

CEMENT IT BETTER

UNLOCKING LOW-CARBON CONCRETE
IN EUROPE

JULY 2026

CEMENT IT BETTER - Unlocking low-carbon concrete in Europe

We are Europe's largest network of environmental citizens' organisations. We bring together over 190 civil society organisations from more than 41 European countries. Together, we work for a better future where people and nature thrive together.

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Responsible editor: Patrick Ten Brink

Lead Author: Jai Krishna Ranganathan, European Environmental Bureau



Laetitia Aumont, Fynn Hauschke, Alikri Kriekouki, Riccardo Nigro,
Sonja Leyvraz and Christian Schaible.



Simon de Jonge. Contributions from Sander Brouwers.



Benjamin Hague. Contributions from Zuzana Hejlová.



Joren Verschaeve.



Contributions from Philippine Ménager.

Energy Policy Group Contributions from Sabina Strîmbovski.

Reviewer: Alberto Vela, European Environmental Bureau

With thanks to Erwin Cornelis, formerly ECOS.

European Environmental Bureau (EEB)
Rue des Deux Eglises 14-16
1000 Brussels, Belgium
sustainableindustry@eeb.org
eeb.org
meta.eeb.org



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Introduction

Decarbonising heavy industry in the EU has been traditionally framed around sectors considered 'hard to abate' versus those that can electrify their way to climate neutrality. The decarbonisation of the production of Portland cement remains particularly challenging. This is primarily because achieving near-zero emissions require fundamental changes to feedstocks and chemical processes, rather than electrification alone. Portland clinker production remains one of the few industrial processes in which process emissions account for almost 60% of total CO₂ emissions from cement production.

Even if electrification were a silver bullet, the scale of energy infrastructure required to supply these industries would remain a major constraint, given their energy- and capital- intensive nature. For Portland cement, the need to reduce process CO₂ emissions by changing feedstocks or capturing carbon emissions entails additional effort in coordinated investment across infrastructure, industrial supply chains and end-markets. This is equally true for the development of CO₂ capture, transport and permanent storage systems (CCS) or its conversion into permanent products.

Over the past two decades, significant progress has been made in improving processes and products: such as reducing clinker content by increased blending of supplementary cementitious materials (SCM) in cement, using recycled aggregates in concrete and replacing fossil fuel-based heat to electrical sources. A wide range of low-carbon cements are already available in niche markets, with some novel recipes reducing Portland clinker to a mere 20-30% share in cement, a massive reduction from the average clinker to cement ratio of 74 % in the EU today.

These approaches can deliver substantial emissions reductions. With electrification reducing about 40% of the fossil fuel emissions, and the corresponding reduction in energy demand for clinker calcination, the carbon footprint of these novel recipes can be up to 70% lower compared to Portland cement or even 75% with renewable electricity. The remaining 20-25% of emissions cannot be abated without the use of alternative feedstock or permanent carbon capture.

Achieving a Paris compatible mitigation pathway requires very deep reductions of GHG emissions in the cement sector. The sectoral pathways by the Science Based Targets initiative expects a reduction of over 55% by 2050 as compared to 2019 emissions, implying accelerating reductions in the mid-term, while also implying non-zero emissions in 2050. This is a pathway based on decarbonisation options currently recognised as feasible.

Yet near-zero-emissions cements are possible and are being commercially produced today both in Europe and beyond. While some of them depend on Portland clinker-based systems and integrate carbon capture, others have proved it possible to synthesize a new binder which does not generate any process CO₂ emissions. Alternative pathways also include the use of circular feedstocks recovered from construction and demolition waste. These innovations are not theoretical; they have already been applied in real-world projects, from the Athletes' Village built for the Paris 2024 Olympic Games to tunnel segments of the Grand Paris Express.

Despite their technical readiness, these alternative low-carbon binders¹, or even the novel recipes of Portland cement with low clinker shares, cannot place their products in the single market because they cannot be certified as a cement in the EU.

This bottleneck is not technological, but regulatory.

As a result, investments in low-carbon binders are slow and the transition remains uneven and faces structural barriers that go beyond technology.

Executive summary

Low-carbon binders and novel cement formulations are technically viable and increasingly available. However, their uptake in the EU is constrained by regulatory, market and systemic barriers rather than technological limitations.

A key obstacle is the current standardisation framework. Existing standards conferring automatic access to the EU single market do not exist for most low-carbon binders. The EN 197-1 class of cements, last updated in 2011, along with the subsequent EN 197-5 and EN 197-6, does not allow cements which have a different percentage of clinker (a different recipe) or new SCM's to be certified as cement. As a result, many low-carbon products cannot obtain harmonised certification or be specified in public procurement contracts at scale, even when they demonstrate strong performance.

To address this, the EU must transition towards performance-based standardisation under the Construction Products Regulation (CPR). Such an approach would assess materials based on their technical performance, low environmental and health impacts as well as net zero emissions. A performance-based standard could be the most effective approach supporting the use of low-carbon binders rather than recipe-based prescriptive standards. The USA has had a performance-based standard since 1992, and many Latin American countries have also adopted similar standards.

Policy frameworks must keep pace with innovation. The Industrial Emissions Directive (IED) should recognise and promote state-of-the-art low-carbon production techniques through ambitious Best Available Techniques (BAT) benchmarks. This includes prioritising clinker substitution and supporting breakthrough processes, while ensuring that carbon capture -where used- is limited to residual emissions and meets high standards for CO₂ capture rates (>95%) and permanent storage.

Creating lead markets for low-carbon binders will also be essential. Green public procurement can play a decisive role by mandating environmentally and socially responsible criteria in strategic sectors where decarbonisation needs acceleration, especially with long-term and high value infrastructure contracts which can catalyse innovations. Alternative low-carbon binders should be provided labels ranking their comprehensive environmental performance according to the CPR complemented by the proposed Industrial Accelerator Act (IAA), while public procurement can provide incentives to the top two performance classes in its lead markets, until low-carbon binders are widely available.

Decarbonising the cement value chain also requires stronger collaboration across the construction ecosystem. This includes buildings and infrastructure that drive the production of cement/ concrete and embody its carbon footprint. Sufficiency, circularity and material efficiency should be the priority for decarbonising the use of cement and concrete in buildings and infrastructure. Revising building codes to reduce overspecification and setting limits on embodied carbon per square meter of built area can further encourage low-carbon binders. Pre-demolition audits, selective deconstruction, extended producer responsibility for construction projects and green taxation favouring reused or recycled products can help bring parity among circular feedstocks and primary materials by increasing the availability of circular feedstocks.

Circular feedstocks can make a distinct contribution to cement decarbonisation by reducing the generation of process emissions of Portland clinker. The recovery of recycled cement paste with its unreacted clinker fraction from construction and demolition waste (CDW) for reuse in new cement production, or the use of recycled concrete fines as an SCM in cement or as aggregates in concrete are all valuable strategies in reducing carbon emissions of cement and concrete.

Supply chain engagement for deep decarbonisation is vital for reaching net zero. The most prominent stakeholders in the construction value chain are the infrastructure and structural engineering companies. As these are large consumers of cement and concrete, reduction of scope 3 upstream emissions in their operations could include efforts to encourage the use of low-carbon binders in many member states, especially when these binders don't have harmonised standards to certify them for the EU single market. Collaborations between low-carbon binder manufacturers and infrastructure companies need to move beyond trials towards demand commitments, including long term offtake agreements, which can create a lead market led by private procurement.

A transparent and interoperable data are essential to benchmark environmental performance and guide decision-making. Interoperable data linking reporting of polluting emissions from the IED, raw material consumption from the Industrial emissions portal regulation (IEP-R) and core environmental performance parameters reported in the Environmental management systems regulation (EMAS) are vital for setting benchmarks. Environmental product declarations (EPD) mandated by the CPR and those published by EPD operators, together with the data from IED, IEP-R and EMAS legislations are not yet available in a transparent or interoperable manner to assess the real advantages and drawbacks of a cement over its full lifecycle of impacts.

Data reporting systems from the procurement directive, which only covers about 30% of all procurement in the single market available at the EU level, need to ensure that all national procurement data, at least in targeted sectors, are made available to track the progress of lead market creation and green public procurement. Aligning data from industrial emissions reporting, environmental management systems and product-level declarations, alongside improved procurement data, will enable a more accurate assessment of lifecycle impacts and support the scaling of the most sustainable solutions.

Small and Medium enterprises (SMEs) constitute an overwhelming majority of the construction ecosystem in Europe, and their engagement is essential for any decarbonisation pathway involving the use of low-carbon cements or to prioritise sufficiency, circularity and material efficiency in construction. Alternative low-carbon binders also require extensive reskilling of the SMEs' workforce, while the lack of harmonised standards and technical guidance increases the perception of risk associated with their use. While lead markets may deliver the demand signal for deep decarbonisation of the construction ecosystem, measures to simplify the adoption for SMEs need to go in tandem with efforts for a sector-wide transition.

Together, these measures can enable a structural transformation of the cement value chain, moving beyond incremental improvements towards a genuine, deeply decarbonised cement sector. The technologies and solutions already exist; the challenge now is to remove regulatory and market barriers so that low-carbon binders can move from niche to norm across the European construction sector.



Concrete waste from demolition can be processed to produce low-carbon SCM's and clinker substitutes. Photo: Daniel Verkijk, courtesy Everox.

State of the EU cement/concrete transition

1.1 An overview of European cement and concrete production

There are over about 300 cement installations² in the EU, in almost all EU countries, except The Netherlands and Malta. Over 63% of the total production capacity of approximately 390 million tonnes is concentrated in 4 countries, Germany, Spain, France and Italy. The EU-27 accounts for over 5 % of global production capacity. Although almost 80% of capacity is in Asia, EU-27 is one of the largest clusters other than China and India which are covered by a single market.

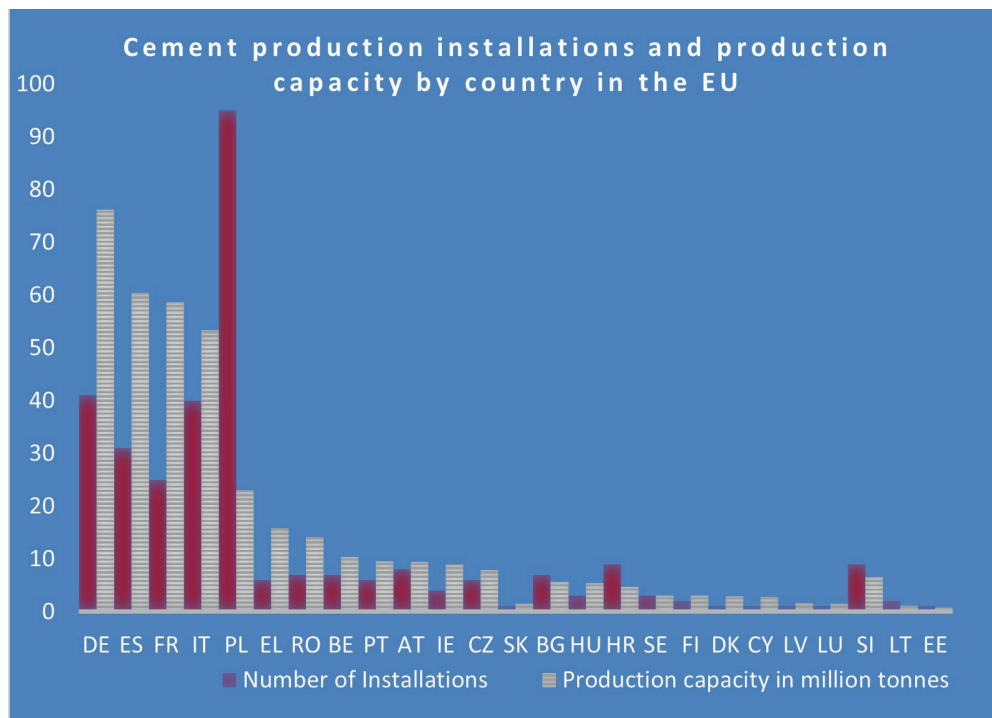


Figure 1: Cement production installations and production capacity in the EU.

Cement Europe reports³ the total production of cement in the EU at 161 million tonnes in 2023. Of this production, 56% of cement is delivered to produce ready mix concrete, 17% for precast concrete and 27% for other purposes including site mixed concrete and other direct uses of cement. The European ready mix concrete organisation (ERMCO) reports⁴ that the total concrete production in the EU is at 239 million cubic metres. The cement content in the ready-mix concrete reported by ERMCO varies widely across the EU from 230 kg/m³ in Ireland to 361 kg/m³ in Finland with an EU average of 272 kg/m³. Eurostat also reports annual ready-mix concrete production at 563 million tonnes for the year 2023. With wide variations across the EU, and missing data for some member states in the Eurostat data, we cannot estimate the total concrete production covering ready-mix, pre-cast and site mixed concrete at the EU level with confidence. Therefore, all statistics in this report are based on cement production data.

Most of the cement production installations (60 %) are less than 25 years old, while 40% of the installations don't have valid data on their permit granting dates and are listed as "No data" in the chart below.

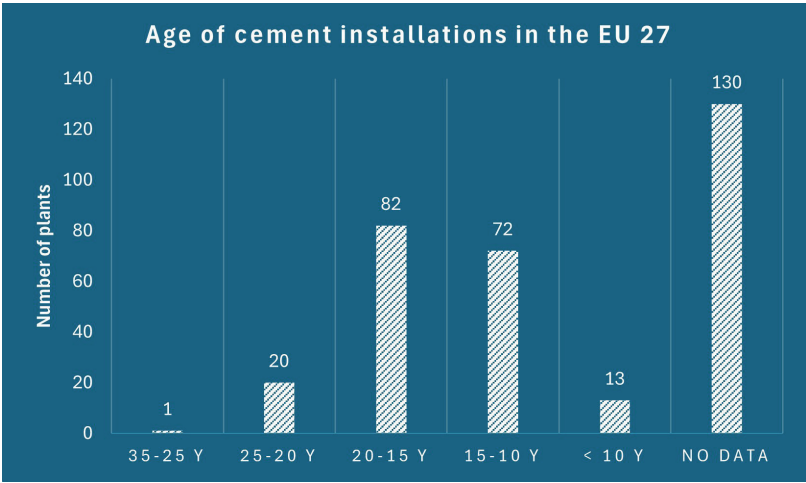


Figure 2: Age of cement installations in the EU-27

The lifetime of a cement kiln is usually around 30-50 years. Unlike steel plants, which need a high investment in blast furnace relining every 20-25 years, cement plants usually have low investment periodic maintenance for most of the plant (other than the refractory lining in the rotary kiln every 2-5 years). In practice, the preheater cyclones, clinker cooler or the burner are completely replaced after 20-30 years. It's expected that over 30% of the cement capacity in the EU may require reinvestment by 2030⁵.

