Transforming industrial waste into global green construction through scaling green cement and cement-free solutions

Reddal – Industrial waste in green construction report

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REDDAL

For improved global commercialization, green cement and cement-free materials' providers need to trade waste sidestreams, enhance data sharing, and increase product awareness

Executive summary

Construction's carbon footprint and contribution of cement production

- The buildings and construction sector accounts for ~37% of global CO^2 emissions
- Cement production is responsible for ~7-8% of global CO^2 emissions

Green cement blends and cement-free solutions

- Established green cement blends: Fly-ash and slag-based cement
- Emerging green cement blends: LC3, blended with natural pozzolans
- Cement-free materials (geopolymer)

State incentives and accelerating adoption of green materials

- US and Canada enacted regulations incentivizing low-carbon materials
- Asian governments introduced green construction materials' procurement laws and SCMs-related standards

Key use cases of green cement and cement-free materials

- Infrastructure: Precast applications, pavements, load-bearing structures
- Residential and commercial buildings
- Specialized applications requiring temperature and chemical resistance

Commercialization challenges of green cement and cement-free materials

Industrial waste sidestreams are likely facing scarcity, threatening commercial scaling, so for instance many waste streams (such as, fly ash) are already utilized in other sectors (for instance in road construction), creating competition; besides, mining and metal industries generate ~500 million tons of unused slag annually – insufficient for scaling green cement production

Construction players are still lagging in terms of digitalization and data sharing, whereby data silos and inconsistent protocols prevent efficient collaboration and only 35% of firms share data willingly, with larger companies more likely to do so

Sustainable cement-free materials are not yet widely known or adopted with construction companies prioritizing proven materials to avoid perceived risks, even when alternatives offer environmental benefits

Solutions for better commercialization of green cement and cement-free materials

Trading waste sidestreams by expanding digital ecosystems into marketplaces for side-stream trading could address raw material volatility, as well as establishing regional hubs for side-stream collection, processing, and distribution of alternative raw materials such as vanadium, phosphate, and titanium

Enhancing data sharing to overcome data sparsity by prioritizing the development of comprehensive, standardized data repositories specifically for cement alternatives (geopolymer formulations, processing parameters, and performance characteristics)

Increasing product awareness of green materials though demonstration projects that would serve as powerful tools for building construction industry confidence and providing real-world performance data

Source: Company websites, PBCToday (2024), World Cement (2025), Reddal analysis.

Asian and North American governments have been introducing green construction procurement incentives in the form of regulations and emission accounting standards

Overview of key governmental incentives for green construction in North America and Asia Pacific

Regulatory incentives for green construction in Asia Pacific and North America

Asian governments have introduced green construction materials' procurement laws, but also some states have specifically targeted cement and concrete industry with SCMs-related standards

Public green construction materials' procurement regulations:
- In China, the government enacted the revised General Rules for Grading and Certification of Green Construction Materials (effective January 1st, 2024)
- In India, the government has implemented green building criteria for public housing projects; for example, the Lucknow Development Authority mandatorily adopted Green Building Criteria for all its residential and commercial buildings focusing on among other things the use of low-carbon materials
- Thailand has implemented policies supporting low-carbon public procurement, including the use of eco-labeling and specific product categories
- South Korea's government has introduced the Zero Energy Building (ZEB) Certification mandate

Targeted cement and SCMs-related standards and rules:
- Indian IS 456 standard provides guidelines for replacing cement with SCMs, specifically mentioning ground granulated blast-furnace slag and fly ash
- Singapore has adopted a modified version of EN 206, which includes provisions for using SCMs in concrete
- Indonesian SNI 03-4433 standard allows for flexible use of SCMs in concrete mix designs
- In Indonesia, Industry Minister regulation of 2012 requires cement producers to decarbonize their products by 2–3 percent per ton every four years

Both US and Canada have implemented federal regulations incentivizing low-carbon materials, but also individual states can have additional tighter rules, such as emissions accounting requirements

Federal legislations:
- The U.S. Inflation Reduction Act (IRA) includes 2.15BUSD for the General Services Administration and 2BUSD for the Federal Highway Administration to spend on materials with substantially lower embodied greenhouse gas emissions
- The Canadian federal government introduced a Carbon Capture, Utilization and Storage (CCUS) tax credit to support the cement industry's decarbonization

