Green cement

Low-carbon alternative materials for cement production

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Increasing clinker substitution is a key strategy in the cement industry's roadmap to reduce its carbon footprint.

Despite other emission reduction strategies, using alternative materials remains one of the most practical options in the short term.

WHAT ARE CLINKER SUBSTITUTES?

Mineral additions used as a partial replacement of Portland cement, also known in part as Supplementary Cementitious Materials (SCMs).

An SCM is defined by ASTM International *as "an inorganic material that contributes to the properties of a cementitious mixture through hydraulic or pozzolanic activity, or both".*

Although the definition is focused on technical advantages, cost and **environmental impacts** have shifted the perspective on their use.

Most of the material replacements currently in use are the **conventional** ones (such as blast furnace slag and fly ash). However, there are concerns about the **availability** of these materials.

Companies are exploring **innovative combinations** of materials. New startups are also testing cutting-edge material technologies, but these are still at the R&D and pilot levels.

Among the new materials being used, the most promising include **limestone**, **activated/ calcined clay**. Regional materials may also be considered depending on the location, such as rice husk ash.

New materials can lead to a **reduction** of **6% to 13% in total emissions.** A case study showed that reducing clinker content by 8% cut emissions by **9,000 tons** and saved **~86K USD annually** for a plant in Brazil.

Lowering the clinker factor can lead to a slight **reduction in performance**. Performance-enhancing **additives** are available to mitigate these effects.

Further development of **testing protocols** and standards is also needed to ensure these new formulations meet safety and performance **requirements**.

This report highlights **9 companies developing low-carbon cement products**, to meet the market demand for low-CO_2 alternatives.

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Reducing CO_2 emissions in the cement industry

The cement industry ranks as the second-largest emitter of CO_2 among industrial sectors only behind the iron and steel industry.

The cement industry also produces the **most CO_2 emissions** per dollar of revenue.

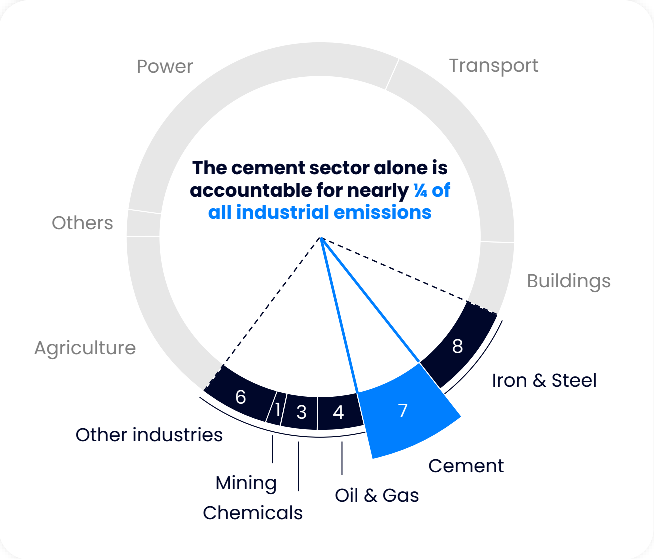


Figure. Share of global CO_2 emissions (both direct industrial processes and energy-related), % in 2017. Source: McKinsey (2020).

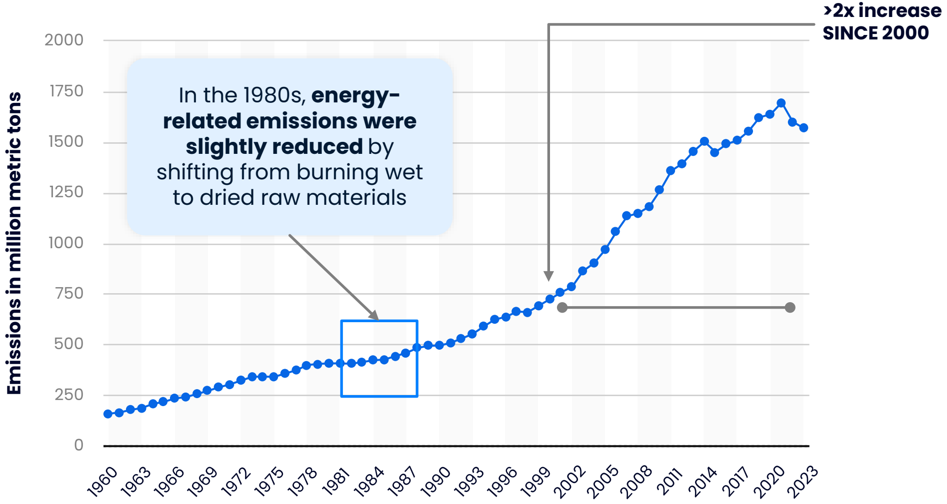


Figure. CO_2 emissions from the manufacture of cement worldwide. Source: Statista (2023).

Since the 1960s, emissions from cement production have increased substantially. Currently, the global production of cement exceeds 4 billion metric tons annually, which generates **around 1.7 billion metric tons of CO_2 per year**. If we compare this to the total CO_2 emissions by country, **only China**, **the United States**, and **India** produce more CO_2 than the entire combined cement industry.

Most of the CO_2 emissions in cement and concrete are related to clinker.

Cement is the key component in concrete, and clinker is the main element of Portland cement (OPC).

CO_2 emissions are **directly proportional** to the quantity of clinker used in cement production:

0.83 tons of CO_2

emitted per ton of clinker produced

0.54 tons of CO_2

emitted per ton of OPC produced

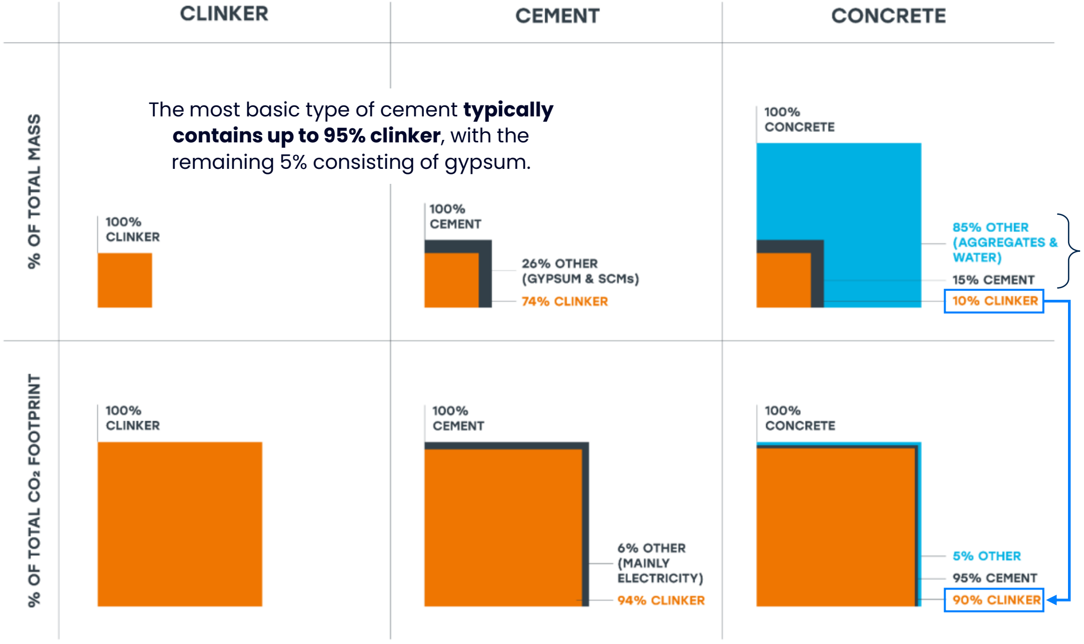
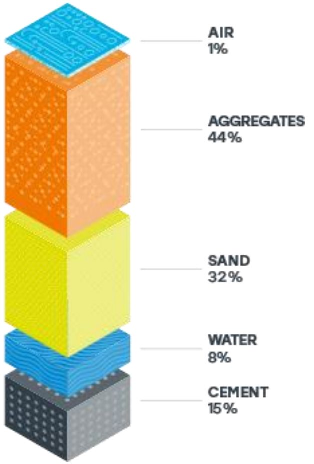


Figure. Clinker production is the primary source of emissions in cement and concrete. Source: Ecocem (2022).



While clinker represents only around 10% of the total mass of concrete, it is **responsible for over 90% of the carbon footprint of concrete**.

Materials and processes contribute to 60% of the emissions…

Calcination is the most carbon-intensive stage.

In Portland-based cement production, raw materials — a mixture of **clay**, **limestone and sand** — undergo high-temperature heating in a kiln through a fuel-intensive process. This process creates **clinker**, small stone-like material, which is then finely ground into powder and mixed with additional ingredients to create cement and concrete.