CO₂ emissions from the production of Portland clinker

In 2023, the cement sector emitted 94 million tonnes of CO₂ in the EU27 distributed over 201 sites. This represents 8% of the verified emissions of all stationary installations falling under the EU ETS⁶. The trend shows a decrease of emissions from 2019 continuing till 2023 which roughly matches the average declining production trend post 2021⁷.

Based on the 2023 EU ETS data for verified emissions, we note that the top 5 companies with highest CO₂ emissions, account for over 50% of the total verified emissions.

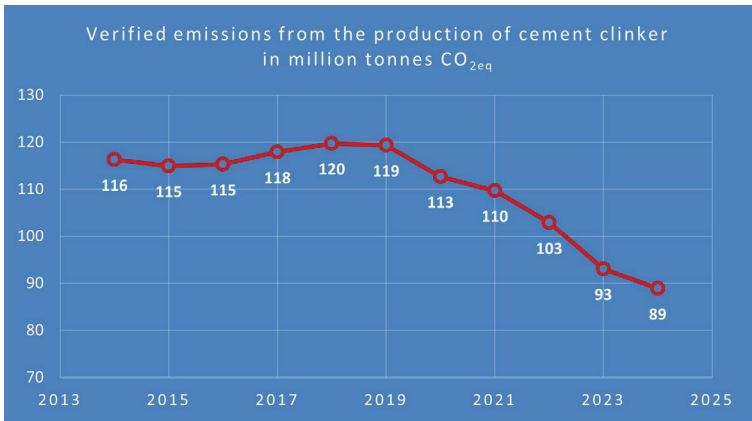


Figure 3: Verified emissions of Portland clinker production in EU27.

Table 1: GHG emissions of Installations producing Portland clinker, grouped by parent companies (covering > 80 % of total emissions)

Parent Company	Verified emissions under EU ETS, 2023 (tCO _{2eq}) in '000s	share of total emissions (%)	Free allowances (tCO _{2eq}) in '000s	Free allowances/ verified emissions (%)
Heidelberg Materials AG	18318	19.4	1811	9.9
Holcim Ltd.	14615.9	15.5	748	5.1
Buzzi Unicem S.p.A.	7217.8	7.6	3142	43.5
CRH Plc	6585.1	7.0	1546	23.5
Cemex S.A.B de C.V.	4691	5.0	511	10.9
Schwenk Zement GmbH & Co. KG	3785.2	4.0	770	20.3
Fomento de Construcciones y Contratas, S.A.	2991.2	3.2	359	12.0
Titan Cement International S.A.	2963.9	3.1	2623	88.5
Cementir Holding N.V.	2639.6	2.8	1798	68.1
Colacem S.p.A.	2396.2	2.5	2033	84.8
Intercement Participacoes S.A.	1972.7	2.1	2074	105.2
Vicat S.A.	1499.5	1.6	1693	112.9
Cementownia Warta S.A.	1342.6	1.4	1220	90.9
Sociedade de Investimento e Gestão, SGPS, S.A	1341.1	1.4	197	14.7
Thomas Beteiligungen GmbH	1160.3	1.2	743	64.0
Corporación Masaveu, S.A	1152.8	1.2	44	3.8
Votorantim Cimentos España, S.A.	1113.1	1.2	1444	129.7
Total	75785.9	80.2	22756	30

Environmental pollution from the production of Portland clinker.

Based on 2021 data, the 2024 report of the EEA⁸⁹ lists the top 30 most polluting cement plants.

The major pollutants from the cement industry are usually particulate matter (dust), sulphur oxides (SO_x), nitrogen oxides (NO_x) and mercury. Alongside the iron and steel sector, cement ranks among the worst-performing industries on the EU Industrial Emissions Portal. While emissions from the energy sector are expected to decline significantly due to the EU's coal phase-out policies, the cement industry remains a major source of air pollution—particularly from Portland clinker production.

The total damage costs estimated using the value of statistical life (VSL) methodology for these 30 plants is over 6 billion EUR, for just one year of operation.

Table 2: The top 30 most polluting cement production plants, EEA, based on 2021 data and their damage costs in Value of Statistical life (VSL)

Country	Number of plants in the top 30 list	Damage costs (VSL) in € millions
France	11	1916
Belgium	4	1490
Italy	7	1085
Germany	3	833
Croatia	2	291
Slovenia	1	208
Spain	2	205
Total		6.2 € billions.
Data from EEA and reporting stream of the Industrial Emissions Directive(IED)		

It is both noteworthy and surprising that there are still plants in Europe (9 in France, 1 in Estonia) derogating from the current emission limits set by the 2013 CLM BREF, even if those standards are based on outdated, 15-year-old data. There are about 10 sites that are still derogating from the EU standards for emissions to air, in particular BAT 21 on SO₂ emissions (allowing for daily average emissions exceeding 400 mg/Nm³) as well as 3 derogations for dust emission levels.

Imports and exports of cement in the EU

The EU is a net clinker importer and a net cement exporter⁹.

When it comes to cements, more than 83% of the cement is imported in 8 member states, Italy, Romania, Poland, Bulgaria, Spain, Croatia, France and Ireland. Italy is the largest importer with 22% of the total import share. Exports of cements are dominated by 5 member states, Greece, Spain, Germany, Ireland and Croatia with Greece exporting almost 31% of all EU exports.

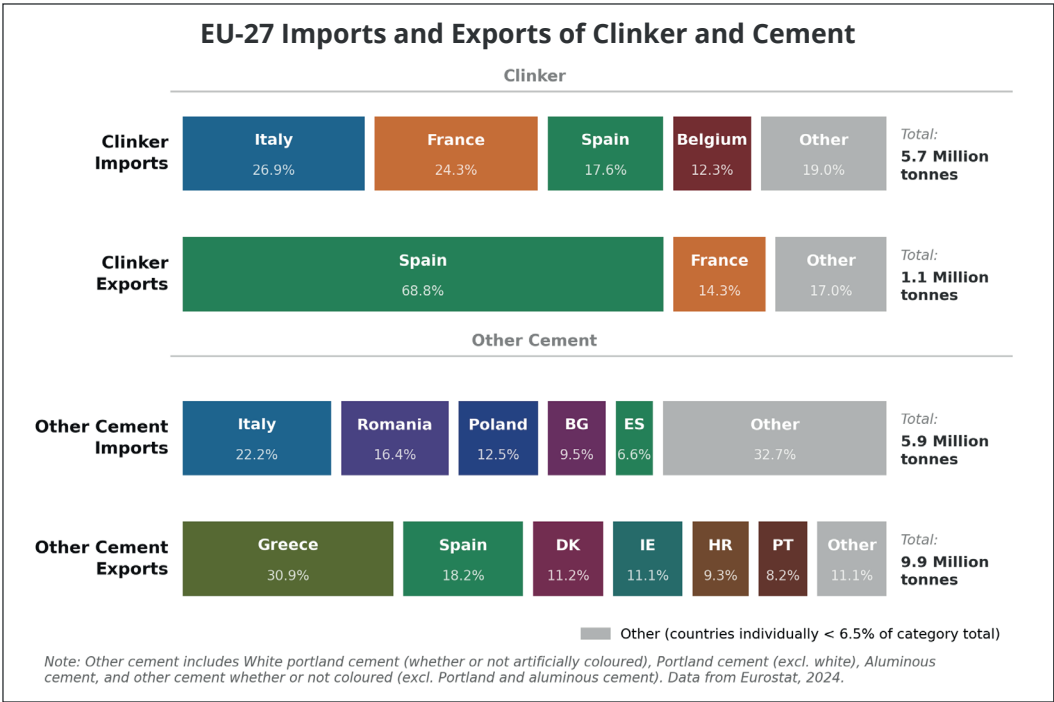


Figure 4 EU 27 Imports and exports of clinker and cement- Member States, Image generated by AI based on user provided data

1.2 Overview of the existing production process

More than 99% of cement consumed is based on Portland clinker, contains four major oxides: (CaO, SiO₂, Al₂O₃ and Fe₂O₃). The raw meal entering the kiln consists mainly of impure limestone, clay and other minor components, such as iron ore, bauxite, and sand to reach the desired chemical composition. Raw materials are quarried, crushed, transported to the clinker and cement manufacturing plant, where they are mixed and milled into a raw meal¹⁰.

This raw meal is heated in the pre-heating system with the hot off gases from the following process step to dissociate the limestone (CaCO₃) into calcium oxide (CaO) and carbon dioxide, beginning at 600°C and complete by approximately 900°C. This pre-calcination step is a major source of CO₂ emissions; it accounts for 60% of the total CO₂ footprint of cement. The formation of the various phases of Portland clinker (alite, belite, aluminate and ferrite) are energy intensive and critical for the strength and performance characteristics of cement. But they do not intrinsically generate CO₂ as no carbonate decomposition occurs during these reactions. These emissions are process emissions and are not caused using fossil fuels.

The meal is then sintered in a rotary kiln, which is heated at a high temperature of 1450°C (around 1650-1800MJ/t). The calcium oxide reacts with the other elements to produce calcium silicates, ferrites and aluminates. This sintering step (clinkerisation) is the next major source of CO₂ emissions, as fossil fuels take a large share of the energy input. This accounts for about one third of the total CO₂ footprint of cement. The melted material is then cooled rapidly to form an assemblage of aggregates, called Portland clinker.

It is then inter-ground with gypsum (about 3%) to a finer product called cement. This final step only accounts for about 3-5% of the total CO₂-emissions of cement production; most of the emissions can be attributed to the production of Portland clinker (>90%).

As a result of the Portland clinker's high specific CO₂ footprint, in combination with the high volumes produced globally-cement manufacturing is one the most significant contributors to the anthropomorphic greenhouse gas emissions. If cement production were a country, it would rank third after China and the United States.

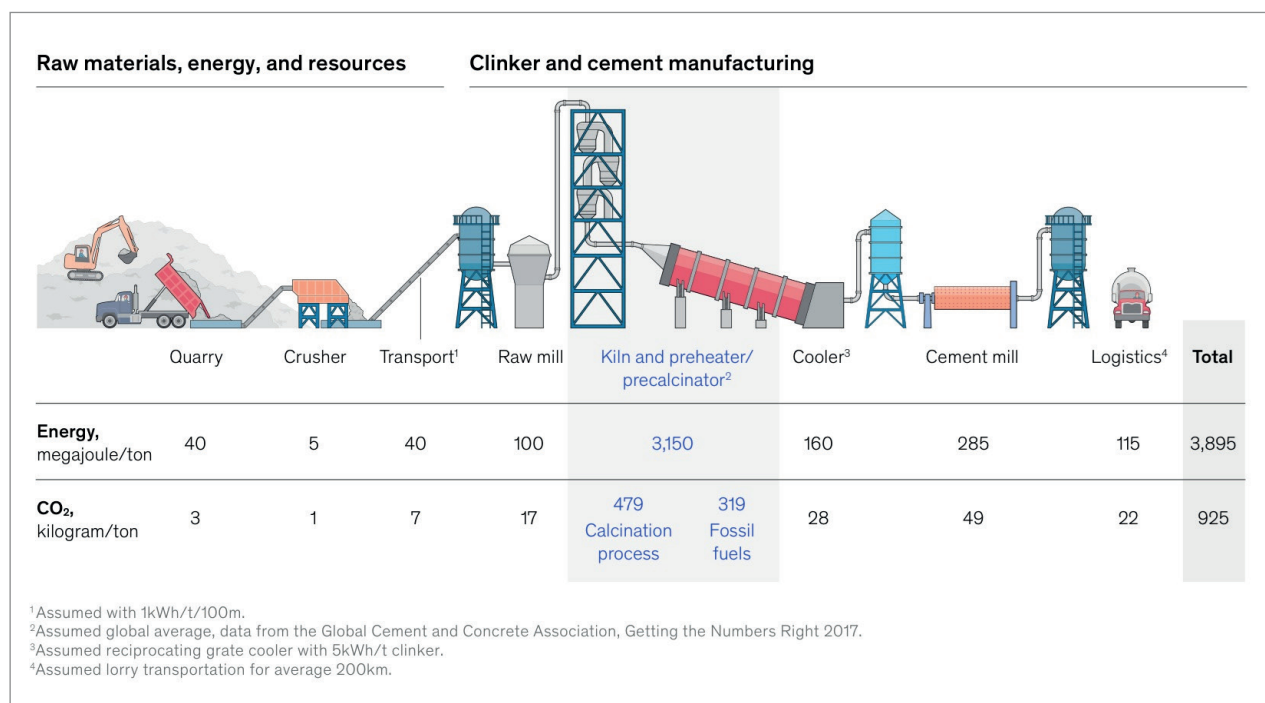


Figure 5: Estimated energy consumption and CO₂ emissions associated to each step of the cement production chain¹¹

Summary of pathways for low-carbon cements

2.1 Cement blending, clinker substitution, and alternative low-carbon binders

2.1.1 Cement blending and clinker substitution.

Clinker is the primary component of traditional cement with the largest GHG emissions and is usually a mix of limestone, clay and other minor components. Producing Portland clinker requires calcination, which involves temperatures up to 1450°C. About 926 kg¹² of CO₂ is emitted to produce a tonne of Portland clinker, which is more than 95% of the carbon footprint of cement. On an average, cement constitutes about 14% of the weight of concrete but accounts for approximately 95% of the carbon footprint of concrete¹³.

Reducing the clinker-to-cement ratio through cement blending with supplementary cementitious materials (SCMs) or low-carbon fillers lowers the total GHG emissions of cement and reduces dependence on high-energy, high-temperature Portland clinker production. It is in fact one of the fastest and most efficient levers to reduce CO₂ emissions as it directly reduces the amount of carbon- and energy-intensive Portland clinker used (material efficiency) and is, therefore, significant for short-medium term progress on decarbonisation. Yet current clinker-to-cement ratios continue to be high globally– and has risen from 66% to 71% from 2015 till 2022¹⁴.

