systems**				
1	Nghi Sơn 1	Thanh Hóa	6.000	18.00	2026
2	Nghi Sơn 2	Thanh Hóa	6.000		
3	Đồng Lâm	TT Huế	5.000	7.00	2026
4	INSEE 2	Kiên Giang	5.000	7.00	2027
5	Vicem (VC) Hoàng Mai	Nghệ An	4.000	6.00	2025
6	VC Hoàng Thạch 2	Hải Dương	3.300	10.00	2025
7	VC Hoàng Thạch 3	Hải Dương	3.300		
8	VC Bình Phước	Bình Phước	6.000	8.00	2025
9	VC Hải Phòng	Hải Phòng	4.000	6.00	2026
10	VC Tam Điệp	Ninh Bình	4.000	6.00	2025
11	VC Bỉm Sơn 2	Thanh Hóa	4.000	12.00	2026
12	VC Bỉm Sơn 3	Thanh Hóa	5.500		
13	VC Hạ Long	Quảng Ninh	4.000	6.00	2027
14	Liên Khê	Hải Phòng	4.000	6.50	2025
15	Trung Sơn	Hoà Bình	2.500	4.00	2025
16	Duyên Hà 1	Ninh Bình	2.500	10.00	2026
17	Duyên Hà 2	Ninh Bình	5.000		
18	Hoàng Long 2	Hoà Bình	6.000	8.00	2025
19	Xuân Sơn	Hoà Bình	6.000	8.00	2027
	Total			**123.50**	

Table A.3 Cement plants using alternative fuels in Vietnam

(Source: adapted VNCA Oct. 2025)

STT	Plant name	Waste use status	Notes
1	Song Thao cement plant	Uses industrial waste	25% substitution; fed into the calciner
2	But Son cement plant	Uses industrial waste	In 2024: about 40%; fed into the calciner
3	Tam Diep cement plant	Started using	Negligible amount
4	Lam Thach cement plant	Uses industrial waste	In 2024: 30% coal replacement
5	Yen Bai cement plant	Currently using	In 2024: about 30%
6	Song Gianh cement plant (SCG)	Yes	Jan 2024: 16%
7	Quang Phuc cement plant (SCG)	Yes	About 13%
8	Tan Thang cement plant	Yes	Reached 32% when used, but not consistently
9	Insee cement plant	Uses industrial waste	About 40%
10	Ha Tien cement plant	Uses industrial waste	About 20%
11	Tay Ninh cement plant	Uses industrial waste	Negligible
12	Binh Phuoc cement plant	Uses industrial waste	Small amount

Table A.4 Planned Use of Alternative Raw Materials at Selected Cement Plants to 2030

(Source: adapted from (Tâm NT 2023))

No.	Plant Name	Capacity (t clinker/day)	2025 – Alternative Materials (%)			2030 – Alternative Materials (%)		
			Blast-furnace slag	Fly ash	Bottom ash	Blast-furnace slag	Fly ash	Bottom ash
1	Chinfon Cement Company	10,000	12.0	8.0		12.0	8.0	
2	Binh Phuoc Cement Plant	5,500		15.0	10.0		15.0	10.0
3	Tay Ninh Cement Plant	3,986		20			30	
4	Dong Lam Cement JSC	5,000	10.0			15.0	10.0	
5	Vicem Hoang Mai Cement JSC	4,484	7.0	7.0	7.0	7.0	7.0	7.0
6	Ha Tien 1 Cement JSC – Kien Luong Plant	3,000	5.0	15.0		5.0	25.0	
7	Lam Thach Cement Plant – Line 1	1,628		8-12				
9	Thanh Cong III Building Materials JSC	1,350	2.0			2.0		
10	Thanh Thang Cement Group	19,800	10.0	15.0		15.0	15.0	
11	Vissai Ninh Binh Cement JSC		14.0	10.0				
12	Cam Pha Cement JSC	6,000	4	12		4	12	

No.	Plant Name	Capacity (t clinker/day)	2025 – Alternative Materials (%)			2030 – Alternative Materials (%)		
			Blast-furnace slag	Fly ash	Bottom ash	Blast-furnace slag	Fly ash	Bottom ash
13	Cong Thanh Cement JSC	12,500	12	6		15	10	

Table A.5 Planned Use of Alternative Fuels at Selected Cement Plants to 2030

No.	Plant Name	Capacity (t clinker/ day)	2025, %						2030, %					
			Coal	Industrial Waste	Biomass	Waste oil	Waste tyre	Municipal waste	Coal	Municipal waste	Industrial Waste	Biomass	Waste tyre	Waste oil
1	Chinfon Cement Company			15										
2	Binh Phuoc Cement Plant	5,500	65	20	15				60		20	15	15	5
3	Tay Ninh Cement Plant	3,986	85	15					70		30			
4	Dong Lam Cement JSC	5,000	100						80		20			
5	Vicem Hoang Mai Cement JSC	4,484	70	30					70		30			
6	Ha Tien 1 Cement JSC – Kien Luong Plant	3,000		25					25					
7	Lam Thach Cement Plant – Line DC1	1,628	70-85	25-35										

No.	Plant Name	Capacity (t clinker/ day)	2025, %						2030, %					
			Coal	Industrial Waste	Bio-mass	Waste oil	Waste tyre	Municipal waste	Coal	Municipal waste	Industrial Waste	Bio-mass	Waste tyre	Waste oil
8	Thanh Thang Cement Group	19,800	89		5	1		5	79	10		10	10	1
9	Cam Pha Cement JSC	6,000	70	30					70		30			
10	Cong Thanh Cement JSC	12,500	96	4					96		4			
11	Xuan Thanh Cement JSC	27,500	85	10					70	5	20		5	
12	Quang Son Cement Co. Ltd		70	13	5	2			58	10	20	5	5	2

Annex 2: Definition of TRL (Technology Readiness Level)

The Technology Readiness Level (TRL) is evaluated based on the applicability of the technology at full industrial scale in cement plants.(European Cement Research Academy 2022)

TRL	Description
TRL 1	Basic principles observed
TRL 2	Technology concept formulated
TRL 3	Experimental proof of concept
TRL 4	Technology validated in lab
TRL 5	technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7	system prototype demonstration in operational environment
TRL 8	System complete and qualified
TRL 9	Actual system proven in an operational environment (competitive manufacturing in the case of key enabling technologies; or in space)