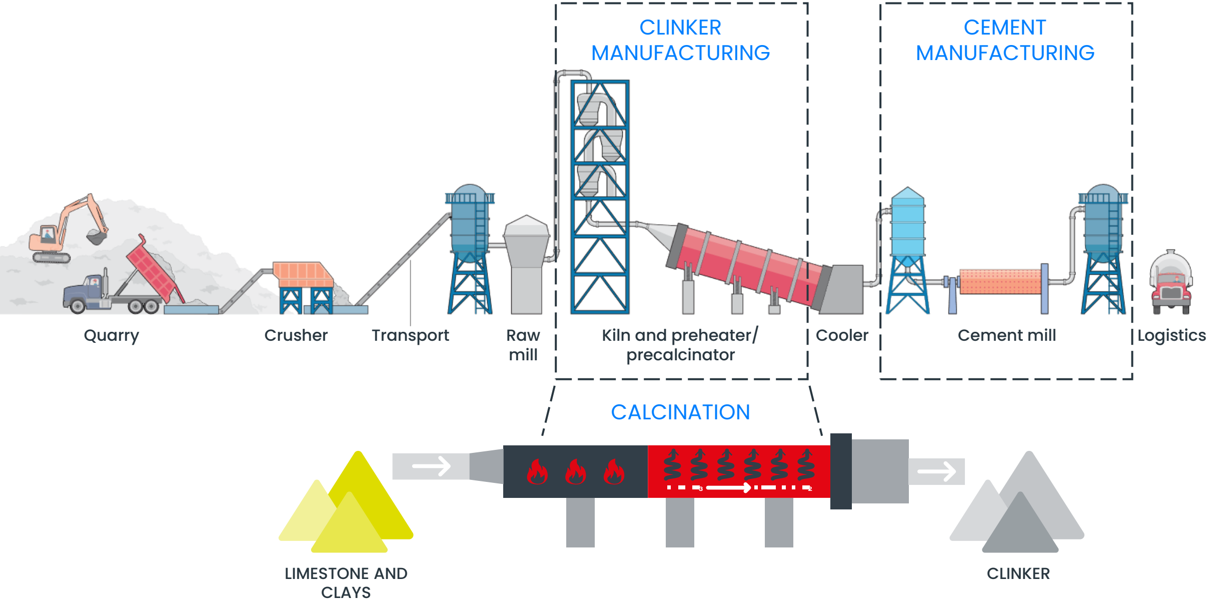


Figure. Cement manufacturing. Sources: McKinsey (2020). Ecocem (2022).

$$CaCO_3 \rightarrow CO_2 + CaO$$

Calcium Carbonate (limestone) — Calcium Oxide

The carbon dioxide release primarily originates from the **decarbonization reaction of limestone**, where calcium carbonate decomposes into calcium oxide and CO_2 at temperatures above 550°C.

… and the remaining 40% is due to the energy required.

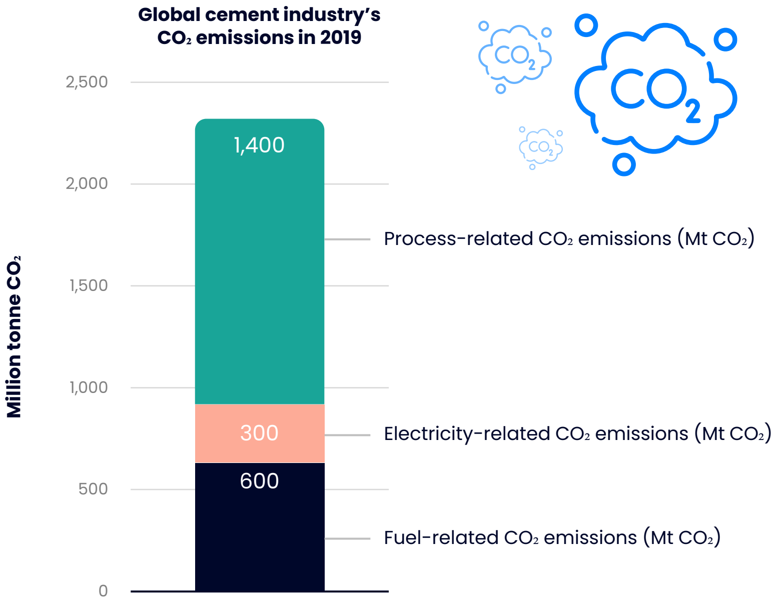


Figure. Global cement industry emissions in 2019.
Source: Global Efficiency Intelligence (2021).

60%

Process-related
(mainly from the chemical reaction during the calcination process)

40%

Energy-related, including fuel (direct emissions) and electricity use (indirect emissions)

For a substantial decrease in emissions, it's essential to focus on the process, which includes the **material composition**.

Over the past 30 years, while CO_2 emissions have increased overall, emissions per ton of cement have been reduced by 23%.

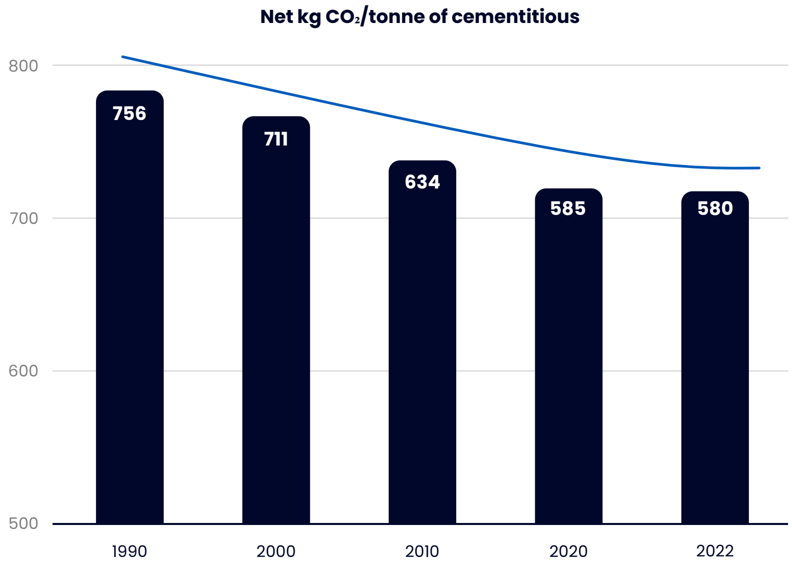


Figure. Reduction in CO_2 emissions per ton of cementitious material.
Source: [Global Cement and Concrete Association (2024)].

BREAKTHROUGH ENERGY VENTURES

[BEV], founded by Bill Gates, is a major supporter of low-carbon cement technologies, strategically investing in many emerging startups such as [Brimstone], [Terra CO2], [CarbonCure], [Ecocem], and [Solidia]. This implies strong confidence in the sector's potential for impact and profitability.

Changes in processes and materials are already happening.

Clinker substitutes to reduce the clinker factor

Several approaches have been investigated to reduce the emissions in this industry, considering both alternative materials and energy sources.

Clinker Substitutes in Portland-based cements*

Reducing the cement/clinker ratio, also called clinker factor — percentage of clinker relative to other non-clinker components — for example by replacing clinker with Supplementary Cementitious Materials (SCMs), in Ordinary Portland Cement (OPC).

Alternative Fuels and Energy Efficiency

Using less carbon-intensive fuels, such as waste and biomass, or electrifying the clinker production process can reduce emissions. Additionally, advanced analytics and self-learning models enhance energy efficiency.

>> Mainly focused in the **kiln** process which constitute around **90% of the total energy consumption**. The cement sector is the third-largest industrial energy consumer globally.

*main focus of this report

Less drastic approaches remain **the most realistic options** in the short term.

Innovative Technologies

Deploying emerging and innovative technologies such as carbon capture, use, and storage (CCUS), carbon-cured concrete, 3D printing, etc.

Alternative Binding Technologies

Development of new binders as alternatives to clinker-based cements, such as Belite-rich clinkers, Calcium Sulfoaluminate and Belite-Ye’elimite-Ferrite cements, etc.

Alternative Building Materials

Other approaches including cross-laminated timber, lean design, prefabricated/modular construction, and building information modeling.

Materials-related Energy-related

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Experts anticipate that Portland cement clinker-based cement will remain dominant in the next 20-30 years.

A multi-stakeholder working group initiated by the United Nations Environment Program Sustainable Building and Climate Initiative (UNEP-SBCI) believe that Portland-based cement approaches will likely take the lead over the next decades, mainly because of:

Economies of **scale** of production

Levels of process **optimization**

Availability of raw materials

Market confidence in long-term **durability** based on extensive and prolonged use

When looking into viable solutions for a low-CO_2 cement-based materials industry, the following **approaches** could significantly reduce global CO_2 emissions:

1. Increasing the utilization of low-CO_2 additives or supplementary cementitious materials (SCMs) to **partially substitute Portland cement clinker**.
2. Enhancing the **efficiency of OPC clinker** use in mortars and concretes.

SCMs are one of the most popular and effective ways to reduce both costs and CO_2 emissions in cement production.

Alternative materials have been applied for many years now, but the rate of clinker substitution has stabilized over the past decade.

"We need to transition to new materials, but the challenge lies in determining when and how to introduce them within a conservative industry.