Clinker substitution is defined in this report as replacement of a share of primary clinker share in Portland based cements with supplementary cementitious materials or alternative binders and thereby lowering or eliminating process CO₂ emissions from calcination.

Promising supplementary cementitious materials

The cement industry has a long tradition of using reactive by-products from other industries to reduce Portland clinker in cement. These were largely restricted to fly ashes (FA) from coal-fired power plants, and granulated blast furnace slags (GBFS) from blast-furnace iron production. Their supply, however, is modest compared to the total volumes of cement (and Portland clinker) production in the world. Moreover, the availability



The new Nantes University hospital in France uses two types of Exegy low-carbon concrete in 7 of its 13 buildings.

of FA and GBFS will gradually reduce – and potentially even disappear – given that coal power plants are destined to close in the next 10-15 years and steel manufacturing will progressively move towards processes such as direct reduction of iron (DRI), H₂ reduction or recycling of steel in electric arc furnaces that generate lower quantities and have different physical properties than blast furnace slags. It should be noted, though, that in the case of FA, there still are quite significant (historic) landfills that can be reclaimed¹⁵ for usage as demand for FA in cement only surpassed supply in recent years.

Fortunately, there are numerous SCM's to reduce the share of Portland clinker in cement, and underlying technologies are in full development. This clearly reflects from systematic literature overviews. For example, Snellings (et al)¹⁶ conducted a recent literature review, ranking existing and emerging SCMs on the basis of maturity, processing intensity and supply volumes (see figure below).

Amongst others, natural pozzolans, silica fume, rice husk ash, limestone (fillers), calcined clays (LC3 systems), recycled concrete fines (RCFs) have been demonstrated and make good candidates. A recent success in Portland clinker reduction by cement blending is the new mixture limestone and calcined clays (LC3) with around 50 % clinker to cement ratio. LC3 based cements have begun commercial production or are widely trialled in large markets in Asia, Africa and South America. The advantage of LC3 based cements are that the SCM's (high kaolin clays and limestone) are abundantly available worldwide, therefore this cement has global scale potential to deliver a reduction of CO₂ of up to 50% compared to Portland clinker. Furthermore, continued research on LC3 type showcase that further improvements can be made, with promising mix designs further bringing down the share of Portland clinker¹⁷ to 35% for a wide range of applications. In addition, also the use of carbonatable materials (e.g. olivine) is gaining traction as SCMs due to their capacity to permanently store CO₂ in concrete.

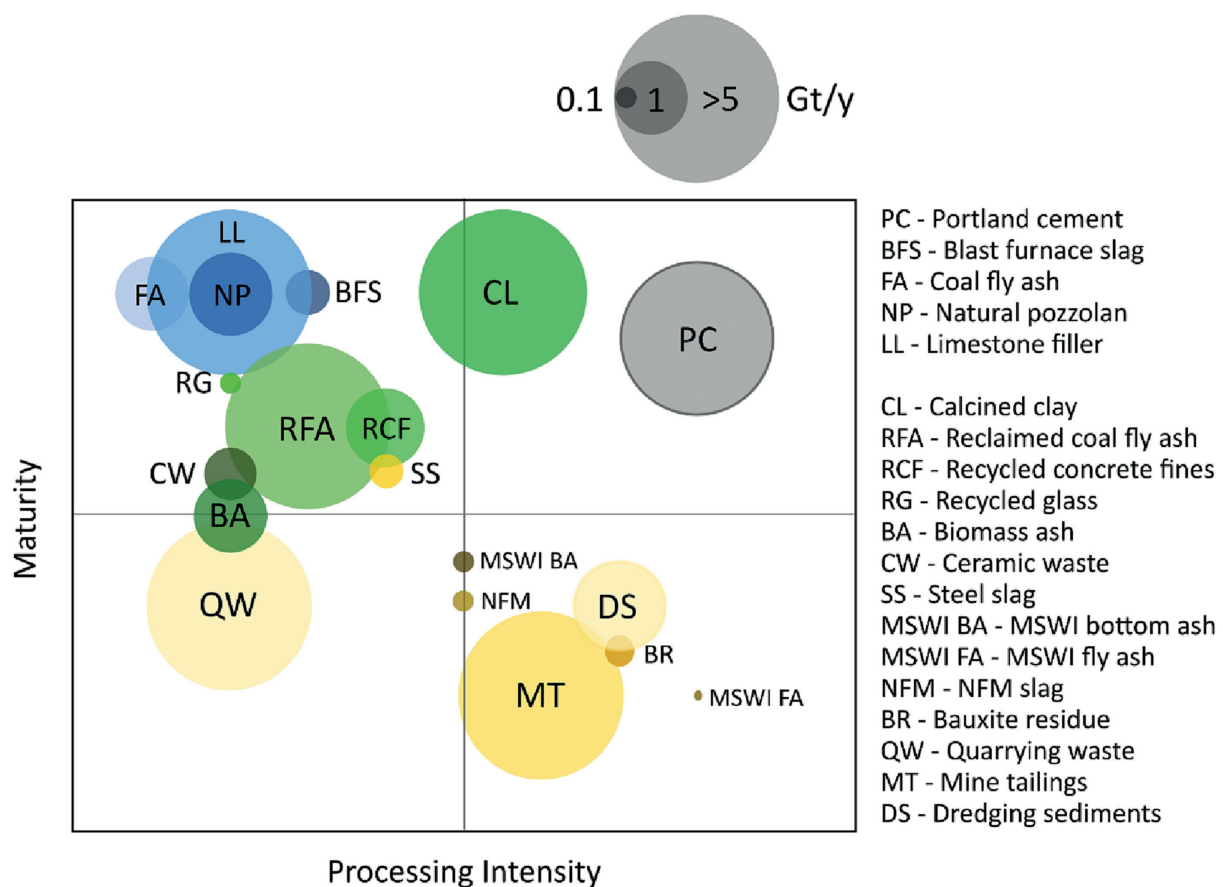


Figure 6: Overview of existing and emerging SCMs. Source: Snellings, Suraneni & Skibsted, 2022

Limestone calcined clay (LC3)

Prof. Karen Scrivener established the scientific basis of LC3 in the late 2000's. LC3 is a blended cement with reduced clinker content by combining calcined clay with limestone along with Portland clinker and gypsum. The process does not change the chemistry but is an innovation in reducing Portland clinker and including new feedstocks.

Kaolinite, $(Al_2Si_2O_5(OH)_4)$, a naturally occurring clay mineral, is calcined in a separate calciner for around 700-850°C to form metakaolin, an aluminosilicate. The calcined clay is then added to clinker, limestone and gypsum and grounded together to produce the final cement. The interactions between alumina (Al_2O_3) from metakaolin and limestone enables the formation of carboaluminate phase, supporting strength development while enabling reduction in clinker share of the cement.

The cement recipe is then: 50% clinker, 30% calcined clay, 15 % limestone and 5% gypsum, giving a clinker to cement ratio of 50%, as compared to the EU's present rate of 74-75%. This specific recipe is called LC3-50. The recently approved EN 197-5 standard (not harmonised yet) allows many similar recipes, and many are already in commercial production¹⁸ in the EU.

Key considerations for the LC3 family include the quality of kaolinite bearing clays and the need for modest plant adaptations for clay calcination and blending, which can be implemented as auxiliary extensions¹⁹ in current plants.

The pathways for cement decarbonisation are constructed from the premise that near zero scalable alternatives to Portland cement and calcination are not yet available at scale. This is evident in the gradual emission reductions trajectories toward 2030 and steeper reductions after 2040 to achieve net zero in 2050²⁰. The use of LC3 as a lever to increase the efficient use of Portland cement clinker was already proposed as a route to reduce the scale of cost of investments needed for CCS/ U in 2016²¹. LC3 family of cements can accelerate the near-term emission reductions in 2030 and can reduce the investment needs for CCS/U, while allowing time for other alternative low-carbon binders to mature, easing the overall transition towards net zero.

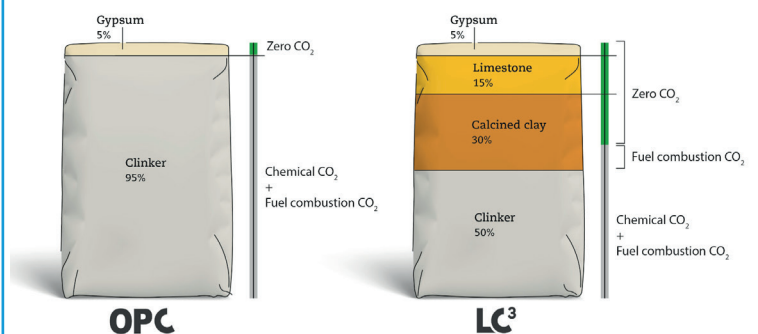
Clinker substitution using recycled materials

For obvious reasons, Portland clinker recycling holds – in a similar fashion to the use of SCMs – the potential to drastically reduce the need for Portland clinker production. It involves the processing demolished concrete – and more precisely the cement paste. This is done through mechanically separating the fine (hydrated) cement particles from larger aggregates while crushing old concrete. This paste, in turn, can be reactivated via thermal activation into cement particles (equivalent to Portland clinker) with binding and hydraulic properties. Importantly, recent years have seen a surge in research and development into Portland clinker recycling.

Arguably, most far-advanced is the technique of recycling Portland clinker in existing steel infrastructure, where the recovered cement paste is used as a partial substitute for the lime-dolomite flux used in steel recycling as the byproduct from this process produces ready to use Portland clinker. This process is currently in industrial trial. According to a recent peer-reviewed study²² in Nature, Portland clinker recycling could produce zero-emission clinker at scale as a product of steel recycling.

One important caveat is that Portland clinker recycling is most efficient when clinker rich legacy concrete is used as a feedstock. In the longer term such mixes will most likely become harder to find though the existing stock of clinker rich concrete remains significant. Furthermore, research is underway to develop new types of binders (including Portland clinker alternatives) which are more efficient from a recycling point of view.

CO₂ reduction using LC3



Courtesy, Zoi Environment Network and EPFL

Alternative binders

Several technologies seek to produce a binder/cement with alternative raw materials, as such seeking to avoid the process emissions coming from the carbonation of limestone – as well as alter the production process (e.g. electrification).

To be a truly near zero alternative to Portland cement, a low-carbon binder should reduce its life cycle emissions to near zero as possible, with the use of renewable energy.

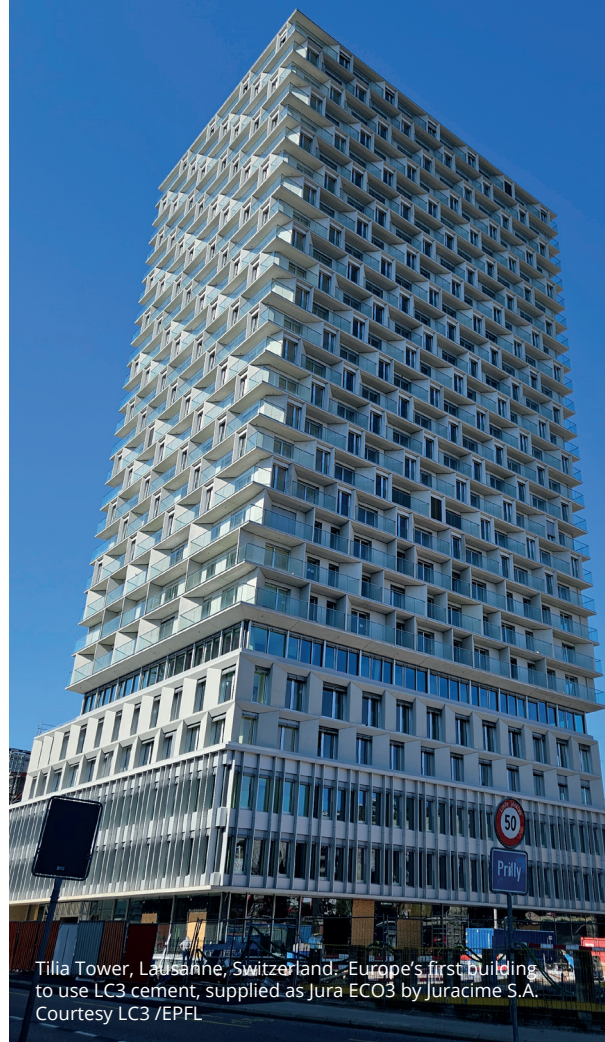
Achieving a Paris compatible mitigation pathway requires very deep reductions of GHG emissions in the cement sector. The sectoral pathways used for target setting by the Science Based Targets initiative²³ allocates the cement industry a 30-year carbon budget (2020-2050) which expects a reduction of over 55% as compared to 2019 emissions, implying accelerating reductions towards 2030 and 2040, while also implying non-zero emissions in 2050. This is a pathway based on decarbonisation options currently recognised as feasible.

Alternative binders are binder systems that do not rely on Portland clinker chemistry as the primary hydraulic phase and instead use different chemical reaction pathways to achieve strength and durability. Alternative binders may be low-carbon, where chemical pathways or feedstock choices inherently limit process CO₂ emissions, or high-carbon, where calcination or sintering routes produce process emissions that require carbon capture to achieve deep decarbonisation.

To drive the very deep decarbonisation required, such binders should adopt a primary decarbonisation pathway aimed at material and chemistry change that avoids clinker related process CO₂ emissions, such that large-scale carbon capture is not necessary to achieve deep emission reductions and the binder production process should be 'easy to abate'. For this report, alternative binders meeting these criteria are referred to as low-carbon binders (LCBs).

Promising low-carbon alternatives to Portland clinker cements:

'Clinker', as a term refers to Portland clinker, the primary constituent of ordinary Portland cement, which is a binder with a high GHG footprint. There are a few types of alternatives to Portland clinker which can act like binders that are in advanced



stages of technology readiness levels (TRL) which also provide the highest carbon reductions possible today.

Alkali activated cements:

It has been established for over 70 years that cements can also be created without the use of the Portland clinker, with the use of alkali-activated cements (AAC). The underlying technology to do so has a lot in common to how blended cements (CEM II, CEM III, CEM IV and CEM V in EN 197-1) have been created by adding supplementary cementitious materials (SCM's) like blast furnace slag, fly ash, paper sludge, red mud and pozzolans to Portland clinker.