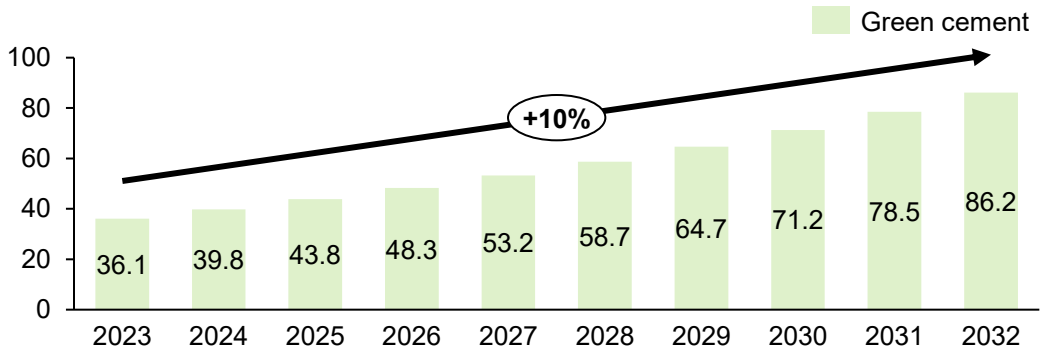
State legislations:
- California's climate legislation requires the cement industry to reach net-zero carbon by 2045
- New York State has implemented rules regulating CO2 limits on concrete used in state-funded public construction projects, so starting 2025, environmental product declarations must be submitted for all concrete mixes
- New Jersey's Bill S-287 of 2023 provides tax credits of up to 3% to concrete producers that supply low-carbon concrete for state-funded construction projects
- Maryland has introduced legislation (HB261) that would require the Department of General Services to establish maximum acceptable global warming potential for concrete or cement mixture materials used in eligible public construction projects by January 1st, 2026

Source: Area Development (2024), WRI (2023), State Capital Lobbyist (2023), Global Cement (2023), Global Efficiency Intelligence, JCI (2015), Enviliance Asia (2024), UNEP (2023), US Dept. of Commerce, Antara News (2024).

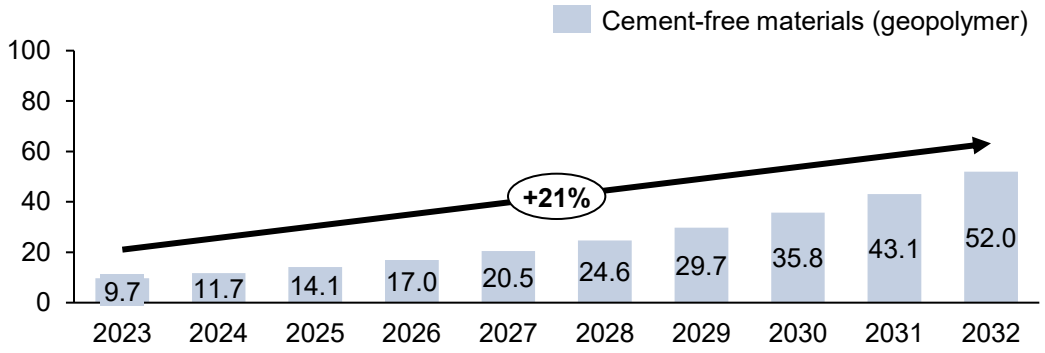
Green cement market will grow at 10% CAGR to reach 86BUSD by 2032, but cement free materials will show staggering 21% growth in the same period

Overview of cement market

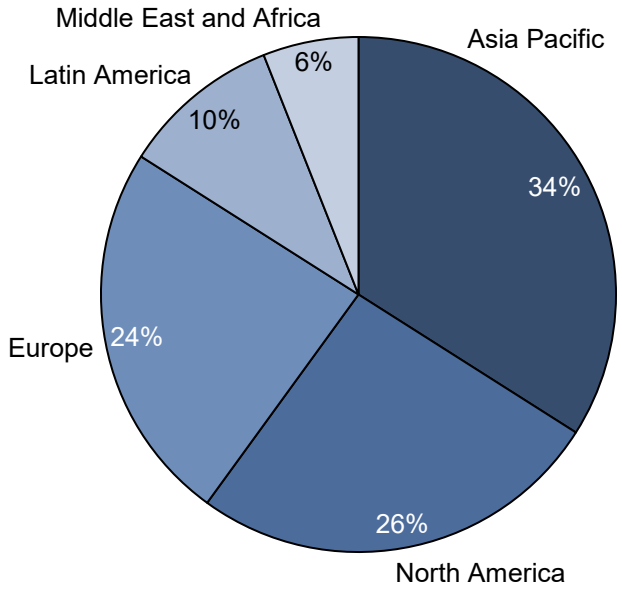
Green cement market size, 2023-2032, BUSD