Andy Zahedi, PhD
Technical Manager, MCON Products

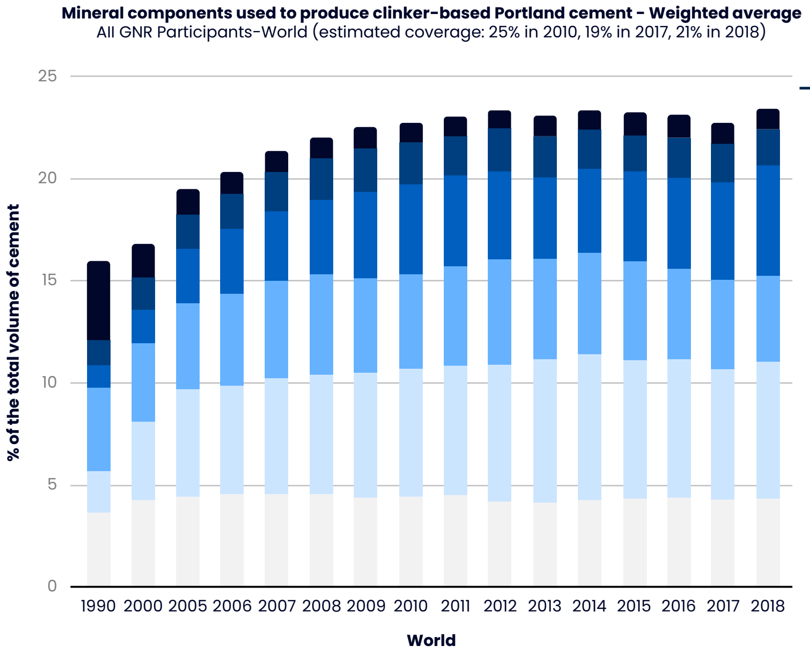


Figure. Evolution of clinker substitutes from 1990 to 2018 for companies in the Getting the Numbers Right (GNR) study by Cement Sustainability Initiative (CSI).
Sources: United Nations Environment Programme (2017), Scrivener (2021).

The overall level of substitution remains **below 25%**.

Note: In traditional cement production, clinker serves as the primary binding agent, with **limestone** as one of its main components. However, limestone can also qualify as an substitute when added separately to the cement mixture. In this role, it is not calcined, which means it does not produce CO_2.

There has been little progress in increasing this level due to the **shortage of most conventional substitute materials**.

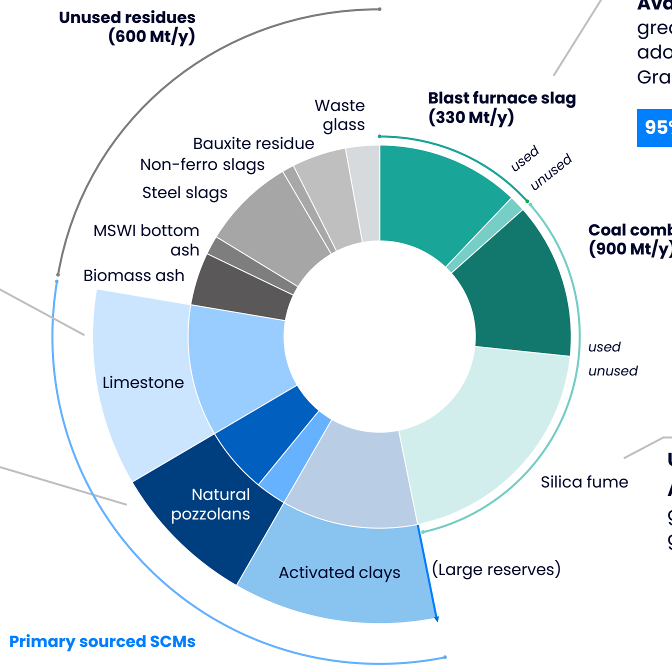
It's evident that **new sources** and beneficiation technologies will need to be implemented.

Availability is the main concern. Most conventional materials — slag and fly ash — meet only about 15% of the cement demand.

Current use is mainly limited to limestone, blast furnace slag, and coal fly ash. Limestone and activated clays are two materials available in viable quantities.

Volume Estimated: 0.3 billion t/y *(in use within the cement industry + potentially available)*
Availability: Abundant worldwide and easily accessible.

Volume Estimated: 0.075 billion t/y *(in use within the cement industry + potentially available)*
Availability: Localized reserves, reactivity varies, and workability challenges (angular particles and internal porosity can increase water demand).



Usage as SCMs: 0.33 billion t/y
Availability: Expected to decrease as a result of greater scrap steel availability for recycling and the adoption of more efficient steel-making technologies. Granulated BFS involves capital investment.

95% of this resource is already used as SCMs.

Usage as SCMs: 0.9 billion t/y
Availability: Availability varies regionally and coal fired electricity production is being phased out. Quality is variable (carbon content, reactivity, etc.).

Usage as SCMs: Less than 0.002 billion t/y
Availability: Increasing total volume available & demand, geographical shift in production, logistics bottlenecks can give local scarcity, quality issues on the increase.

Figure. Supplementary Cementitious Materials: currently used sources and potentially available. Source: Snellings (2016).

Note: Non-ferrous slags include materials such as copper slag and others. MSWI refers to Municipal Solid Waste Incineration.

… and are by-products from other industries, also leading to significant variability; a challenge from a standards perspective.

		Blast Furnace Slag	Natural Pozzolans	Limestone	Silica Fume	Fly Ash
Sources		By-product of the production of iron	Rocks of volcanic origin or sedimentary rocks [*can also include biomass ashes such as rice husk ash (RHA)*]	Sedimentary rock	By-product of silicon or ferrosilicon production in electric arc furnaces	By-product of coal combustion in power stations
Chemistry		Ca-Si-Al	Si-Al	Ca	Si	Si-Al and Si-Ca-Al
Replacement Level (% by mass)	**Europe** (EN 197-1)	Up to 95%	Up to 55%	Up to 35%	Up to 55%	Up to 55%
	USA (ASTM C595)	Up to 95%	Up to 40%	Up to 15%	*May be used as part of Ternary Blended cements*	
	Brazil (ABNT NBR 16697)	Up to 75%	Up to 50%	Up to 50% (at least 75% $CaCO_3$)	N/A	N/A
Average Market Price (2015)		USD 15-20 /ton	Vary USD 400-500 /ton (for metakaolin)	USD 20 to 65/ton	USD 400-500 /ton (but highest profit margin among other materials)	USD 40 /ton

Table. Properties standards and market prices of common cementitious by-products

Also, most standards address only the commonly used sources. A broader adoption of low-Portland-clinker cement will introduce new types of cement to the market and standardized specifications.

Blast Furnace Slag | Natural Pozzolans | Limestone | Silica Fume | Coal Fly Ash

Of the conventional materials, limestone and silica fume have been considered the most relevant options in many regions.

ASIA

- | High
- | High (including RHA)
- | High
- | High — 193 kilotons/year (2020)
- | High — 411.7 million tons/year (2023)

CENTRAL AND SOUTH AMERICA

- | Medium
- | High (including biomass ashes)
- | Low
- | High — 92.39 kilotons/year (2020)
- | Low — 1.3 million tons/ year (2023)

NORTH AMERICA

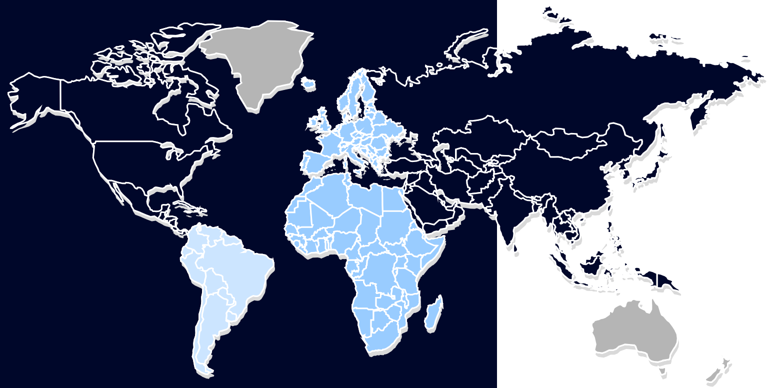
- | High
- | Medium
- | High
- | High — 88.12 kilotons/year (2020)
- | High — 16.6 million tons/year (2023)

AFRICA

- | Only South Africa — copper slags could be alternative
- | High (including RHA, bagasse, cassava, etc.…)
- | High — Dolomitic in West Africa can cause challenges
- | High — 265.20 kilotons/year (2020)
- | Mainly South Africa — 2.9 million tons/year (2023)

EUROPE

- | High
- | Low
- | High
- | Special applications — 46 kilotons/year (2020)
- | High - 24.5 million tons/ year (2023)