In traditional blended cements, the role of Portland clinker is to serve as a source of calcium from the formation of calcium silicate hydrates (C-S-H), producing an alkaline environment and releasing heat, which help in the activation of the SCM's to become binders that lead to their hydration and stronger material properties. In the case of alkali-activated cements, this role is taken up by alkaline mediums which accelerates the activation process like Portland clinker. This can result in a cross-linked, acid-resistant 3D structures with high mechanical strength, forming newer cements with significant less GHG emissions.^{24 25}

Successful applications of AAC's can be found in Europe and the former USSR²⁶ since the 1950s and more recently in Australia, China and North America. This proves their potential as construction materials. So far, their utilisation is limited by the lack of normative and construction guidelines. In the absence of such standards, it is de facto impossible to market these products at scale in a conservative sector like construction, which is why cement standards – set by traditional Portland clinker producers – tend to keep silent about this competitive technology. Recent years, however, have seen important changes in this regard, most notably in North America where ASTM (the dominant standardisation body) developed a devoted standard for this type of cements (ASTM C1948). This could have important implications for the market uptake of this technology. For example, the World Cement Association (WCA) established in 2024 that the market share of non-Portland binder cements could be as high as 22,5% by 2050²⁷.

Carbonatable cements:

Carbonatable cements are a relatively new member of the cement family. Unlike other hydraulic cements (e.g. Portland cements), carbonatable cements harden through their reaction with CO₂. As such, this type of cement holds potential for the utilisation of CO₂ from industry sources. Research is still in full swing, though commercially available products on the market today already (e.g. Solidia in the US) demonstrate that in comparison to traditional Portland cement this type of cement has – in a number of applications – potential to significantly reduce both CO₂ as well as mercury, NO_x and SO_x emissions.²⁸

Magnesium cement:

Magnesium is an abundant mineral, widely available in the earth crust. So far, however, it has been little used in cement production, apart from niche applications (e.g. lightweight panels, industrial flooring) where it has a long track-record. Recent years, however, have seen an increased attention to this type of technologies as its production is potentially associated with low CO₂ emissions. It should be pointed out, though, that research to further unravel the underlying mechanisms has only gained traction in the last 5 years²⁹. As such it is too early to assess its market potential for a wider range of applications.



The Circular Arch Bridge at The Green Village, Delft, The Netherlands — a 14-meter pedestrian bridge built from prefabricated concrete blocks made with 100% recycled aggregate, held together by compression rather than mortar. Photo: Daniel Verkijk, courtesy Everox.

Conclusion:

Taken together, the availability of a variety of SCM's as well as advancements in low-carbon binders (LCB) provide varying levels of carbon reduction, summarised in the table below. Many stakeholders argue that the reduction potential of these new types of SCMs and alternative cements would even be higher if its use would be expanded to more applications. However, at present, the uptake of new low-carbon cement alternatives is hampered by standardisation processes, i.e. incumbent industries being overly descriptive on what cement types can be used and enter the concrete mixes. This is particularly true for Europe where its main standards for cement (EN 197 series) and concrete (EN206) are overly prescriptive, as such standing in sharp contrast with the approach taken in other regions (e.g. ASTM standards, refer section 3.2).

Table 3: Common SCM's and low-carbon binders and their GHG reduction potentials

SCM/ Low-carbon binder	Direct CO _{2eq} reductions compared to Portland cement or clinker - in kg CO _{2eq} /t	Assumptions- Raw material by weight (tonnes)	TRL score ¹ (Max- 9)	GHG evolution in process emissions.
Blast furnace slag – as raw material for Portland clinker production	100 kg CO _{2eq} /tonne	15- 20% per tonne of Portland clinker	Already in market	No, eliminates process emissions to the extent it replaces limestone.
Granulated blast furnace slag as SCM	629 kg CO _{2eq} /tonne	80% per tonne of cement	Already in market	No, eliminates process emissions to the extent it replaces clinker.
Unburnt limestone ~30% as SCM	251 kg CO _{2eq} /tonne	30% limestone per tonne of cement.	9, already in market	No, eliminates process emissions to the extent it replaces clinker.
Unburnt limestone ~ 50% as SCM	375 kg CO _{2eq} /tonne	50% limestone per tonne of cement.	8	No, eliminates process emissions to the extent it replaces clinker.
Recycled concrete fines as raw material for Portland clinker production 68 kg CO _{2eq} /tonne	68 kg CO _{2eq} /tonne	16% by mass per tonne of Portland clinker, with assumption of cement paste share at 50%, Portland clinker share of cement paste at 95% and 20% of CO _{2eq} reduction via re-carbonation	8, Heidelberg Materials (ReConcrete) ² CEMENT 2 ZERO. ³	Yes, but process emissions are offset using recycled material.
Recycled concrete fines (enforced carbonated, as SCM)	184 kg CO _{2eq} /tonne	20% per tonne of cement, with assumption of cement paste share at 50% in fines, Portland clinker share of cement paste at 95% and 20% of CO _{2e} reduction via recarbonation.	6 (for enforced carbonation)	No, negative emissions from recarbonation.
Recycled concrete fines (as SCM, without enforced carbonation)	170 kg CO _{2eq} /tonne	20%	9, Everox ⁴	No, eliminates process emissions to the extent it replaces clinker.
Natural Pozzolanas as SCM	205 kg CO _{2eq} /tonne	35% per tonne of cement	9, Materrup ⁵ is producing cements from calcined clay.	No, as its silicates and alumino silicates, not carbonates.
Fly ash as SCM	250 kg CO _{2eq} /tonne	35% per tonne of cement	9	No, eliminates process emissions to the extent it replaces clinker.
Alkali activated cements	Average of 50% ^{6, 7} , compared to concrete from Portland cement. Reported potential up to 90% reduction. Largely dependent on alkaline medium production emissions.	100% replacement per tonne of cement	H- UKR from Hoffmann cements ⁸ . Mevocem ⁹ Cemonite ¹⁰	No, zero process emissions.
Carbonation of calcium silicates	First industrial trials estimate 30% reduction compared to Portland cement, up to 70% for concrete	1.38 tonnes raw meal for 1 tonne of cement		Yes, clinker still contains limestone, but partially reabsorbed while curing.
Pre-hydrated calcium silicates	Potential CO ₂ reduction of 30-50% (compared to Portland cement)	100% replacement per tonne of cement	Celitement ¹¹	Yes, use of limestone.
Belite cements (90% belite, C2S=Ca2SiO4)	48-54 % CO ₂ reduction/ tonne of Portland cement	Nearly same volume of raw meal as Portland cement, 1.51 tonne per tonne of cement.	9	Yes, use of limestone.

Belite - Calcium sulfoaluminate	20-30% CO ₂ reduction / tonne of Portland cement	100% replacement per tonne of cement		Yes, use of limestone.
Magnesium oxide (MgO)-based cements	Potentially Carbon negative			Yes, but negative emissions potential from recarbonation.
Calcium silicate-based cement (non-carbonation)	For example, Brimstone's cement. ¹² 50-60% reduction compared to Portland cement, due to avoided process emissions. Potential for carbon negative emissions.		First to receive ASTM C150 standards certification, similar to Portland cement. Sublime Systems ¹³ , Cemvision. ¹⁴	No, based on silicates.
General assumptions: Comparisons based on a reference plant from Getting the numbers right – 2019, dry process, CO₂eq – 832 kg of fossil CO₂/ tonne of Portland clinker. For comparisons related to SCM's, clinker share of Portland cement is taken at 95% unless specified. Raw meal/ clinker factor- 1.55 Based on data and findings from the Technology Papers published by the European Cement Research Academy (ECRA, 2022).				
1. Basic principle observed; 9-commercial deployment 2. https://www.heidelbergmaterials.com/en/sustainability/we-decarbonize-the-construction-industry/taking-concrete-recycling-to-the-next-level 3. https://www.mpiuk.com/research-project-cement-2-zero.htm 4. https://www.everox.tech 5. https://www.materrup.com/en_GB/mcc2-cement 6. https://www.sciencedirect.com/science/article/pii/S2405844023029250 7. https://doi.org/10.3389/fbuil.2023.1196246 8. https://www.ciments-hoffmann.com/en/ 9. https://www.materialevolution.com/ 10. https://www.cemonite.com 11. https://celitement.de/en/product/manufacturing/ 12. https://www.brimstone.com 13. https://sublime-systems.com 14. https://www.cemvision.tech				

2.2 Efficiency gains, alternative fuels and electrification

2.2.1 Improved efficiency of Portland clinker production

The production of Portland clinker is the most energy-intensive production step of cement making, as it takes place at high temperatures (around 1500 °C). Improving the efficiency of this production step hence directly leads to a significant decrease of the carbon-footprint of cement. The following section details the main routes to achieve greater energy efficiency in the production process.

Preheating via internal heat recovery

One straightforward route is to increase the efficiency of cement manufacture by internal heat recovery: the hot outlet air of the kiln is used to preheat the feed. Different configurations have been developed over time, involving multiple stages of preheating and a pre-calcination step. Efficiency of cement production is related to the inclusion of more stages³⁰. Kiln systems with four to six cyclone preheater stages and pre-calciner are considered as a standard technique for new dry process plants. State of the art techniques achieve typical energy efficiency levels of 2 900 –3300 MJ/tonne of Portland clinker, for a kiln capacity of about 3000 tonnes per day.

Among EU- 27 and Switzerland, in countries with large number of production facilities, Germany, Poland, Spain and France have less than 50% of their installations with the dry process, with preheater and pre-calciner³¹.

Waste heat recovery

Kiln exhaust streams, from the clinker cooler and the kiln preheater system, still contain useful thermal energy. Depending on the number of preheater stages (two to six), the exhaust temperatures from a cement kiln system typically range from 280 to 450° C, while the waste air temperatures from the clinker cooler are typically 250 to 330° C³². Waste heat can be recovered and can provide up to 30 percent of a cement plant's overall energy needs³³.

Three types of primary waste heat recovery power generation systems are available, differentiated by the type of working fluid: steam (Steam Rankine Cycle), organic fluids such as pentane (Organic Rankine Cycle) or a binary mixture of ammonia and water (Kalina Cycle). The ORC systems can be utilized for waste heat sources as low as 150° C, whereas steam systems are limited to heat sources greater than 260° C. The Kalina cycle has an operating temperature range that can accept waste heat at temperatures of 95° C to 535° C and is claimed to be 15 to 25 percent more efficient than ORCs. Yet the technology is in the early stage of market introduction with limited suppliers and experience.

Application of waste heat recovery power systems to cement kilns can be challenging. The exhaust gases from the kiln preheaters and clinker cooler typically contain relatively high dust concentrations that sometimes exceed 50 g/Nm³ and the waste gas temperatures can fluctuate widely during kiln operation. Another bottleneck is the initial investment and a long payback period depending on local electricity costs³⁴.

Waste heat can also be provided to a district heating grid to cover the thermal needs of other energy consumers in the neighbourhood. Yet the potential fluctuating supply of the heat can create operational challenges for the operator of the district heating system. In addition, the industry is less likely to commit for long-term supply contracts while district heating systems are usually amortised over several decades.

Despite the issues in commercialising waste heat recovery into the heating grids, it's undeniable that up to 30% of a plant's thermal energy input is just being wasted to environment. ORC based heat recovery systems are sometimes treated as cogeneration technology rather than waste

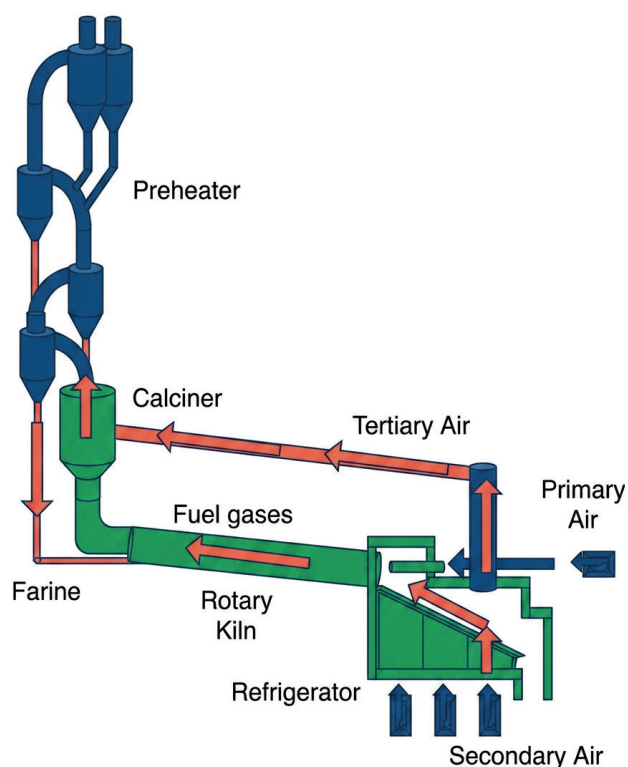


Figure 7: Schematic of a 4-stage preheater plus calcinatory.

to power technology³⁵ indicating that ORC's are more suitable for a combined heat and power production. Analysis done by CE Delft³⁶ shows that cement plants have a positive internal rate of return (14-35%) for the investment on ORC and a CO₂ savings of 1900-15000 tonnes each year. A recent study³⁷ on thermal energy harvesting also shows that Portland clinker production in just 7 countries (BE, DK, FR, DE, IT, NL and UK) has a potential of about 447 MW of power generation capacity and a total of 6.6 GW for all industries.

2.2.2 Alternative Fuels

The cement industry in EU has been diversifying its fuel use for almost 3 decades now. The diversification was primarily aimed at cost reductions and subsequent legislations on waste; industrial emissions and the EU ETS shaped the use of various alternative fuels in the cement kiln.

Today, almost 53 %³⁸ of the fuels used in cement kilns are alternative fuels, containing refuse derived fuels (RDF), biomass, sewage sludge, waste oils, end of life tyres and other types of waste. The remaining share is covered by pet coke, coal, lignite and a small share of other fuels. The alternative fuels also include fossil fuel products like plastics and tyres which contribute to the overall carbon emissions of cement.

Industrial and municipal waste as fuels:

Refuse derived fuels (RDF) are processed fuels based on municipal and industrial solid waste and usually contain high calorific value products like plastics, tyres, paper, cardboard, wood and textiles, accounting for approximately 34 % of the municipal solid waste. While RDF has no EN or ISO standards, the RDF that complies with EU standards is termed solid recovered fuels (SRF) under EN ISO 21640: 2021. Cement kilns usually prefer class 1 or class 1 RDF with higher calorific value³⁹.