Cement-free materials (geopolymer) market size, 2023-2032, BUSD



Green cement market size by region, 2023



Selected key industry trends

Green cement and decarbonization

- Major industry players are setting ambitious targets to reduce carbon emissions; for instance, Holcim has pledged to achieve net-zero CO_2 emissions by 2030
- Green cement products are advancing through the development of low-carbon cement alternatives
- Cement producers are increasingly adopting alternative fuels and moving away from coal

Technological advancements

- Cement producers are increasingly integrating automation technologies, robotics, and predictive maintenance; for instance, both Lafarge and Holcim are adopting “Plants of Tomorrow” programs

Regulatory and policy developments

- Programs like the U.S. Federal Buy Clean Initiative (2021) and California's Cement Decarbonization Legislation (2021) are promoting the use of lower-carbon materials
- In Asia Pacific, several regulations have been introduced, such as Singapore's Green Mark Scheme (2005), Australia’s Environmentally Sustainable Procurement Policy (2024), China’s Action Plan for Energy Saving and Carbon Reduction in the Cement Industry (2022), and others

Source: Precedence Research, Allied Market Research 1 2, The Times, Holcim 1, 2, Lafarge, Time, BCA, OneClickLCA (2024), China Climate Cooperation (2024).

Several types of industrial waste are used to produce SCMs that allow to make low-carbon cement blends containing less of clinker

Overview of cement production

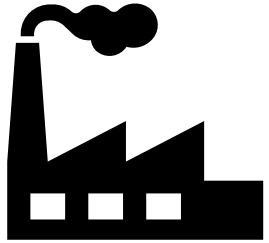
Non-green cement blends
Established green cement blends
Emerging green blends

Clinker
SCM
Limestone
Gypsum
Chemicals
Aggregates

Process flow chart and end products

Raw materials

- Limestone, clay, and marl
- **Additional components**
  - Silica sand
  - Iron ore
- **Supplementary Cementitious Materials (SCMs)**
  - Fly ash waste
  - Slag waste
  - Demolition waste



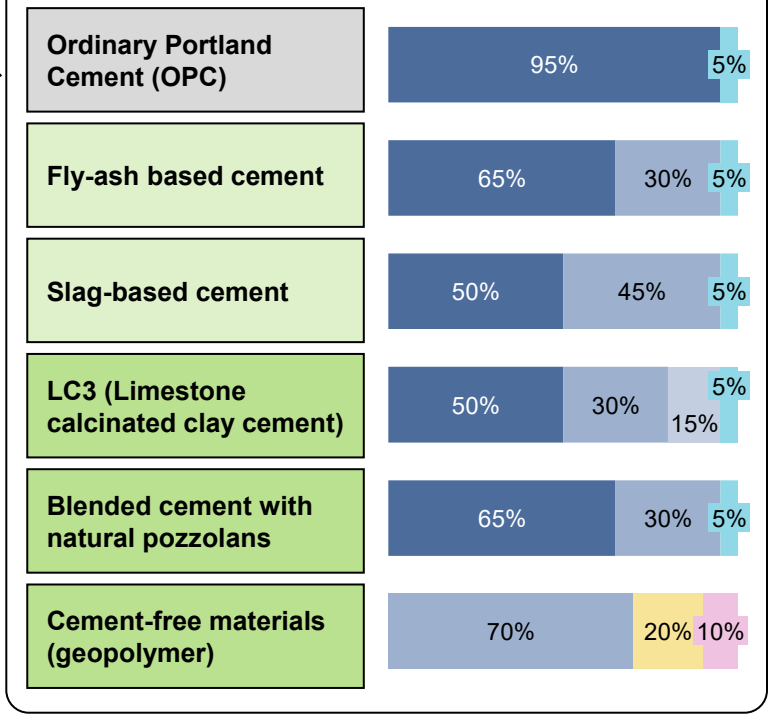
Processing plant

Crushing and grinding the raw materials → Blending the materials in the correct proportions → Burning the prepared mix in a kiln → Grinding the clinker with some gypsum

Gypsum and other additives

Up to 85% of emissions in cement production come from traditional clinker that can be partially replaced by SCMs.

End products and their compositions (in %)



Source: US Department of Energy (2023), McKinsey (2024), Brittanica,Heidelberg Materials, Geopolymer 1, 2.