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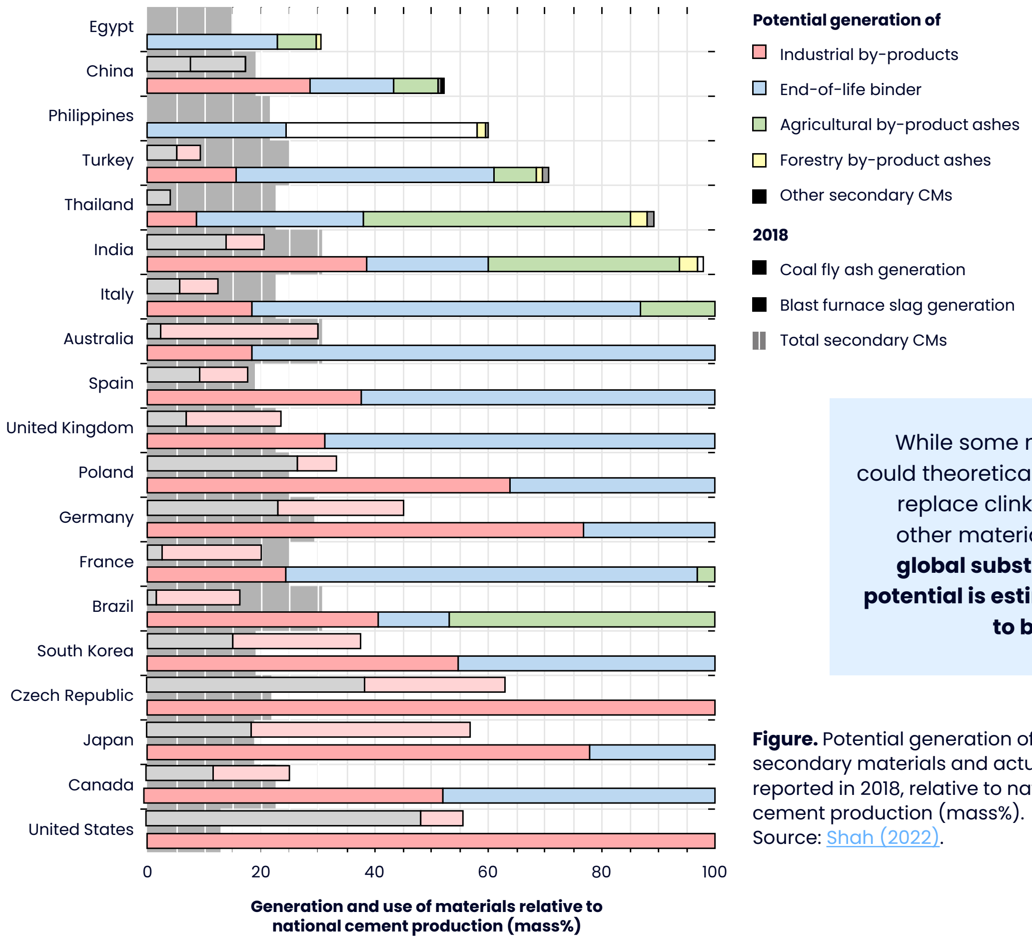
Countries can generate materials in quantities comparable to or exceeding their cement production.

The United States, Germany, and South Korea could generate **more industrial by-products and end-of-life binders cumulatively than their domestic cement production**. Typically, those are regions with substantial industrial activities.

In contrast, countries like China, the Philippines, and Egypt produce more cement than their potential for generating alternative materials, requiring imports. In some cases, this is due to limited industrial activities.

From a different perspective, specific countries can generate more of one type of material, like agricultural by-product ashes in Brazil.



While some nations could theoretically fully replace clinker with other materials, the **global substitution potential is estimated to be 86%.**

Figure. Potential generation of secondary materials and actual reported in 2018, relative to national cement production (mass%). Source: Shah (2022).

Given the need for new materials, a range of alternative sources is being investigated in academic research and industry.

Filler: Inert, serving as **nucleation sites**, accelerating the hydration and hardening. At the same time, they **fill pores** within the cement, contributing to a denser microstructure.

- Limestone ○
- Marble Powder ☗
- Concrete Powder ☗

Note: There are different compositions of Blast Furnace Slag and Fly Ash, and the extent of its pozzolanic reactivity can vary.

Non Pozzolanic: Active materials that exhibit **independent hydraulic properties**, meaning they can set and harden when mixed with water.

- Granulated Blast Furnace Slag ☗
- Calcareous Fly Ash ☗
- Burnt Oil Shale ☗

Factors such as **performance**, **environmental impact**, and **cost-benefit analysis** are still limiting the commercial use of many of these potential materials.

Pozzolanic: Active materials **not inherently hydraulic**, but when finely ground can react in the presence of water at ambient temperatures to form compounds with cementitious properties.

- Granulated Blast Furnace Slag ☗
- Siliceous Fly Ash ☗
- Silica Fume ☗
- Agroforestry Waste ☗ (including Rice Husk Ash)
- Natural Siliceous (pumice, tuff, diatomaceous earth, opaline rock, moler, and gaize) ○
- Clays ○ and clay-like materials ☗ (calcined clay, bentonite, metakaolin [from kaolin crude clays])
- Construction & Demolition Waste ☗ and Masonry Waste ☗
- Ornamental Stone Waste ☗
- Paper Sludge ☗
- Glass Powder ☗

○ Natural
(which require no processing other than grinding)

☗ Artificial/Engineered Product
(resulting from chemical or structural alterations to materials with initially only weak or no pozzolanicity)

Limestone, clays, and fly ash are the top 3 trends.

“Many materials need to be activated (e.g., through heating or even chemical processes) before they can be used effectively, further increasing the complexity of their adoption.

Andy Zahedi, PhD
Technical Manager, MCON Products

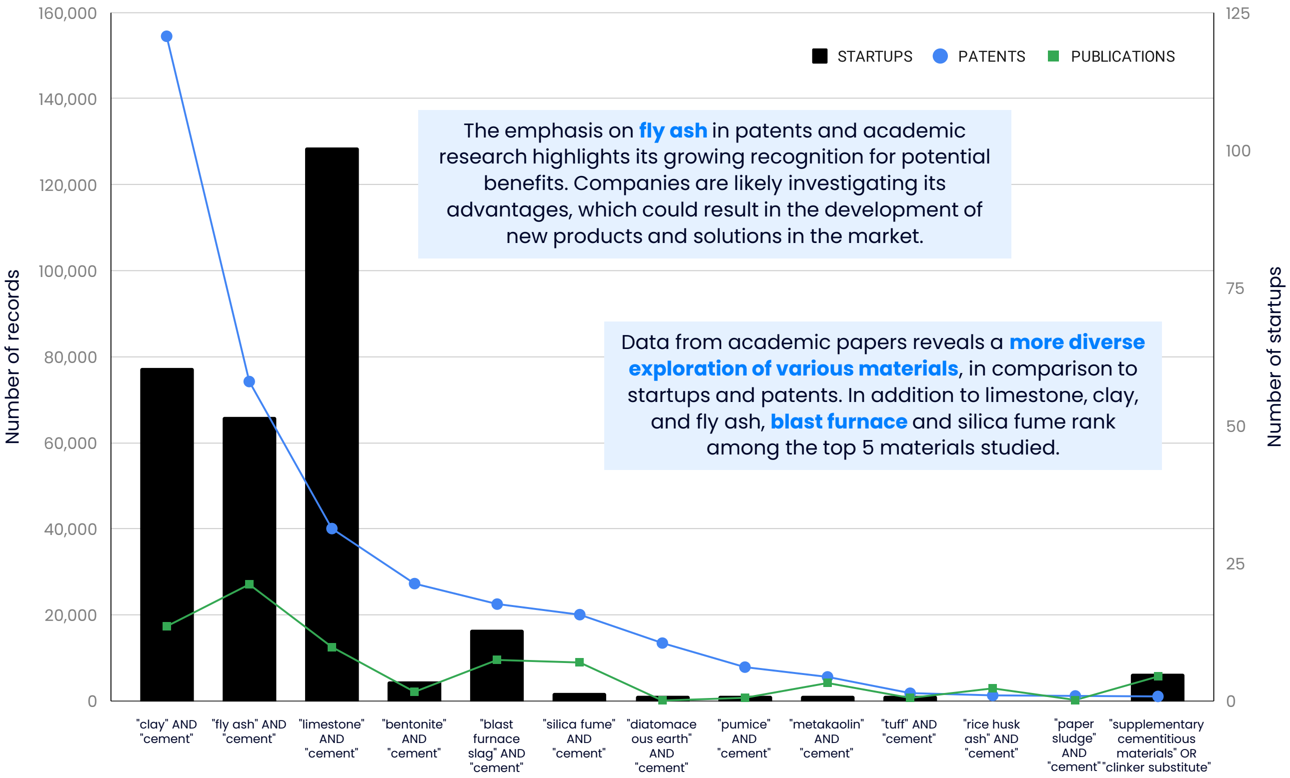


Figure. Trends in research patents and startups for supplementary cementitious materials. Numbers were determined based on keywords and represent an average across the sources available to PreScouter. For startups, data was gathered from Crunchbase and Pitchbook; for patents, from PatSnap and Lens; and for academic publications, from Lens.

Among the biomass or vegetable ashes, Rice Husk Ash (RHA) is the most studied one, being economically viable and known as the only renewable source of silica.

It's produced by burning Rice Husk. If properly processed, results in **85-94%** silica-rich **pozzolan**, with high chemical reactivity.

Similar to conventional materials, it also presents variability and production is often dispersed near agricultural areas.

Beneficiation is challenging due to potential formation of unreactive crystalline quartz and carbon contamination from incomplete combustion.

Other applications include exploration of agricultural wastes for fuel, soil amendment (mineral fertilizer) and landscaping; often more logistically convenient.