According to Cement Europe⁴⁰, 46% of the alternative fuels used is RDF, 43% of it contains mixed industrial waste, end of life tyres, animal and bone meal, impregnated saw dust and other non-recyclable wastes and the rest covering biomass, solvents and sewage sludge.

Existing EU industry roadmaps⁴¹ aim to increase the share of alternative fuels up to 95% by 2050. While the Global cement and concrete association (GCCA)⁴² expects the share of alternative fuels at 43% by 2050. This is, as GCCA explains, is dependent on the regional availability of waste streams and policies regulating waste management in the region. The EU's strict waste management policies, since 1980's has contributed to the high availability of processed waste fuels for EU cement industry.

However, the use of these alternative fuels is more challenging than the conventional ones; their energy density and moisture, volatile and ash contents can lead to incomplete combustion, reduced flame temperature and poor heat distribution; unstable pre-calciner operation, clogging in the pre-heater cyclones, build-ups in the kiln riser ducts and, higher emissions of SO_x , NO_x , CO and particulate matter⁴³. Heavy metals like Mercury, Cadmium, Chromium and lead are present in comparable quantities to coal in alternative fuels like sewage sludge, waste oils, solvents, plastic and tyres.

Therefore, cement kilns are regulated under the industrial emissions directive to have strict emission limits, although the emission limits are far lower than those for waste incineration without energy recovery.⁴⁴

Table 4: Emission limit values for cement production and waste incineration.

Pollutant	Emissions limit values prescribed under cement lime and magnesia BREF, 2013 ⁴⁴	Emissions limit values prescribed under waste Incineration BREF, 2019 ⁴⁵
Dust	10-20 mg/Nm ³	2-5 mg/Nm ³
NO _x	200-500 mg/Nm ³	50-150 mg/Nm ³
SO ₂	50-400 mg/Nm ³	5-40 mg/Nm ³
Mercury	50 µg/Nm ³	10 µg/Nm ³



Considering that in many EU countries, cement kilns burn more waste than many member state entire incinerator fleets^{46 47}, these differences contribute to additional pollution from cement plants co-incinerating waste and indirectly lead to higher health damages (refer to section 1.1). Apart from less stricter emission limits, co-incinerating cement plants also have less obligations to continuously monitor some pollutants. In fact, many civil society organisations opine that co-incineration is just incineration with a different name as waste streams expand.

Incineration occupies a lower position in the EU waste hierarchy than reuse, repair and recycling, which should be prioritised⁴⁸, but statistics show⁴⁹ that incineration has doubled in the past 3 decades in the EU. While the use of waste as alternative fuel in cement manufacturing is intended to rely on residual streams, current regulatory framework and market can create a risk of diverting materials away from higher-value recycling pathways. This risk is particularly relevant for biomass fractions, which often have competing material applications, implying that their availability for energy recovery is constrained as circularity improves.

Alternative fuel use as a carbon reduction strategy:

Apart from cost economics of fuel use, the use of alternative fuels with biogenic fractions like wood, paper and some textiles is also used to reduce carbon emissions. Since the biogenic sources of carbon are considered carbon neutral, it's not counted as fossil carbon under the EU ETS. Therefore the proportion of biogenic carbon emissions can be reduced from the total fossil carbon emissions per tonne of Portland clinker resulting in cost savings from not buying EU ETS allocations.

Despite free allocations, these reductions, along with gate fees paid by waste operators to cement factories for the uptake of RDF, constitute a small but growing savings in cost, which will increase when free allocations are reduced or phased out.

But, based on a recent study⁵⁰ on carbon reductions from alternative fuels, the benefit from adding biogenic sources on carbon reduction is hardly 2% even when RDF based on municipal solid waste replaces all other options.

2.2.3 Hydrogen as a fuel and potential co-production

Hydrogen fully replacing existing fuels in cement kilns has not been commercially tried so far. Most of the pilot's plants test hydrogen up to 50% and while it's possible to use 100% hydrogen in a ce-

ment kiln, its use in the cement sector is not one of the highest priorities for hydrogen in the EU.

The main reason why hydrogen is not seen as effective in industrial processes requiring radiative heat (like rotary kilns, glass or ceramic furnaces) is because hydrogen flames carry a lot of total energy but have low emissivity and deliver much lesser radiative heat⁵¹ to solids like Portland clinker. As a result, the excess heat energy remains in the gas phase without effective transfer to the materials.

The flame characteristics of hydrogen are significantly different from those of conventional fuels, and this poses challenges when switching to hydrogen. The hydrogen flames are typically shorter and hotter which can lead to the formation of more NO_x⁵² compared to conventional fuels. The heat radiation from the flame is lower, which can disturb the clinker burning process. Due to its high auto-ignition temperature (585 °C), the kiln start-up will require some additional ignition sources like natural gas as it is difficult to ignite a hydrogen/air mixture with heat alone.

With these challenges, hydrogen is unlikely to be a standalone alternative fuel in cement kilns and needs to be blended with other fuels or diluted with an inert media like nitrogen, steam or flue gases from the plant. While the addition of nitrogen may in some cases increase the NO_x formation in the process, steam dilution reduces it. Steam dilution also lowers the reactivity and flame speed of hydrogen, which can prevent the risk of flame flash-back. The combination of steam injection and hydrogen can provide controllable combustion, but increasing the heat transfer efficiency requires other fuels to be considered. In 2022, one of the largest trials to switch to zero CO₂ emission fuel in a cement kiln was done in the UK, at Ribblesdale by the BEIS-MKA⁵³ in the plant of Hanson UK, now part of the Heidelberg Materials. The study largely confirmed the unsuitability of hydrogen for Portland clinker formation and suggested that combined use of biomass can help overcome some combustion characteristics. Further research^{54 55} with a fuel mix of hydrogen, glycerine, meat and bone meal was used to partially replace coal in the kiln and concluded that the Portland clinker produced fulfils the market requirements.

Several pilots in the EU, notably by Heidelberg, Holcim⁵⁶ and CEMEX⁵⁷ show the potential for hydrogen switching and reduction of GHG emissions in cement production. Holcim is the only cement producer who managed to increase the share of hydrogen to over 58%, the highest reported so far in the EU.

The EU's hydrogen policy aims to use hydrogen as a priority for industrial sectors with no easy decarbonisation pathways, especially when electrification is feasible. There is only one project under IPCEI (Important projects of common European interest) granted for hydrogen as a fuel in cement production, in 3 sites in Greece by Titan cements⁵⁸.

However, as said earlier, strategies to use hydrogen to reduce GHG emissions can cover only 35-40% of the total emissions from the fuels used in cement production. Therefore, its best possibility to reduce emissions remain capped at 40% unless it's used as a fuel source in production of LCBs.

Hydrogen production in cement plants:

As the importance of hydrogen grows as a crucial input for industrial decarbonisation, many cement producers have realised the co-benefits of hydrogen production, including the possibility of selling excess hydrogen to the market.

In general, hydrogen production is envisaged in a cement plant for,

- Capturing the CO₂ from the production of blue hydrogen via steam methane reforming (SMR) or auto thermal reforming (ATR) with a CCS unit as a strategy for sharing CCS infrastructure with the option to capturing CO₂ from flue gases in the future.
- Storage and use of such hydrogen as an energy carrier, not restricted to co firing as an alternative fuel.
- Sale of such hydrogen for other users

The production of hydrogen in a cement plant using SMR or ATR can be used as a commercial strategy, which leverages the siting advantages of the cement plant and creates a new revenue stream. Often this is seen as a first step in the investment of CCS in a cement plant, as capturing a pure stream of CO₂ from the flue gas is technically complex apart from being expensive in energy, cost and time as compared to capturing CO₂ from SMR or ATR based hydrogen production. This is also evident from the cost⁵⁹ of blue hydrogen⁶⁰ as compared to green hydrogen which is typically cheaper by 50% today (till 2030) and will remain cheaper in the midterm (post 2030) and becomes comparable only in the long term (2040-2050).

Costs of hydrogen is also a steep barrier for its use in cement kilns. Cement kilns need to use green hydrogen to make the best use of hydrogen to reduce carbon emissions. Grey hydrogen only increases net carbon emissions as the role of hydrogen is just a supplementary fuel in the cement industry compared to a reducing agent in

the steel industry. The cost of green hydrogen produced using renewable energy is typically in the range of 7-10 Euro/kg today⁶¹, several times more expensive than hydrogen produced using methane in a SMR. However, producing green hydrogen specifically as a fuel for cement kilns is extremely energy intensive and represents an inefficient use of renewable electricity, given the significant conversion losses during electrolysis and heat transfer during combustion.

The use of hydrogen in the cement industry as an alternative fuel is relatively new. The technological readiness is still low – level 5⁶² on a scale of 9 -and its rollout requires more considerations on the economic viability of hydrogen production at site rather than the purchase of hydrogen, at least in the short term.

2.2.4 Electrification

Electrification in the production of cement involves at least three broad categories of technologies, electrolysis, electrified heating and other electrochemical processes.

Electrified heating can help in decarbonising the use of fossil and alternative fuels in electrified kilns or calciners, but it can only reduce fuel related share of the total GHG emissions from cement production. This is because the process emissions in Portland clinker production (calcination) are inherent to the chemistry and not dependent on the external energy source used.

Electrolysis, an emerging technique, has wider applications. When used in the production of Portland clinker, it enables the recovery of purer CO₂ streams from the carbonate decomposition, which can then be captured and stored or used for the further production of aggregates and additives for cement and concrete.

Electrolysis can also be used in the production of some LCB's, like calcium silicate-based cements, where the process does not generate CO₂ and the cement produced can achieve near zero GHG emissions, if renewable electricity is used and the raw materials are also decarbonised.

Electrified heating:

Electrified heating usually refers to supplying the thermal energy needed for limestone calcination and subsequent clinker phases, using electricity rather than fuel combustion. While it can significantly reduce the emissions intensity, it does not remove process emissions from calcination. When compared with hydrogen, electrified heating is more efficient as it avoids the conversion losses in the production and combustion of hydrogen.

However, the higher the temperature, the more

difficult it is to replace a combustion process by an electric one. This remains true even today and achieving full electrification in the non-metallic minerals sector is already known⁶³ to pose a challenge in the coming years. Advances in high temperature electrification also helps in the production of LCBs by decarbonising remaining thermal demand, as their binder synthesis pathway reduces the largest source of CO₂ emissions as compared to Portland cement.

Overall, many electrified heating techniques can be considered as a CCUS facilitated pathway for cement production and therefore cannot be considered as an LCB facilitating pathway. This also means that any technoeconomic analysis of these techniques demonstrating a higher TRL needs to consider the CO₂ avoidance costs and their dependence on emerging CO₂ markets.

Broadly, there are four different electrified heating techniques that are leading this innovation further.

Resistive heating:

Resistive heating is the most mature technology capable of providing high temperature heat for calcination. Limestone decomposition via calcination has already been demonstrated at 950°C in 2017 with resistive heating but the substantial capital involved has been a big barrier towards commercial use.

Many pilots⁶⁴ have been conducted since 2015 in the EU to mature electrification. Some of these projects explored electrified heating as a dual strategy- to reduce fossil fuel use as well as to enable purer CO₂ streams required for CCUS. Many of them had explored synergies for high temperature heat required for other industry like ceramics and many studies were done on resistive as well as plasma and microwave heating. Five of the eleven projects listed are still ongoing.

Despite being the most mature of other electrified heating techniques, resistive heating is not a general solution to Portland clinker production as it faces scale up and efficiency challenges apart from retrofitting costs⁶⁵.

However, its relevance lies in medium temperature alternative binders and SCM production. In these areas, resistive heating provides better control of temperatures, avoids combustion related pollution and the related cost of pollution control equipment apart from delivering purer CO₂ streams.

Inductive heating:

Induction heating is more efficient as it converts electricity directly into heat rapidly but only for materials with high conductivity. The raw meal for Portland clinker has a low electric conductivity and therefore the heat from induction coils must be transferred to the raw meal with an efficient heat exchange system. The additional energy required for cooling the induction coils to prevent the heat transfer (radiative and conductive) from the raw meal to the coils makes thermal efficiency a challenge in these systems. Some of the past projects in the EU (ELSE-1 and CEM ZERO) have explored induction heating for cement production but they favoured resistive heating in their final analysis. Overall, induction heating has far more challenges than resistive heating to be used in cement production.

Plasma heating:

Plasma is a technique where the ionised superheated state of matter with temperatures over 10000°C is used to heat the raw meal for binder/ cement production. Plasma techniques have been successfully commercialised in waste gasification for decades, providing a track record for high temperature electrification in industrial processes. Plasma heating is more efficient than resistive heating (85-90% compared to 60-70%).

Plasma can be generated by heating a gas or ionising it with an electrical discharge producing an electrically charged superheated gas. This plasma is then directed to the pre-calciner where it induces the pre-calcination process. The heat is mostly radiative, similar to hydrogen flames, but is easily resolved by using a mix of gases which deliver the heat to the raw meal by convection rather than radiation.

Further research has identified that the unavoidable process CO₂ along with injected N₂ or other inert gases can be suitable for heat transfer. This offers two advantages- isolating a relatively purer stream of CO₂ (60 %) for CCUS and prevention of NO_x formation due to an inert air environment. Plasma heating therefore aligns with the limestone raw meal and calcination process used, making it a CCUS facilitated cement production route.

The high temperatures involved also require robust cooling systems to extend the service life of the electrodes, a notable addition to the techno economic assessments on plasma heating.

A fully electrified cement plant with a capacity of

1 Mt/ year clinker production will typically require around 70-85 MW⁶⁶ of total electrical load, compared to 20-40 MW for a conventional cement plant today. The thermal processes of such a plant can account for almost 60 MW. This shows the massive increase in electrical demand and the need for utility scale infrastructure to bring this technique to reality in cement production.

Many EU⁶⁷ and global pilots exist in this area of research. Notably, the collaboration between SaltX and Holcim⁶⁸ to create the world's first all-electric plant based (ZEQL- zero emission quicklime), with salt X's electric arc calciner (EAC) technique integrated with carbon capture, is an example of long-term commercial potential for plasma heating techniques.