Fly-ash, slag, and natural pozzolans'-based blends show high performance; however, geopolymer blends lead in terms of performance and carbon reduction potential

Overview of green cement blends' potential use cases

Established green cement blends
Emerging green blends

Green cement blends	Availability considerations	Performance characteristics	Key applications	Selected key suppliers
Fly-ash based cement	• Available near coal plants	• Enhances workability, durability, and sulfate resistance	• Roads and pavements • Marine and hydraulic structures • Mass concrete works (dams)	UltraTech Cement – The Engineer's Choice; LafargeHolcim
Slag-based cement	• Available near steel plants utilizing the Blast Furnace (BF) or Basic Oxygen Furnace (BOF)	• Excellent durability and resistance to chloride and sulfate attack	• Coastal and marine structures • Underground structures (tunnels, basements) • Bridges and roads	Heidelberg Materials; JSW Cement – The Leaders' Choice
LC3 (Limestone calcinated clay cement)	• Clay is a typical raw material for a cement plant; however, at a smaller share compared to limestone	• Comparable performance to OPC	• General construction (residential, infrastructure) • Precast concrete elements	LafargeHolcim
Blended cement with natural pozzolans	• Available in dry or volcanic regions	• Enhances long-term strength and resistance to chemical attack	• Marine and sulfate-rich environments • Mass concreting and hydraulic structures • Restoration of heritage structures	CEMEX
Cement-free materials (geopolymer)	• Requires not only the availability of SCMs, but also availability of activation chemicals	• Contains no clinker, offering very low carbon emissions • Excellent chemical resistance and high durability	• Infrastructure exposed to aggressive chemicals (wastewater treatment plants) • Fire-resistant concrete applications • Precast parts and high-performance cases	BETOLAR; oxara; slb; CarbiCrete; Cemfree; Rieder; WAGNERS

Source: US Department of Energy, Polymers 1, 2, Eco Material Technology, Kirkland Mining, JACS (2024), Materials (2023), ACEEE, ENR, LC3, SCA, Pro Road Global.

Most of the cement-free materials' providers operate in Europe and North America due to sustainability requirements; with some attempting market entry into Asia and Africa

Geographical distribution of cement-free materials' providers

Providers	Products	Geographic presence
BETOLAR	• Geoprime®	
WAGNERS	• Earth Friendly Concrete®	
CarbiCrete	• Cement-free CMUs (Concrete Masonry Units)	
C-Crete TECHNOLOGIES	• Cement-free concrete	
Cemfree	• Cemfree Masonry Mortar	
CCP	• Greenbloc Technology	
oxara	• Oxacrete®, Oxabrick®	
mace	• Prefabricated building 'cassettes' from cement-free concrete	

Implications

North America, Oceania, and Europe:

- Cement-free materials' providers should establish a solid ground in Europe, Oceania, and North American regions due to stricter government regulations and standards on sustainable construction materials' procurement

Asia and Africa:

- Successful GTM-cases to Asia and Africa of European players show that market entry should be done through local partnerships and integrated solutions approach, so for instance:
  - In the West and South of India, Betolar has established strategic tie-ups to produce low-carbon, cement-free precast concrete products, for example with Vyara Tiles
  - In India, Betolar provides fully integrated end-to-end solutions, which include designing recipes, dosing of Geoprime, and post-production technical support

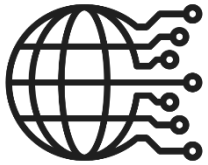
Source: Company websites, Inderes.

To effectively commercialize cement-free solutions globally the focus is to be put on trading waste sidestreams, enhancing data sharing, and increasing product awareness

Cement-free materials' commercialization challenges and potential solutions

Industrial waste sidestreams are likely facing scarcity, threatening commercial scaling

- Expanding digital ecosystems (such as Betolar's SidePrime platform) into marketplaces for side-stream trading could address raw material volatility
- Establishing regional hubs for side-stream collection, processing, and distribution would address scarcity challenges; for instance, by forming partnerships with mining companies that can provide alternative raw materials for geopolymer production, such as vanadium, phosphate, and titanium



Construction players are still lagging in terms of digitalization and data sharing

- To overcome data sparsity, the industry must prioritize the development of comprehensive, standardized data repositories specifically for cement alternatives (geopolymer formulations, processing parameters, and performance characteristics)
- Industry associations, academic institutions, and government agencies should collaborate to establish data standards that facilitate interoperability and knowledge sharing while respecting intellectual property concerns

Sustainable cement-free materials are not yet widely known or adopted

- Education and awareness programs play a crucial role in accelerating market adoption, whereby the construction industry's unfamiliarity with geopolymer technology contributes to resistance to change
- Demonstration projects would serve as powerful tools for building industry confidence and providing real-world performance data, whereby high-profile demonstration projects that showcase geopolymer concrete in various applications would provide tangible evidence of its viability and performance capabilities

Source: Company websites, Reddal analysis.

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