In general, environmental footprint, availability, and the ability to enhance concrete properties are key attributes that make a material an ideal candidate.

> Scalable, easily available, and cheap feedstocks are essential for any new product looking to bring more environmentally friendly, cost-competitive solutions to this market.
>
> Bill Yearsley, PhD
> CEO at Terra CO2

Environmental footprint

The material in use should have a lower environmental footprint than the original cement.

Ability to enhance concrete properties

It should be able to improve the engineering properties of concrete, specifically in terms of workability, strength, and durability.

Broad availability at a reasonable price

Costs can differ significantly based on factors like availability, regional demand, and production expenses.

Fly ash, derived from coal combustion, is typically the most cost-effective and widely available. This is particularly true in countries such as the USA, China, and India, which represent the largest consumers of coal for electricity generation, contributing to coal's 35.5% share of the global energy mix in 2023.

Many startups are also developing materials based on silicate-type feedstocks, which are among the most common rocks on the Earth's surface. These advancements are expected to make alternatives more affordable and widely available in future.

As we shift to cleaner energy sources and adopt new green methods, the supply of commonly used materials is expected to decrease, making it essential to **develop new materials**.

Potential performance issues and how to overcome those

Reducing the clinker factor may result in performance challenges, particularly in terms of early strength development.

One of the main drawbacks of lowering the clinker factor is that high blended cements may exhibit **slow or loss** of early-age **strength development** and **uncertainty** on the **long-term durability**, because clinker is responsible for the rapid hardening and strength gain in the initial stages of cement hydration. Replacing a significant portion of the clinker can slow down this process and lead to **reduced compressive strengths**, especially in the first few days after concrete placement.

For example, a 1% increase in SCM content can potentially lead to a decrease in 28-day mortar strength ranging from 0.2 to 0.8 MPa, depending on factors such as SCM type, cement fineness, grinding system, and clinker characteristics.

Alternative materials can be incorporated, but the ***mechanical requirements remain the same****.* *It's important to ensure that the performance remains consistent.*

Minimal variation and even increase in 91-day mortar strength with fly ash additions ranging from 5% to 15%.

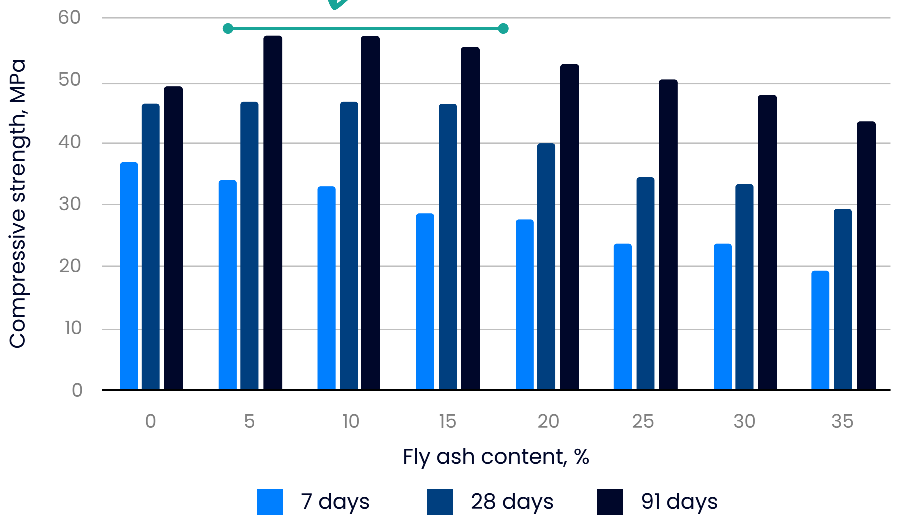


Figure. Decrease in compressive strength of a mortar at 7, 28, and 91 days, with increasing fly ash content. Source: Lam (2020).

Researchers have explored various strategies such as C-S-H seeding, combinations w/ synergistic effects, and fineness adjustment.

Using C-S-H seeding, which involves adding **small amounts of synthetic Calcium Silicate Hydrate (C-S-H)** to the mix, to accelerate the hydration process and enhance strength development.

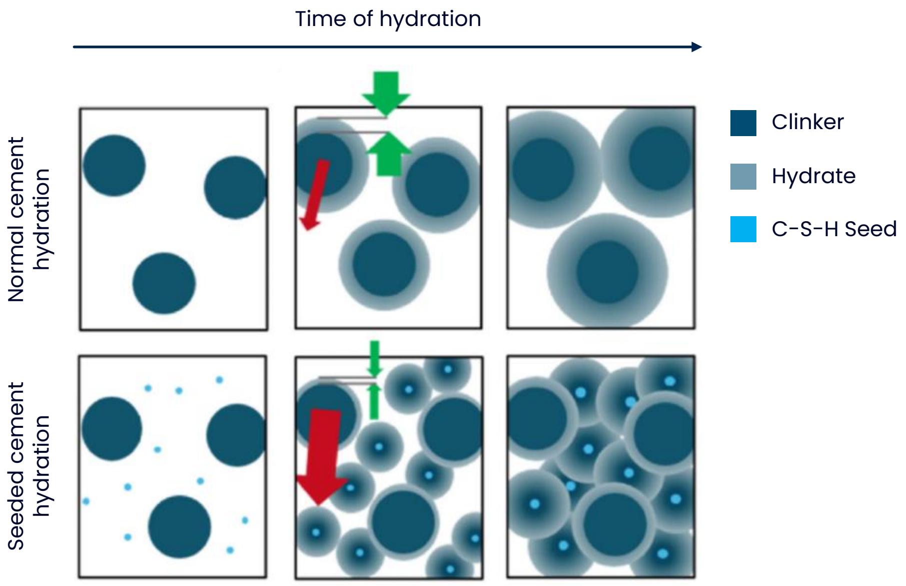


Figure. Schematic representation of the role of C-S-H nucleation seeding on the hydration of OPC. Source: John (2018).

Optimizing the **combination** of materials to enable a **synergistic effect** and achieve suitable early and late strength, for example with only 0.5 clinker content.

Adjusting the **fineness** of the cement components, as finer grinding can enhance **reactivity**.

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Ensuring workability also involves optimizing the formulation, particle size distribution, and potentially using additives.

Workability, in terms of rheology, is one significant challenge also connected to performance in various application scenarios. Flowability plays a vital role in the typical construction industry processes, including pumping, spreading, molding, and compacting cement-based materials.

When alternative materials are incorporated to Portland cement, it's essential to adjust the water content, also known as the water-to-binder ratio, representing the weight of water per weight of cementitious materials (in this case, Portland cement + alternative materials), since any **excess water** added solely for flow purposes does not participate in the reaction and instead **forms small water pockets**, leading to voids that may **compromise the strength and durability** of the final material.

To maintain the desired flowability, the particle size distributions of the cement can also be optimized and commercial superplasticizers, such as polycarboxylate ether (PCE), can be introduced with mixing water.

A linear correlation exists between the dosage level of commercial superplasticizers and the content of SCMs or additives
(e.g., 0.3-0.4 wt% for PCE in cements blended with calcined clay).

> Inconsistencies in quality and processing difficulties of new materials can also lead to reduced workability. This is particularly important when aiming for self-consolidating concrete.