Microwave heating:

Microwave heating differs in its mode of interaction which is not convection or radiation but rapid oscillation of polar molecules in the binder feedstock.

Two dominant frequencies are used in the industry 0.915 ± 0.013 GHz and 2.45 ± 0.05 GHz, but the heating depends on the dielectric properties of the material as non-conductive materials are more conducive for microwave heating.

Since most of the energy emitted by the magnets are theoretically absorbable, the heat transfer by photons raises temperatures rapidly. This means that the kiln doesn't have to be heated to high temperatures than what is needed for calcination, saving energy.

While the technique has been largely applied for limestone calcination, recent research also shows that microwave heating accelerates⁶⁹ geo-polymerisation in the hardening and curing of metakaolin based geopolymer binders.

Solar thermal heating:

Largely based on concentrated solar power systems using mirrors or lenses to concentrate solar power to a small area, this technique has the potential to produce heat as well as generate electricity. This heat is transferred to a heat transfer fluid, which can reach temperature up to 1000°C, which makes it a useful heat source for the calcination process. Most research in solar thermal heating has been on its use in calcination, solar thermal heating techniques can also be largely classified as a CCUS facilitated cement production pathway.

Notable pilots include the CEMEX-Synhelion project^{70 71}, supplying 1500°C heat to a rotary kiln, using the Synhelion's solar receiver. The heat

transfer fluid is composed of water and CO₂, making post process CO₂ extraction straightforward.

2.2.5 Electrolysis based production techniques

Electrolysis bypasses calcination by producing calcium hydroxide which later reacts with siliceous or aluminosilicate materials to form other types of cementitious phases. These binders can in principle deliver a comparable performance to Portland clinker produced by the conventional thermal route. However, the generation of CO₂ is dependent on whether the source of calcium feedstock used contains carbonates. CO₂ produced in such electrolysis-based processes using carbonates is typically released as a purer stream simplifying its capture and potentially reducing the cost of carbon capture systems.

Recent literature surveys⁷² on use of electrolysis in cement production identify many promising techniques, summarised in the table below.

From the point of view of this report, we can broadly classify these techniques as carbonate feedstock-based electrolysis techniques and sea water feedstock-based electrolysis.

Carbonate feedstock-based electrolysis:

These techniques are largely dependent on solid carbonates from non- seawater-based sources. The use of carbonate feedstock (limestone) generally indicates the generation of CO₂ but as is common in many electrolysis-based techniques, the CO₂ is typically purer than industrial flue gases and offering an economical advantage for carbon capture and use systems (CCU).

However, two of these three techniques can avoid the generation of CO₂, retaining it as carbonates - ZeroCAL and Solar thermal electrochemical process (STEP).

ZeroCAL, uses a three-step process:

1. dissolution of calcium carbonate using chelators which removes (chelates) the Calcium ions from the equilibrium, accelerating dissolution.
2. nano filtration followed by acid promoted decomplexation to recover calcium from the chelator; and
3. an ultrafast precipitation of calcium hydroxide using the alkalinity produced in the process.

The process, while producing hydrogen, oxygen and sodium bicarbonate as by products, avoids generation of CO₂ as a gas by retaining it in bi-

carbonates. While sea water use in ZeroCAL process is not strictly required for carbon retention, it provides the conditions that favour the stabilisation of CO₂ into bicarbonates.

STEP, on the other hand, is a technique originally developed for high temperature electrochemical processes but has been adapted for limestone processing and CO₂ conversion to industrial precursors. When used for binder production, STEP avoids CO₂ generation by electrochemically converting carbonate into solid carbon and carbon monoxide rather than releasing it as CO₂. Higher operating temperatures (around 700-900°C) aid carbon monoxide formation, which has its use as industrial precursors, low temperature heat (400- 550°C) produces both solid carbon and carbon monoxide.

Sublime Systems, an USA based scale-up company backed by Holcim and CRH, has developed a method where calcium is extracted from a wide range of wide range of calcium rich minerals through electrochemical process at ambient temperatures. When non carbonate calcium feedstocks⁷³ are used, the process can produce cements⁷⁴ without any CO₂ emissions. Sublime cements are currently in pilot and early commercial demonstrations.⁷⁵

Table 5: Carbonate feedstock-based emerging electrolysis techniques for binder production:

Technique	Additional feedstocks and inputs used in trials	Generation* of CO ₂ emissions
ZeroCAL process ⁷⁵	No additional feedstocks or thermal energy	Avoided and retained as bicarbonates
Sublime Systems ⁷⁶	No additional feedstocks or thermal energy	Yes, the purer streams allow capture and use.
STEP (Solar Thermal Electrochemical Process)	High or low temperature heat from concentrated solar power	Avoided, high temperatures aid more carbon monoxide formation, while low temperature favour solid carbon and carbon monoxide.

Sea water-based electrolysis:

This familiar technique was initially used for electrochemical precipitation of dissolved carbonates and metal hydroxides from sea water but can be extended to produce calcium and magnesium rich hydroxides. These materials can serve as precursors for producing electrochemically derived binders /cements. While some of these binders are chemically related to the broader Portland cement family and can be processed into similar hydraulic binders, they can also be used to produce non-Portland binders. While most of the techniques discussed produce relatively pure streams of CO₂ emissions, a specific variant using ultra filtration membranes and renewable low temperature heat (500° C) can avoid the generation of CO₂ (from carbonate decomposition) and directly produce calcium oxides, a precursor for Portland cement production.

In techniques which use carbonate-based feedstocks, binder production is intrinsic to the process, and most outputs are Portland-like or non-Portland hydraulic binders but avoid calcination and high temperature processes. In contrast, for sea water-based techniques- based on dissolved species of calcium and magnesium rather than solid carbonate rocks, its useful to explicitly assess the potential to produce LCBs, as binder production is not the primary objective of many of these processes.⁷⁷

Table 6: List of emerging sea water-based electrolysis techniques for binder production

Technique	Additional feedstocks* and inputs used in trials	Generation** of CO₂ emissions	Potential for low carbon binders (LCB)	Primary goal
Conventional seawater process (Hilbertz method)	No additional feedstocks or thermal energy	Yes, but high purity is dependent on system parameters.	No, but outputs can be used for SCM/s based on calcium and magnesium.	Production of binders and CO ₂ removal
Equatic process ⁷⁷	Industrial flue gas CO ₂	Yes, but existing research does not demonstrate 100% CO ₂ capture under all operating conditions	No, produces Ca- and Mg-rich solid phases with potential applicability as non-Portland binders or as Ca/Mg-based SCM's, subject to downstream processing.	CO ₂ removal.
Ultra Filtration membrane process	Renewable heat (500° C)	Avoidable, as the direct production of calcium oxides avoids carbonate decomposition by to dehydrating Calcium hydroxide using low temperature heat	Yes, in principle. SCM's and Magnesium based cements can also be produced with additional CO ₂ from industrial flue gas.	Production of binders or carbon negative mineralisation
Membrane-less electrolysis and Cl-mediated / Ca-looping	No additional feedstocks	Yes, but CO ₂ can be mineralised into solid carbonate phases.	Yes – in principle. The solid Ca/Mg carbonate or hydroxide phases generated could be routed into LCB production.	Carbon negative mineralisation for Membrane less electrolysis and CO ₂ removal for Cl-mediated / Ca-looping
Note: *The feedstocks for sea water-based electrolysis techniques are dissolved sea water ions (Ca ²⁺ , Mg ²⁺) and seawater-derived dissolved inorganic carbon (as carbonates and bicarbonates). Any new additions to the process are included in the table. **Generation of CO ₂ emissions refers to process-level CO ₂ evolution; net CO ₂ outcome depends on downstream capture, mineralisation, and system boundaries.				

Conclusion:

Electrification of cement production is inevitable regardless of the technique used or the binders manufactured. The high temperature heat required for calcination is still a big barrier towards electrifying heat while electrolysis-based methods find an alternative process pathway to achieve similar results. However, electrolysis-based methods are more conducive for low-carbon binders despite the binders produced as well as the technique used are both emerging techniques while offering a potential best-case scenario where low-carbon binders can be produced with energy efficient techniques. Regardless of operational efficiencies or heating techniques, the minimum theoretical electrical energy required for calcination-based cements are high (at 2.1 GJ/t of clinker). Electrification of Portland cement production places huge demand on electricity infrastructure.

2.3 Sufficiency, circularity and material efficiency in the decarbonization of cement and concrete

Sufficiency, circularity and material efficiency strategies contribute significantly to decarbonisation of cement and concrete through cumulative CO₂ emissions savings over the full value chain. This includes, in descending order of decarbonisation potential:

- applying sufficiency measures to reduce demand for new construction by making better use of existing spaces and extending the lifetimes of buildings through renovation and retrofitting.
- full or partial replacement of concrete in individual buildings and structures by alternative low-emission materials, such as timber and other bio-based materials.
- reduction in the amount of concrete used in buildings and concrete structures through digitalisation, waste prevention and materially efficient structural design and material specifications.
- reduction of the cement-to-concrete ratio in concrete end-use applications.
- use of decarbonised waste streams as alternative raw materials (ARMs) to replace limestone in clinker firing or as SCMs to replace Portland clinker in cement.
- use of recycled concrete to replace aggregates in concrete production, where this reduces emissions from their transportation from quarries.

Sufficiency measures, defined by the IPCC as “a set of measures and daily practices that avoid demand for energy, materials, land and water while delivering human well-being for all within planetary boundaries”⁷⁸, are essential to achieve a carbon neutral and sustainable building stock. In contrast to other circular economy and material efficiency strategies aimed at material or component level, sufficiency strategies are about rethinking building usage and thereby reducing the demand for new buildings altogether. Such measures include reducing vacancy rates, converting vacant buildings to new uses (especially commercial properties to housing), prioritising primary housing in high-pressure areas, making better use of underoccupied dwellings (e.g., promoting co-living, splitting or swapping houses), topping up (adding one or more floors to existing build-

ings), and extending the lifetime of buildings (prioritising renovation and reconstruction over new construction), as well as designing buildings for adaptability⁷⁹. These strategies are the most significant in terms of reducing embodied carbon in buildings from concrete and other materials, as well as operational energy use.

Beyond sufficiency measures, increasing the share of bio-based construction materials, such as timber, as an alternative to concrete or in hybrid structures is a key strategy for reducing demand for concrete and the lifecycle carbon of buildings, especially in new construction. In building design and construction, the unit consumption of concrete and other emission-intensive materials relative to constructed space can be reduced, e.g. by optimising spaces and structures in buildings, using lightweight materials, adapting material specifications closer to actual performance parameters, using prefabricated building structures and components, or reducing the volume of construction waste generated on sites. These material efficiency strategies are analogous to energy efficiency in reducing energy consumption during the operational phase of buildings.

Reducing cement content in concrete mixes (the cement-to-concrete ratio) requires fundamental changes to current industrial practices, including extending the curing time of concrete and coordinated action along the entire value chain. Thus far, practice in this area has focused mainly on replacing natural aggregates in concrete mixes with recycled concrete. Concrete mixes with a lower cement content are used, for example, in foundations. However, the general practice on construction sites is to use as few different concrete mixes (types of concrete) as possible, which leads to excessive overall use of cement in concrete.

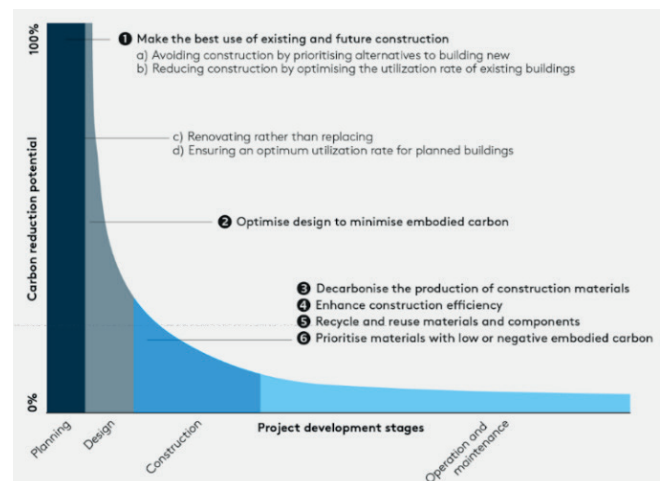


Figure 8 : Carbon footprint reduction curve for buildings. Source: UK Green Construction Board (graphics); Shifting Paradigms (2023). Embodied carbon regulation in the European construction sector - An analysis of the economic impact (list of measures)

In contrast to use of scrap for production of steel through the EAF route, secondary raw materials (from waste streams) have only a limited impact on reduction of process emissions from production of clinker and cement. At EU level, there will be a gradual decrease in availability of fly ash (currently the most widely used ARM for clinker production, with a 20% share)⁸⁰ due to the phasing out of coal-fired power plants. A similar trend is expected for (ungranulated) blast furnace and converter slag as steelworks transition to the direct reduced iron (DRI) process using hydrogen and the production of recycled steel in EAFs. New or prospectively growing sources of ARMs include slag from the incineration of sludge and other waste, steel slag (from electric arc furnaces), construction and demolition waste (CDW) including recycled concrete fines, waste bricks and roof tiles, and contaminated soils, with some of these resources requiring pre-treatment and additional decarbonisation⁸¹.

Given the standstill in the standardisation of constructions products via harmonised standards caused by the James Elliot ruling⁸², the cement industry has in recent years followed a non-harmonised approach to developing new standards for low-carbon cements. The non-harmonised European standard EN 197-6 defines requirements for cement incorporating recycled building materials. It allows for the use of concrete fines in cement composition up to 35% in combination only with clinker (CEM II/F), up to 29% in combination with another additional component (CEM II/M) and up to 20% for blended cements in combination with clinker and blast furnace slag (CEM VI). A key condition for increased uptake of high-quality recycled concrete and other usable CDW streams (including recovery of concrete fines) for use in clinker and cement will be the mainstreaming of pre-demolition audits, selective demolition of buildings and on-site sorting of CDW as part of standard construction practice, including the adoption of related standards at national level.

In the 2022 net zero roadmap of the Global Cement and Concrete Association (GCCA), 45% of total CO₂ emissions savings from cement and concrete by 2050 are attributable to circularity or material efficiency measures, including 22% from “efficiency in design & construction”, 11% from “efficiency in concrete production”, 9% from “savings in cement and binders” (from cement blending by SCMs, both primary and secondary/recycled) and approx. 2% from use of decarbonated ARMs in clinker production⁸³. Cembureau’s (now Cement Europe) 2024 updated net zero roadmap for cement in the EU attributes 10% of CO₂ emissions savings by 2050 (relative to a 2021 baseline) to “concrete mix”, 21% to cement blending (by both primary and secondary SCMs)

and 4% to use of decarbonated ARMs in clinker production. It does not reflect potential savings from lower concrete demand related to efficiency in design and construction of buildings and infrastructure⁸⁴.

2.4 CCS- why, when, where and how much support?

The cement sector is characterised by an important amount of process CO₂ emissions due to clinker production, the key constituent of cement. While CCS is commonly promoted as the main solution to decarbonise cement production to reduce the high share of process emissions (~60%), of the total cement manufacturing emissions, other effective and readily deployable solutions are available, such as alternative binders or advanced recycling technologies for recovered cement but often overlooked.

According to the Alliance for Low-Carbon Cement and Concrete (ALCCC)⁸⁵, clinker substitution and cement blending can play a much bigger role in reducing GHG emissions than it does today. Existing and commercially available solutions can be scaled up at near zero costs, and when done successfully, cut the cement industry’s footprint by 50%. The potential for abatement is even higher given that other technologies with high TRLs are in full development, showing great potential to further bring down clinker use in cement due to more complex mixing designs or even substitute it altogether (e.g. cement-free concrete mixes).

While the LIFE Scenario⁸⁶ considers a 70% clinker-to-cement ratio as an ambitious target to increase emissions reductions, a study by The New Climate Institute and the Environmental Coalition on Standards⁸⁷ modelled different mitigation scenarios where the clinker-to-cement ratio in Europe reaches 60%, 50%, or even 40% by 2050. The study shows a significant potential for CO₂ reduction, with annual emission savings of up to 52% in the most optimal scenario. More recent insights and research show that it is possible to go faster and further in clinker reduction in Europe, with the possibility of reaching a 40% ratio by 2030 and a 25% ratio by 2035⁸⁸.

The implementation of other non-CCS decarbonisation strategies will further allow to bring emissions down:

- Increasing material efficiency by reducing over-specification and specifying low-carbon concretes in building construction without compromising safety would allow to reduce the emissions from concrete up to 40%.

- Increasing the energy efficiency of dry kilns by 13%.
- Increasing the electrification of kilns by 70% by 2050⁸⁹.
- Increasing the lifetime of buildings through deep renovations instead of building new constructions.

CCS might have a role to play in cement production by capturing residual CO₂ emissions, but it would be only a complementary role. At the EU level, a 40% reduction in overspecifications can bring down emissions to 56 Mt CO_{2eq} annually⁹⁰. With ambitious clinker-to-cement ratios this figure can be brought down to 28 Mt. Improving energy efficiency can lower it further, while electrification would significantly reduce CO₂ in the first place by preventing combustion of fossil fuels. This approximate calculation is consistent with what is envisaged by the PAC scenario, which in its more ambitious pathways consider a range from 0 to 23 MtCO_{2eq}/year to be captured with CCS in all sectors.

A recent report by Bellona Europa⁹¹ models the various levers for decarbonisation of the cement sector, into four scenarios. The scenarios include sufficiency, material efficiency, concrete subti-

tution using timber, clinker substitution using SCMs, fuel substitution and permanent carbon capture. In two of the four scenarios where sufficiency, resource efficiency and clinker substitutions are prioritised (implying that standards permit higher substitution by many SCMs), the total need for permanent carbon capture is less than 8 Mt CO_{2eq} / year. However, in a scenario where carbon capture is prioritised (no change in standards), the role of CCS rises up to 30 Mt / year.

Also, a key role is played by the actual capture rate; Heidelberg Materials first industrial-scale CCS facility in the cement industry in Brevik, Norway, which is able to capture only 50% of the CO₂ emitted by the plant⁹². But this is changing, and the recent investment decision at Padeswood (UK) aims to capture nearly all CO₂ emissions of the plant⁹³.

All things considered, the decarbonisation roadmap promoted by Cement Europe⁹⁴ foreseeing the use of CCUS (Carbon Capture, Usage and Storage)⁹⁵ to capture 50 Mt of CO₂ per year by 2040 and 62 Mt by 2050 looks exaggerated and risky, since it relies too much on an unproven, expensive/unprofitable and unsafe technology⁹⁶ that, to date, is still very far from ensuring such a high amount of capacity⁹⁷.



Recycled-aggregate concrete blocks tested for long-term saltwater and freeze-thaw resistance at the South Pier Living Lab, IJmuiden, The Netherlands — part of ongoing research into circular concrete performance. Courtesy Everox.

Policies supporting the transition to low-carbon binders in Europe

3.1 Harmonised standards and the CPR

3.1.1 The Construction products regulation

The Construction Products Regulation (CPR) is the main legal framework for construction products in the EU. It lays down the harmonised rules for the placement of construction products on the internal market, by providing a common technical language to assess the performance of construction products. This is done through the development of harmonised standards. The overarching objective of the CPR is to ensure that construction products (like cement) are offered a level-playing field for market entrance across the Single Market, by providing a harmonised framework on how to assess the performance of a certain product. Importantly, standards developed under the CPR need to be performance-based and technology neutral in order to comply with EU law. This is spelled out explicitly in the standardisation requests which are the guiding document for CEN when drafting a harmonised standard.

Importantly, the CPR has recently been revised with the new version having entered into force in December 2024. The underlying ambition of the revision was threefold: (i) strengthening the development of standards; (ii) integrating environmental and sustainability considerations to advance the EU's climate objectives; and (iii) to promote digitalisation. Of relevance for cement, is also the Eco-design Sustainable Products Regulation (ESPR) as it has a clear deadline included by when the CPR needs to deliver on Ecodesign, i.e. 2029.

In terms of actual standards development, the main body of relevance for CPR implementation is the so-called CPR acquis process. This refers to a constellation of working groups and bodies with experts from Member States and other stakeholders, on a topic and product basis. For example, for cement there is a devoted subgroup, as is also the case for most other construction materials. The main task of the CPR acquis is to provide input on forthcoming standardisation requests. These standardisation requests outline for a given product how the future standard should look like and can be seen as a legal mandate provided by the European Commission in the form of an implementing act to recognised European Standardisation Bodies (in this case CEN). Given the technical nature of these discussions, today's CPR acquis subgroups have a strong bias towards a strong overrepresentation of industry representatives. The final step in the standardisation drafting process is the actual drafting of the standard. Upon accepting a standardisation request, this happens in the designated technical committee of CEN. Given that CEN is a private entity, representing different national standardisation bodies which bring together industry representatives per topic. Engagement of other societal stakeholders is therefore also much more limited.

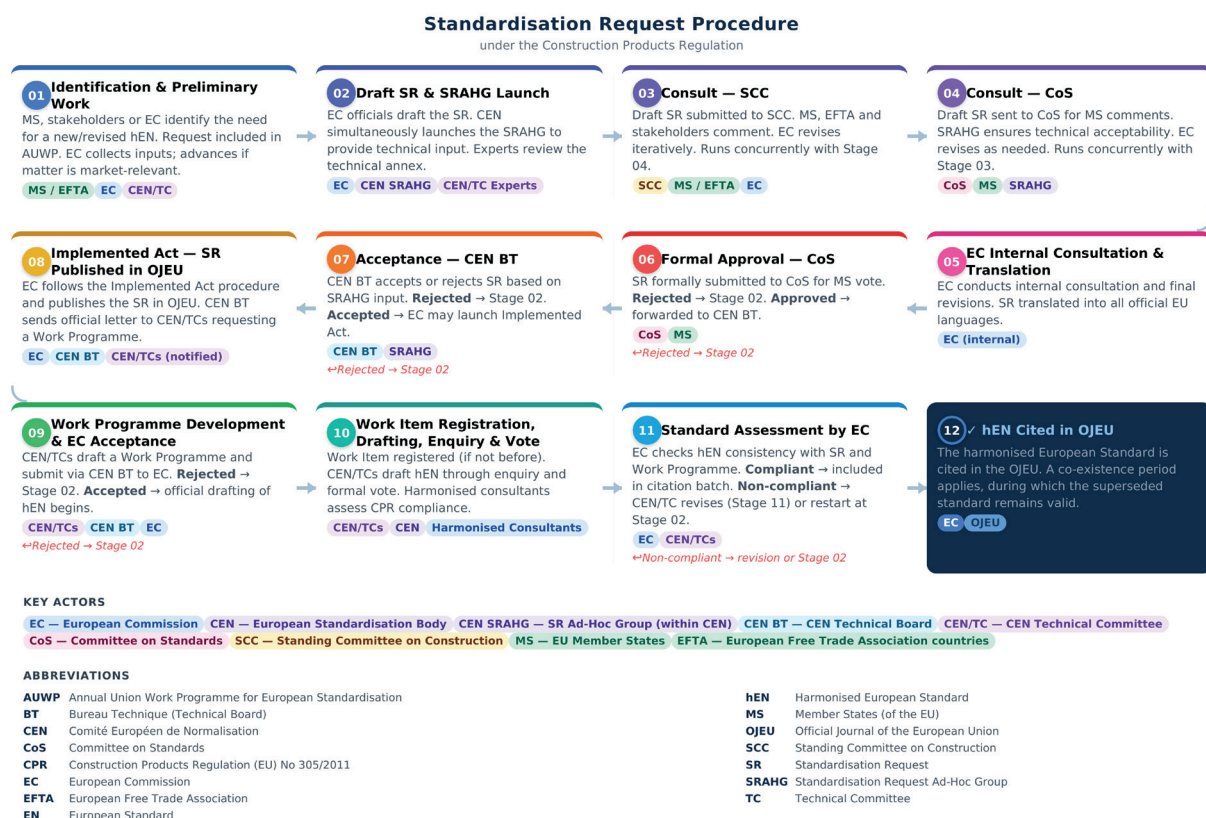


Figure 9: CPR standardisation request procedure. Image generated by AI, based on https://www.cencenelec.eu/media/CEN-CENELEC/AreasOfWork/CEN%20sectors/Construction/Quicklinks/Doc%20and%20Materials/2023/jis_action_5_2019-11-29_standardisation_request_procedure.pdf

3.1.2 Challenges for clinker substitution-lack of standards

The global clinker-to-cement ratio has increased at an annual average of 1.1% since 2015, from 0.66 increasing to 0.71 in 2022. As such, the industry is well-off track to meet the 2030 targets put forward by the International Energy Agency (IEA). This is problematic as clinker substitution and cement blending are key decarbonisation levers, representing a wide range of proven, scalable and cost-effective solutions. As pointed out by the IEA – but also the IPCC and many others – this can be attributed first and foremost to existing cement and concrete standards. These are set by industry actors – predominantly clinker producers – as such creating a situation whereby few actual incentives are present on their end to open the market to clinker substitution technologies.

The clinker to cement ratio in the EU is 73-74%⁹⁸. Indeed, the major challenge to increasing the use of clinker substitution or cement blending, even those that are already used and standardised

today, is the prescriptive approach to product specification in standards. These standards include only a fixed list of constituent products, with recipes that limit the level to which a certain SCM can be used in combination with clinker, water, and other input materials (see Annex illustrating the required ingredients of the different cement types allowed on – in this case – the European market, as put down in EN 197-1). This is further reinforced at the level of concrete standards (i.e. the main/only application of cement) where we even have a situation in Europe where no harmonised approach exists to standardisation. As such, the main European concrete standard (EN 206) is translated – and adjusted – per Member State via their national (private) standardisation committee to cater the local needs. This is motivated by the fact that building traditions and climatic conditions vary across Europe, and while true, the underlying reality is equally showing that national concrete standards first and foremost reflect (and protect) the types of cement and concrete produced in a given Member State.

For obvious reasons, all of the above greatly hinders material innovation and market access. In essence, reference to EN 197 series that prescribe these recipes is then referred to in the equivalent concrete standard EN 206, which is then referred to in building codes and project or procurement requirements. This results in a situation, unless proposed by the incumbent cement manufacturers themselves, innovations cannot find a way into European standards. Finally, recent breakthroughs in cement standardisation at the European level face issues in ratification at the Member State level, mainly because the EU concrete standard (EN 206-1) is not harmonized leaving the specifications and conditions for use of a new cement type in concrete to national member state committees.

To fix the above issues, there is an urgent need to adopt a performance-based approach to cement and concrete standardisation in Europe, as such bringing standards in line with legal requirements put forward by the article 1 of EU's CPR. The performance-based approach is based on the assessment and validation of performance characteristics of cement, regardless of composition. This approach is commonly viewed as a key solution to drive decarbonisation of cement and concrete, yet currently still very much opposed by industry who currently seek to remedy the existing recipe-based standards in a slow and incremental way. Unfortunately, ongoing reforms⁹⁹ at EU level in the context of the CPR acquis show that the above strategy is still common ground. While European cement standards (EN 197) will widen to some new compositions, a wide range of technologies still remain outside of scope (e.g. alkali-activated cements¹⁰⁰; novel cement types; new types of SCMs). This raises wider questions about the ability of European standardisation bodies – with their current composition – to deliver.

3.2 Global comparison of standards

While Europe is in urgent need of performance-based cement and concrete standards, a fast-growing number of countries have successfully transitioned to a standardisation landscape which is already (partly) delivering on this. Key examples included, but are not limited to:

- **ASTM**: the American Society for Testing Materials (ASTM) is an international standardisation body with a strong track-record in the development of standards for construction materials like cement or concrete. It serves as the main 'competitor' of

the European Standardisation Body (CEN) with ASTM standards for cement and concrete being the main point of reference in large parts of the world (i.e. North, Central and South America and parts of Asia). From a country perspective, key countries include the United States (US), Canada, Mexico, Indonesia, Mexico, Columbia and Peru.

Taking a closer look at ASTM standards, it becomes clear a shift to performance-based standards has been initiated since the early 1990s. More specifically, already in 1992 ASTM C-1157 was first developed. This is a performance-based cement standard for hydraulic cements. It exists alongside two prescriptive cement standards (ASTM C-150 and ASTM C-595), for hydraulic and blended cements respectively. Furthermore, in more recent years, performance-based standards have been developed for alkali-activated cementitious materials (ASTM C1948), as well as a performance-based standard for SCMs and the inclusion of performance-based cement types in traditional compositional standards (ASTM C 595).