Andy Zahedi, PhD
Technical Manager, MCON Products

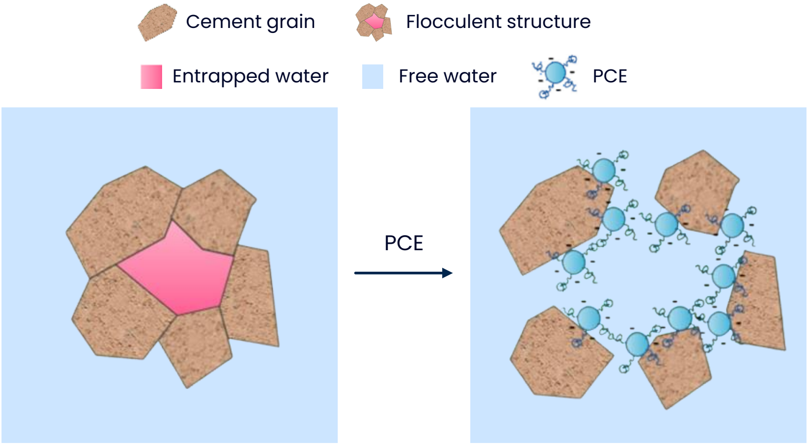
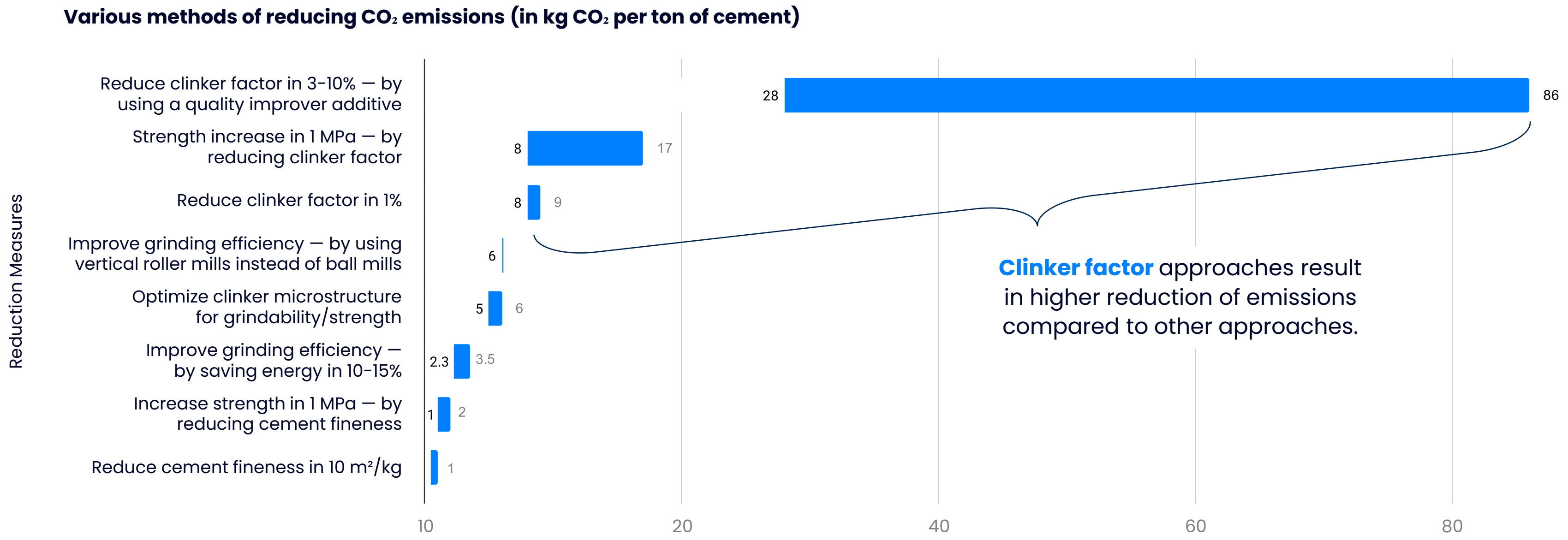


Figure. Schematic diagram of the dispersion mechanism of PCE in cement Source: KZJ New Materials Group (2023).

Data indicates that using a quality improver additive can reduce the total emissions by approximately 6%, equivalent to around 45 kg of CO_2 per ton of cement.



Commercial additives, such as customized quality improvers might enable a 5% increase in clinker substitution with limestone while maintaining cement performance.

Companies leading the way

Alternative materials are already reducing the overall carbon footprint associated with cement and concrete production.

Companies profiled

Large companies are considering more innovative materials, such as calcined/activated clays and construction and demolition waste

Blast Furnace Slag | Natural Pozzolans | Coal Fly Ash

	Headquarters	Materials	Claims	Notable Achievements	Other approaches to reduce the emissions	Scale
LafargeHolcim	Switzerland	Slag, calcined clay, recycled construction and demolition	ECOplanet cement has a **50%** lower CO_2 footprint compared to standard cement	Installed its first 99% clinker-free concrete pavement in North America (2024)	Alternative fuels and renewable energy. Involved in **15+ CCUS projects**	500,000 tons per year for ECOplanet
VOTORANTIM cimentos	Brazil	Steel slag, ash from thermoelectrics, calcined clay, natural pozzolan	Reduction of **9,000 tons of CO_2** in one plant	Various awards in the Sustainable Concrete Awards Program	Alternative fuels and energy efficiency, **Carbon Capture Pilot Program**	52.8 million tons per year total
	France	Industrial by-products (e.g., blast furnace slag) and activated clay	Products emit **70%** less emissions compared to traditional cement	70-meter tower plant entirely made from their own Green concrete	Unique process (vertical production model and "cold"/without heat)	1,000 tons per day facility
SAINT-GOBAIN	France	Blast furnace slag, fly ash, calcined clay, construction and demolition materials	EnviroMix® C-Clay reduces carbon emissions by up to **50%**	Sales grew by over 40%, due to the integration with GCP Applied Technologies (2022)	Funding academic research to test various biomass ashes	Commercial
TERRA CO2	Colorado, USA	Variety of silicate rocks (granite, basalt, alluvial sand, gravel, etc.)	OPUS SCM reduces **70%** of CO_2 emissions and directly replaces fly ash	Raised $61 million Decarbonization Solution of the Year 2024	Unique process (low NO_x reactor)	Scaling up (240,000 tons per year)
BRIMSTONE	California, USA	Calcium silicate rocks and magnesium compounds	Carbon-negative cement, reducing emissions by up to **100%**	1st to achieve ASTM C150 2023 TIME's Best Inventions	Unique process (capable of making cement and SCM at the same time)	Scaling up (140,000 tons per year)
Sublime Systems	Massachusetts, USA	A range of carbon-free materials (rocks, minerals and industrial waste)	"***deep***" reduction in CO_2 emissions, with a clear path to **zero emissions** in the future	Met ASTM C1157 $87 million grant from DOE	Unique process (electrochemical)	Scaling up (250 tons per year)
carbon upcycling	Canada	30+ different feedstocks (incl. fly ash and slag)	Replace up to 50% of clinker, reduction of **1,600 tons of CO_2** annually	Several awards, raised $26 million	Unique process (sequestering CO_2)	Partnering with Cemex to scale up
MATERIAL EVOLUTION	United Kingdom	Industrial by-products	Reduces emissions by **85%**	Raised US$19 million	Unique process (alkaline fusion, "cold")	Plans to scale up

LafargeHolcim

Under the brand name ECOplanet, the company offers **low-carbon** cement products incorporating calcined clay and recycled construction and demolition materials into the formulations. Produced using their proprietary ProximA Tech technology, ECOplanet cement is designed to reach an annual production capacity of up to 500,000 tons. This cement has a **50% lower CO_2 footprint compared to standard** cement (CEM I).

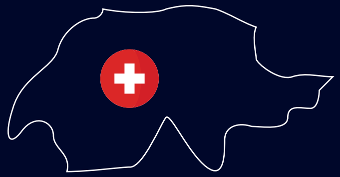
The company aims to reduce net CO_2 emissions per tonne of cement to 550 kg by 2022 and further to 475 kg by 2030. It also targets achieving an **average global clinker factor of 68 by 2030**. To reach these goals, the company plans to repurpose by-products from other industries and construction and demolition waste, invest in calcined clay facilities, and develop novel cements using new binders.

In 2024, Holcim achieved a significant milestone by installing its first **99.2% clinker-free concrete pavement** in North America. By replacing traditional clinker with a slag activator, this innovation resulted in a **75% reduction in CO_2 emissions** compared to standard concrete.

AT A GLANCE

LafargeHolcim

FOUNDED YEAR	2015 (Holcim merged with Lafarge to form LafargeHolcim)
FOCUS	Building Materials
REVENUE	$30.1 Billion USD
LOCATION	HQ Switzerland
NUMBER OF EMPLOYEES	10,001+



Votorantim Cimentos

In 2019, switched from limestone-based cement to slag-based cement in one of its plants, reducing the **clinker factor by 8%**, which equates to a **reduction of 9,000 tons of CO_2** and a savings of **roughly half a million Brazilian reais** per year. Switching to slag can introduce operational issues with grinding and affect cement performance, so GCP Applied Technologies' additives were used to address these challenges.

Their decarbonization strategy is based on 4 pillars, one of which is focused on replacing clinker with by-products from other industries and other materials. Materials mentioned include steel slag, ash from thermoelectric plants, calcined clay, and natural pozzolans.

In 2021, Votorantim Cimentos' North American operations (VCNA) reported a reduction in its **clinker factor by more than 3%**. This improvement is equivalent to eliminating the greenhouse gas **emissions from 28,000 vehicles for one year** or the carbon sequestered by 150,000 acres of forest in a year.

St Marys Cement, part of Votorantim Cimentos' North American operations (VCNA), was recognized in 2021 as the winner of the Slag Cement in Sustainable Concrete Awards Program, presented by the Slag Cement Association. This award was given for their contribution to the Columbus Zoo Project, where they provided a 30% substitution of Portland Cement with Slag Cement. In 2023, St Marys Cement won 3 awards at the Slag Cement in Sustainable Concrete Awards for supplying its slag cement.

Also, launched an open innovation challenge in 2019 seeking startups with solutions to help market products with a **lower clinker content** in their composition.

AT A GLANCE

FOUNDED YEAR	1993
FOCUS	Building Materials
REVENUE	$48.5 Billion BRL
LOCATION	HQ Brazil
NUMBER OF EMPLOYEES	12,000+

Hoffmann Green Cement Technologies

Offers a range of clinker-free cement products — H-UKR, H-EVA, and H-P2A — manufactured cold from industrial by-products, without firing process. These products use ground granulated blast furnace slag, flash/activated clay, gypsum, and various activators and super-activators. According to their website, those products emit only around 250 compared to 880 kg of CO_2 per ton of product produced by traditional cements, a reduction of 70% in emissions.

HGCT's H2 plant in France is a 1000 ton/day clinker-free cement facility. The main section of the plant consists of a 70-meter tower. This vertical production model is unique in the world and enables the use of gravity to optimize the production process. The plant itself was made entirely from Hoffmann Green concrete.

In 2023, signed a deal with Shurfah Group (Saudi company) to build several Hoffman plants, under a 22-year exclusive licensing agreement.

In 2023, partnered with POINT.P (a Saint-Gobain brand), to distribute H-UKR cement to concrete mixing plants and precast factories.

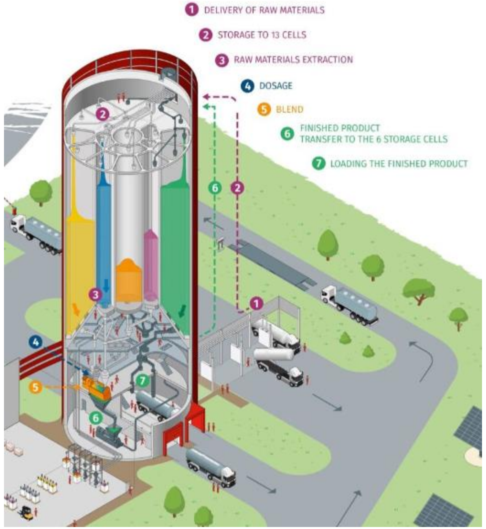


Figure. HGCT's H2 plant

AT A GLANCE

HOFFMANN GREEN CEMENT
Catalyst of Carbon Transition

FOUNDED YEAR	2014
FOCUS	Decarbonized cement products
REVENUE	$6 Million EUR
LOCATION	HQ France
NUMBER OF EMPLOYEES	51 - 100

Saint-Gobain

Collaborated with researchers at École Polytechnique to characterize biomass ash from the combustion of plant materials (such as wood and straw), animal remains (carcasses), and waste (paper), aiming to assess the potential of each type of ash as a replacement for clinker.

Global construction sales grew by over 40%, due mainly to the integration with GCP Applied Technologies in 2022; notably with the CO2ST® and EnviroMix® solutions for developing cement and concrete mixes with a much lighter carbon footprint. Weber continues to replace cement (e.g., with blast furnace slag or fly ash) and sand (with construction demolition materials or excavated earth) in their mortars.

Saint-Gobain Construction Chemicals recently announced the introduction of CHRYSO's EnviroMix® C-Clay, a new range of admixtures aimed at reducing emissions by utilizing calcined clay-based cement in concrete**. Calcined clay cements can reduce carbon emissions by up to 50%** compared to traditional Portland cement and the new admixtures address the technical challenges of using calcined clay, such as high-water demand, enhancing the workability and compressive strength of the concrete.

Signed a partnership agreement with Canadian start-up CarbiCrete to manufacture cement-free concrete blocks; replacing cement with steel slag.

AT A GLANCE

FOUNDED YEAR	1665
FOCUS	Construction materials, high-performance, and other materials
REVENUE	$47.9 Billion EUR
LOCATION	HQ France
NUMBER OF EMPLOYEES	160,000

Terra CO2

Offers **low-carbon concrete** solutions by replacing limestone with a variety of silicate-based igneous rocks. The company has successfully tested materials such as granite, basalt, alluvial sand and gravel, pyroclastic rock, glacial flood gravel, and clay waste streams from North America.

Their product, OPUS ZERO™, is a Portland cement replacement marketed **with zero clinker content**. Additionally, they offer OPUS SCM™, produced in a patent-protected, low-carbon, and low-NOx reactor, which meets [ASTM C-618 standards]. For every ton of traditional cement replaced, a **70% reduction in CO_2 emissions** can be achieved.

The company has raised a total of **$61 million** in funding, including a **$46 million** Series A round co-led by [Bill Gates' Breakthrough Energy Ventures].

Terra CO2 was **recognized as the "Decarbonization Solution of the Year 2024"** at the inaugural CleanTech Breakthrough Awards by [CleanTech Breakthrough], an independent market intelligence organization.

Showcased its real-world performance during a demonstration pour at the Porsche Sugar Land dealership in Houston, Texas, using OPUS SCM™.

Currently, Terra CO2 is **scaling up** its operations and is constructing its first commercial-scale plant in Texas, with a capacity to produce **up to 240,000 tons per year**. The company has also signed an exclusive market license agreement with [Asher Materials] to operate the plant.

AT A GLANCE

FOUNDED YEAR	2016
FOCUS	Decarbonizing the concrete industry
REVENUE	<$5 Million
LOCATION	Colorado, USA
NUMBER OF EMPLOYEES	11-50

Brimstone

Offers **carbon-negative** cement by using carbon-free calcium silicate rocks, instead of limestone, and incorporating magnesium compounds that **absorb atmospheric CO_2**; reducing **emissions by up to 100%** in cement production. Their cement is claimed to be **chemically identical** to conventional Portland cement, and the company also claims to produce SCMs with reduced carbon footprint.

In July 2023, they announced that its cement met the [ASTM C150 standard], which define the regulatory requirements for ordinary Portland cement. They claim to be **the first** ultra-low carbon, carbon-neutral, or carbon-negative cement **to achieve this**.

In 2024, the U.S. Department of Energy's Office of Clean Energy Demonstrations (OCED) awarded the company a **$189 million** federal grant to support its expansion. They also successfully raised **$60 million** from prominent climate investors, including Breakthrough Energy Ventures (founded by Bill Gates), DCVC, Collaborative Fund, and the Amazon Climate Pledge Fund.

TIME magazine and Statista ranked Brimstone **5th** among America's **top 250 GreenTech companies** in 2024.

Currently, the company is focused on **scaling up** the solution for commercialization and is in the process of constructing its first commercial-scale plant, which is **expected to produce up to 140,000 metric tons** of cement and SCM annually.

AT A GLANCE

FOUNDED YEAR	2019
FOCUS	Portland cement alternatives and supplementary cementitious materials (SCM)
REVENUE	Funding of $60.1 Million USD
LOCATION	California, USA
NUMBER OF EMPLOYEES	11-50

Sublime Systems

The company has developed a **low-carbon** cement using an electrochemical process that allows it to serve as a direct replacement for ordinary Portland cement. It extracts reactive calcium and silicates from non-carbonate materials at ambient temperatures, thereby avoiding the emissions typically associated with traditional cement production methods.

The technology leverages clean, renewable energy **to simultaneously produce green hydrogen and cement**. An electrolyzer creates a pH gradient that enables limestone to dissolve at one end and hydrated lime to form at the other. This hydrated lime is then combined with reactive silica to produce **compounds identical to those in traditional cement**.

In 2023, Sublime Cement™ met ASTM C1157 standard and a third-party verification confirmed that it matches ordinary Portland cement in strength and durability.

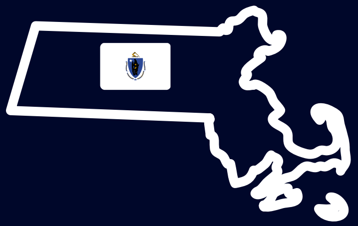
In 2024, the company secured an additional **$87 million** grant from the U.S. Department of Energy to accelerate its commercialization efforts.

The company has **scaled up** production to a pilot capacity of **250 metric tons per year** and is constructing a commercial facility in Massachusetts with a capacity **of up to 30,000 metric tons per year**. This facility is expected to be operational as early as **2026**.

Start up

AT A GLANCE

FOUNDED YEAR	2020
FOCUS	Decarbonized cement products
REVENUE	Funding of $52.56 Million USD
LOCATION	Massachusetts, USA
NUMBER OF EMPLOYEES	11-50



Start up

Carbon Upcycling

The company offers a **low-carbon cement alternative** decreasing GHG emissions in two ways: (1) by capturing CO_2 from industrial flue gases and incorporating it into waste materials (CO_2 removal), and (2) by reducing the amount of cement required in concrete (CO_2 avoidance).

Their technology can convert over 30 different feedstocks, such as fly ash and steel slags, into high-performance SCMs. The company claims that this approach can **replace up to 50% of the clinker in cement**, while also enhancing the strength and durability of the final concrete product.

The company has been **recognized with several awards**, including the Carbon XPrize's X-Factor, NRMCA's 2023 Innovative Company, Cleantech Group's Global Cleantech 100, and Foresight 50's Canada's Most Investable Cleantech Ventures.

In 2023, the company raised **$26 million** in Series A funding. The round was led by BDC Capital and Climate Investment, with strategic investments from Cemex Ventures, CRH, and Oxy Low Carbon Ventures.

Partnering with Cemex, the company is working on **establishing its first commercial-scale plant** to produce cement additives by sequestering CO_2 in glass byproducts. This facility, located at Cemex's cement plant in the UK, is projected to **sequester over 1,600 tons of CO_2 annually** and has received **$3 million** in funding from UK Research and Innovation.

AT A GLANCE

FOUNDED YEAR	2014
FOCUS	Decarbonized cement products
REVENUE	$6.7 Million USD
LOCATION	Canada
NUMBER OF EMPLOYEES	11-50

Start up

Material Evolution

Using an alkaline fusion process rather than traditional calcination and clinkerization (*similar principles to that of nuclear fusion*), the company has developed a **low-carbon** cement technology that reportedly **reduces emissions by 85%** compared to traditional cement production. This process utilizes industrial byproducts, eliminating the need for the kiln and avoiding the use of fossil fuels. According to them, their technology employs a **low-energy**, **low-cost manufacturing process** that operates without heat, directly addressing the CO_2 emissions associated with conventional cement production.

In June 2023, the company secured **$19 million** in Series A funding. This round was led by KOMPAS VC, a venture capital firm specializing in early-stage investments in breakthrough innovations aimed at decarbonizing the building and manufacturing sectors.

The company plans to use the funding primarily to **scale up** its production facilities and **invest in further research and development** to create new products for various construction applications. Additionally, the investment will support the development of blueprints for scaling and licensing the technology across the UK, Europe, and globally.

AT A GLANCE

MATERIAL EVOLUTION

FOUNDED YEAR	2017
FOCUS	Low-carbon cements
REVENUE	<$5 Million USD
LOCATION	United Kingdom
NUMBER OF EMPLOYEES	11-50

Besides working with new materials, emerging startups are also exploring alternative processes.

"Limestone is about ¼ of 1% of the rock in the Earth's crust, and calcium silicate is about 50%.

Bill Yearsley, PhD
CEO at Terra CO2

Achieving **certifications** and meeting **industry standards** are key milestones for startups, as these validate the performance and reliability of their innovations.

Startups are exploring **silicate rocks** as a key material for cement production.

- Low to nil CO_2 emissions compared to limestone
- Silicate rocks, such as basalt and certain types of granite, are abundant and widely available around the world (90% of earth's crust).

New **manufacturing techniques**, including electrochemical synthesis and low-temperature processing, are also being explored to reduce the energy consumption and emissions associated with cement production.

Companies are also leveraging AI to optimize cement and concrete formulations for performance and sustainability, indicating a shift towards data-driven material science.

"The first step is to establish a standardized procedure. (...) Being an active member in various technical committees and engaging in discussions is crucial for influencing standards and shaping building codes.

Andy Zahedi, PhD
Technical Manager, MCON Products

PRESCOUTER

Meet the Expert

Andy Zahedi, PhD

Technical Manager, MCON Products

Andy has a background in Civil Engineering, holding a PhD from the University of Ottawa and postdoctoral research experience at the University of British Columbia. He has 7-8 years of industrial experience, currently working as a Technical Manager at MCON Products, a company specializing in precast concrete. Prior to this, he worked as a Concrete Engineer at CarbiCrete, an R&D company dedicated to developing cement-free concrete using alternative materials. In addition to his industry expertise, he is currently a part-time professor at the University of Ottawa, where he teaches various subjects related to building materials.

Expert Insights

Andy Zahedi, PhD

Technical Manager,
MCON Products

Q: According to our research, the most promising alternative materials currently being explored commercially are limestone and activated clay. Why do you think there is still limited adoption of other materials?

In general this is often **due to the energy and cost required to process** those other materials. Many materials **need to be activated** (e.g., through heating or even chemical processes) before they can be used effectively, further **increasing the complexity of their adoption**.

It’s important to highlight that alternative materials can be categorized as either **binders** or additives. SCMs act as binders and **have active components that contribute to the cementing process**, such as fly ash type C or ground granulated blast furnace slag (GGBS), both of which can replace cement. GGBS is often used more than steel slag. Steel slag is significantly harder and requires extensive grinding, which is both energy-intensive and costly. While GGBS is already a hard material, steel slag's increased hardness means that grinding it demands even more time and resources. This is why you don’t see steel slag being used as often as GGBS. Similarly, the components within fly ash type C are already active, being easier to use.

For clay, we use the calcined/activated version rather than regular clay because heating clay to a certain temperature activates the components within it. That’s why you never see raw clay being used — it's always calcined clay.

Limestone, on the other hand, can also partially replace cement but functions more as an additive — it doesn't "bind" materials together like SCMs do, so the **functions are slightly different and this also impacts usage**.

Expert Insights

Andy Zahedi, PhD

Technical Manager,
MCON Products

Q: Many startups are developing new materials along with innovative processes. Is it because integrating these new materials into existing methods is particularly challenging then?

Exactly. Since many of the new materials **need to be activated before they can be used**, new processes are also being developed in parallel, **to make this activation step easier**.

Historically, some of these materials were used by accident decades ago, and their effectiveness led to continued use. However, I believe things will change by 2030 or 2040, as resources like coal become obsolete. Without coal, there will be no fly ash. A potential decrease in steel production could also reduce the availability of both GGBS and steel slag. **We need to transition to new materials**, but the **challenge lies in determining when and how** to introduce them within a conservative industry.

Expert Insights

Andy Zahedi, PhD

Technical Manager,
MCON Products

Q: A few years ago, Rice Husk Ash was a popular topic and it was the most studied among vegetable ashes. However, recent keyword searches show limited commercial applications. Why isn't this material getting more attention?

There are several reasons and the primary one is likely the **inconsistency in quality**. Quality is heavily influenced by the combustion and grinding processes. Since RHA is derived from rice, it must first be ground into a fine powder before undergoing calcination or combustion. These **processes can be time-consuming**. In contrast, materials like fly ash or slag are typically almost ready for use; slag only requires grinding before application. Inconsistencies in quality and processing difficulties can also lead to **reduced workability**. This is particularly important when aiming for self-consolidating concrete, and RHA can significantly decrease workability.

Also, its **availability varies by region**. Countries such as Brazil, Thailand, and China produce a lot of rice, while others, such as Canada and the United States, have limited rice production. Unlike fly ash or slag, that are widely available, RHA is not easily sourced in many areas.

Lastly, while **life performance assessments** of slag in concrete have been conducted for approximately 60 years, demonstrating its long-term durability, RHA is relatively new and has only been in use for around 20 years. It is still uncommon to see RHA in durable structures like bridges or dams. We **lack data on its performance over a service life of 75-100 years**. In engineering, there is a natural tendency to be conservative, as engineers are responsible for the durability of the structures they design. Some studies suggest that RHA may either mitigate or exacerbate durability issues, such as the alkali-silica reaction, adding to the debate surrounding its use.

Expert Insights

Andy Zahedi, PhD

Technical Manager,
MCON Products

Q: What actions can companies take now to encourage changes in the materials field, especially now that various ideas are still being tested? What can they implement to support this transition?

Overall, launching new products in the market requires a **robust strategic plan**. While developing a new product can be relatively straightforward, attracting customers for it is considerably more difficult without a clear strategy in place.

One key aspect is to have a standard process. Convincing engineers or architects to adopt low cement concrete — who are well aware of cement's importance — can be challenging. If you have certified materials, **e.g., recognized by ASTM or EN standards**, that demonstrate compliance with all requirements, it becomes easier. The first step is to **establish a standardized procedure**, keeping in mind that this may take time. Introducing a new standardized material or obtaining licensing can often take a significant amount of time.

Also, companies and startups must focus on **gaining acceptance from major associations** before attempting to sell these new materials. Active participation from different team members in various technical committees, can help **advocate** for these innovative products, demonstrating that they are on par with, or even superior to, traditional concrete. Being an **active member of these societies and engaging in discussions** is crucial for influencing standards and shaping building codes.

Careful planning and implementation are essential.

Prepare for the impact in your space:

How can PreScouter help you achieve your goals?

Finding more regional standards and regulations

PreScouter can scout for additional standards from different countries and regions to further understand the materials **already approved and the replacement levels that have been standardized** to date, and help your team to rank those that may be easier to implement on a case-by-case basis (e.g., depending on regional availability and sustainability/impact).

Accessing our CCUS Database to discover alternative approaches

To explore alternative approaches to decarbonization in the cement industry, PreScouter offers a CCUS database featuring **30+ projects related to the cement industry**. The database contains information about **large-scale projects and feasibility studies** in the field of CCUS including details on technologies and providers, and can be used to inform decisions about how to best implement CCUS technologies.

Identifying potential partners or collaborators

We help you understand the market dynamics, including the value chain, key players, and their partnerships. We can conduct anonymous interviews with companies to evaluate their potential as partners, assessing their capabilities and willingness to collaborate.

About the Authors

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Marija is the Technical Director for PreScouter's Chemical, Materials, and Packaging verticals. Her work focuses on areas such as sustainability, product and process improvement, innovation strategy, market and technology landscapes, IP and regulation landscapes, among others. Marija holds a master's degree in Chemical Engineering from Belgrade University and a PhD in Organometallic Chemistry and Catalysis from ETH Zurich. Before pursuing her PhD, she gained industry experience in the chemical sector.

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Beatriz is one of PreScouter's Project Architects. She started her career almost 10 years ago and for the last 3 years has been leading projects within the Chemicals, Materials, and Packaging industries. She holds an MSc. with distinction in Materials Science and Engineering, and developed the thesis within the cement industry in Brazil. Before joining PreScouter, Beatriz worked with corporate data analysis and packaging cost estimation while in costs/sales departments of multinational companies.

Mohammed Jimshid

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Jimshid currently works as a Strategic Insights Analyst at PreScouter, with a background in Mechanical Engineering from the National Institute of Technology Calicut, India. Since joining in 2021, he has worked on more than 100 projects, providing strategic insights to help clients solve complex challenges and unlock new opportunities.

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