As a direct result, countries relying on ASTM today have a standardisation system in place which is either hybrid (i.e. recipe-based and performance-based standards are both being used as for example is the case for the US) or fully performance based (i.e. intentional choice to exclusively use performance-based standards as is the case in a growing number of Latin American countries). In both cases, this offers new innovations – including all forms of clinker substitution or cement blending techniques– a clear and common framework against which the performance of their products can be assessed, which is key for building a successful business case towards contractors, investors and insurance players. Amongst others, this helps explaining why some of the more disruptive technologies (e.g. new cement binders) tend to be developed first in the US.

Finally, it is worth highlighting that a shift to a full performance-based system has never given ground to any significant market disruptions. On the contrary, the example of several Central-American countries learns that it helped in further strengthening the resilience, competitiveness and energy performance of the industry (i.e. more flexibility to cope with volatility in material supply and surging energy prices¹⁰¹). Furthermore, given that virtually-all European cement companies operate on a global scale, inclu-

ding in markets dominated by ASTM standards, it is fair to assume a solid level of understanding exists on how to operate in a performance-based system.

BSI: a second interesting case stems from the UK where the British Standards Institute (BSI) has been heavily involved in recent years in developing standards for what is coined alternative binder systems with a lower carbon footprint. Already in 2016, PAS 8820¹⁰² was adopted to serve as a standardised framework for assessing alkali-activated cementitious materials for use in concrete. However, building upon this and other efforts recent years saw the adoption of BSI FLEX 350¹⁰³. This links to the national equivalent of the European concrete standard (EN 206). However, whereas EN 206 is extremely prescriptive in what types of cements can be easily used, BSI Flex 350 introduced more flexibility in the use of new types of SCM (e.g. ground glass) as well as other clinker substitution as well as cement blending techniques.

While the final picture on concrete for the UK still does not offer a fully performance-based picture, it does create significantly more options for a range of low-carbon technologies, as such highlighting the shortcoming to the existing situation whereby solutions are sought (and in this case found) for shortcomings created by the European cement standards (EN 197). Also, from a competitiveness point of view, the adoption of BSI Flex has spurred innovation in the cement and concrete space in the UK, with the number of contractors using SCMs and other clinker substitution and cement blending techniques being at an all-time high¹⁰⁴. Furthermore, in fairly closed regional European market (due to recipe-based standards), a growing traction is created by BSI Flex 350 in terms of attracting and deploying innovations developed in (and beyond) Europe on the domestic market.

3.3 The EU BREF on Cement, Lime and Magnesium oxide production

The revised Industrial and Livestock Rearing Emissions Directive (IED 2.0)¹⁰⁵ as amended by Directive 2024/1785¹⁰⁶, is the main EU instrument to reduce pollutant emissions into air, water and land, and to prevent waste generation from large industrial installations. It now further includes provisions on climate protection and circularity. The directive provides national permitting authorities with environmental norms for the concerned installations, for the granting of operating permits across the EU. At the core of the permits are the **'Best Available Techniques' or**

'BAT' that the operator can employ to prevent or reduce the environmental impact of their activities. BATs are generally identified sector-by-sector through an information exchange managed by the European Commission's EU-BRITE¹⁰⁷. This process relies on the collaborative work of experts from EU agencies, Member States, industry associations, and NGOs, and results in **BAT Reference Documents or BREFs**¹⁰⁸.

Part of the BREFs form the conclusions on BAT, which are adopted as secondary legislative acts, and become the basis for drafting permit conditions by the permitting authorities in Member States.

The cement producers falling under the scope of the IED 2.0¹⁰⁹ are concerned by the EU BREF on Cement, Lime and Magnesium oxide production (CLM BREF)¹¹⁰.

The current CLM BREF was finalised on the technical side already in 2010, the final technical working group meeting took place already in September 2008. This was in a period when the legal framework was revised by the Industrial Emissions Directive (2010/75). While the EU BREF review process was kept unchanged in the IED (2010/75), it took 4 years for the European Commission to propose the BAT Conclusions in the required legal format. These BAT Conclusions were finally published in the official journal of the European Union on 9 April 2013 and the CLM BREF around the same date, however it does not include the more recent and cleaner production routes. The reference plant information dates back to pre-2008, meaning it is outdated by at least 17 years. Its review is foreseen to start in 2027, since the process has been excessively delayed. The mandate of the IED 2.0 provides for an 8-year review cycle, meaning the review of the April 2013 CLM BREF should have been already kick started latest in April 2017, since a BREF review takes in average, 4 years.

It needs to be noted that, cement production is not only intensive in terms of GHG emissions, but also in terms of other harmful pollutant emissions such as particulate matter (dust), sulphur oxides (SO_x), nitrogen oxides (NO_x) and mercury. Alongside the iron and steel sector, cement ranks among the worst-performing industries on the EU Industrial Emissions Portal. While emissions from the energy sector are expected to decline significantly due to the EU's coal phase-out policies, the cement industry remains a major source of air pollution—particularly from Portland clinker production.

The upcoming review of the CLM BREF should primarily focus on transitioning away from Portland clinker-based processes, and on substantially reducing the clinker-to-cement ratio. When this is not feasible, it is important to also investigate end-of-pipe solutions. In a nutshell, the technical options under consideration include:

- the use of less pollution-intensive SCMs such as combustion fly ash or blast furnace slag. The road to net-zero in other industries, however, is likely to limit access to this option.
- the use of alternative low-carbon binders, like alkali activated binders, (Ecocem Ultra¹¹¹, Hoffmann ciments¹¹²) or binders developed by companies TerraCO2¹¹³ (using silicate-based igneous rocks), FUTURECEM¹¹⁴ (combining calcined clay and limestone to replace 40% of Portland clinker in cement) and.
- avoiding the use of limestone altogether, as per the techniques developed by Brimstone¹¹⁵ (producing cement from calcium silicate rock), and Sublime¹¹⁶ (taking calcium out of different minerals).
- fuel switching to renewable fuels or electrification to also address process heat-related emissions.
- end-of-pipe carbon capture solutions, such as CCS.
- advanced end-of-pipe solutions for the abatement of air pollution, incl. for dust, NO_x and mercury emissions from kiln firing. The obsolete provisions of the current BREF need to be updated to reflect the state-of-the-art performance of effective abatement techniques, setting dust levels <5mg/Nm³ (performance associated with the implementation of fabric filter technology), NO_x emissions levels <200 mg/Nm³ (the wide uptake of Selective Catalytic Reduction (SCR) technology in the sector suggests that far lower levels are achievable), and mercury levels <10µg/Nm³.¹¹⁷

An ambitious review of the CLM BREF is, however, only one side of the coin. The other side is to ensure a sound implementation of the standards, with limited derogation permissions. A derogation may only be granted when well-justified due to technical applicability restrictions, or special local conditions, and if granted, it should be limited in time and tied to plant upgrades aiming to improve the environmental performance of the process.

It is both noteworthy and surprising that there are still plants in Europe (in France) derogating from the current 2013 CLM BREF, even if those standards are based on outdated (by more than 15 years) data.

3.4 Industrial emissions directive- Transformation plans and Transition pathways

The revised Industrial Emissions Directive (IED 2.0) obliges operator of cement kilns to elaborate a 'Transformation Plan' (TP) on *"how the installation will transform itself during the 2030-2050 period to contribute to the emergence of a sustainable, clean, circular, resource efficient and climate-neutral economy by 2050, including deep industrial transformation"*.

The TP must be provided by latest 30 June 2030, and it shall be integral part of the Environmental Management System. However, it is for environmental verifiers (auditors) to assess the conformity of the plans with the requirements and minimal content by 30 June 2031 only, as set within a Commission delegated act to be provided prior to 30 June 2026.

The key shortcoming of this provision is that content is 'indicative' non-binding and the absence of clear and measurable key performance indicators as to what the meaning of 'clean' or 'circular' actually is for the sector concerned. There is a risk that this becomes a tick-box exercise without any screening as to the ambition and seriousness of the 'plans of good intentions' set out by the operators. For this reason, the EEB insists that the Commission delegated act should provide the necessary clarity on minimal expectations and content on the how to achieve what, by when¹¹⁸.

The obligation for the biggest cement producers to do this intellectual effort may be challenged through the "simplification of administrative burdens in environmental legislation", which, following a call for evidence¹¹⁹ resulted in a proposal by the European Commission suggesting an outright scrapping of the obligation relating to the TP¹²⁰. The co-decision is in progress at the writing of this report, and it is very likely that the IED TP provisions will be removed. Statements made by the Industrial Alliance, which includes Cement Europe but not present at the meeting held with the European Commission on 8 May 2025, expressed concern that *"the non-binding nature of transformation plans under Article 27(d) is not clear to all"*. It would be a positive surprise if the industry would now prefer binding transformation plans instead.

Business Europe was already successful in emptying the substance of the Climate Neutrality Plans within Art 22(1) of the Directive on Corporate Sustainability Due Diligence¹²¹ which remain at company level and hence would be of no added value to the IED 2.0 implementation. The Corporate Sustainability Due Diligence Directive¹²² requires companies from large undertakings to detail plans of the undertaking (at company level) ensuring that its business model and strategy are compatible with the transition to the Paris Agreement (max 1.5C global warming target).

Currently only the worst performers against the EU ETS benchmark level (higher than 80th percentile of GHG levels) would have to elaborate a Climate Neutrality Plan due to the EU ETS requirements¹²³, and the main purpose is to receive “free allowances” (of GHG pollution). The EU ETS benchmark level is extremely high for grey cement clinker (693kg CO_{2eq}/t) and for White cement clinker (957kg CO_{2eq}/t), making this requirement quasi-irrelevant to most EU cement producers. and unfortunately, can't be considered aligned to a 1.5-degree pathway¹²⁴.

Unlike steel or chemicals, cement has no dedicated European Commissions transition pathway; the Construction Ecosystem Transition Pathway (2023) addresses building renovation, energy performance, and digitalisation but does not cover embodied carbon. This leaves out options for LCB's and novel Portland recipe cements to reduce embodied carbon of concrete in construction.

3.5 EU ETS and sustainable finance benchmarks

The EU ETS benchmark level is extremely high for grey cement clinker (693kg CO_{2eq}/t) and for White cement clinker (957kg CO_{2eq}/t). This reflects the emissions level associated with conventional clinker-based production that remain pollution intensive. The EU ETS benchmark derivation is backwards looking; it is based on the average GHG emissions intensity of the 10% ‘most efficient’ installations in 2016/2017.

The selection criteria are not disincentivising enough to exclude out installations not aligned to net (GHG) zero nor considering most effective production pathways in achieving decarbonisation.

While the revised EU ETS benchmarks were improved slightly to also allow some alternative hydraulic binders (e.g. calcined clays), the product benchmark is based on clinker production (cf. Annex I of the EU ETS). In practice, this means that

only clinker producing installations, including those which produce alternative hydraulic binders, are eligible to benefit under this benchmark for free allocations in the EU ETS framework.

As long as free allocations continue, any clinker-based cement producer, with CO₂ emissions below the benchmark may continue to benefit, while a clinker-free LCBs producer receives no comparable support under the ETS framework.

The EU Taxonomy regulation (2020/852), which produces the technical screening criteria (TSC)¹²⁵ for substantial contribution to climate change mitigation is not legally linked to the revision of ETS benchmarks, though they were derived from them. ETS benchmarks are revised every five years while TSC for transitional activities, including cement manufacturing, are reviewed every 3 years (Article 19.5 of the regulation). The final report on the platform for sustainable finance, which updates the TSC's for the taxonomy regulation, recommends that the TSC's should be updated to reflect the revised ETS benchmark when the sector average is not decarbonising at the minimum annual improvement rate defined in the ETS legislations, (under Article 10.a.2 of 2018/410)- which sets a minimum reduction rate floor of 0.2 % per year capped at a maximum of 1.6 % per year.

For grey cement clinker, the top 10% of the ETS installations improved at around 0.5% over 2008-2017, above the 0.2% floor prompting the revision of ETS benchmarks by 0.5% (0.689t CO_{2eq}/t for 2026-30). The TSC threshold for grey cement clinker is now at 0.722 t CO_{2eq}/t and 0.469 t CO_{2eq}/t for cements and alternative binders and has not been revised but is expected to be adopted by the Commission yet. As it stands, these thresholds do not drive investments towards deep decarbonisation of the cement industry as they are still calibrated for Portland clinker production and do not provide specific incentive for clinker-free low-carbon binders.

The Taxonomy regulation also specifies TSC's for buildings and infrastructure sectors which offer a significant opportunity for low-carbon concrete. However, concrete specific criteria are only listed for the use of concrete in civil engineering as a DNSH (do no significant harm) criteria for climate mitigation and are the same as listed as climate adaptation criteria for the manufacture of cement. This is 0.816 t CO_{2eq}/t for grey cement clinker and 0.53 t CO_{2eq}/t for alternative hydraulic binders.

The TSC's for circular economy specific to concrete include the reuse and recovery of construction

waste, a full life cycle analysis disclosed on demand, pre-demolition audits and limits on the distance between the site of activity and recycling facilities.

3.6 Industrial accelerator act (IAA)

An official proposal for the Industrial Accelerator Act has been published in March 2026. According to the first indications by the European Commission, IAA will target mainly three aspects of industrial decarbonisation:

- Accelerating permitting procedures to improve the access to energy, hydrogen and CCUS infrastructure.
- Identifying and promote priority projects and clusters to support and promote them, including through access to funding.
- Create and protect EU lead markets for low-carbon products, including introducing sustainability and resilience criteria and minimum EU content requirements in public (and in some circumstances, private) procurement in strategic sectors while mandating public procurement quotas for low-carbon products in steel, concrete, Aluminium and electric vehicle components.

A correct prioritisation of measures when it comes to providing public support to industrial decarbonisation is needed to identify projects able to address decarbonisation, strategic autonomy and competitiveness goals.

To do so, it is key to give priority to projects able to reduce the use of energy and materials, phase out fossil fuels, promote circular economy practices, spark electrification and the substitution of carbon-intensive materials with low-carbon alternatives.

When it comes to the creation and the protection of lead markets for low-carbon products, firstly a sound and technology-neutral definition of «low-carbon» is needed. Then, the protection of lead markets should be based on environmental and social standards rather than just GHG emission footprint.

It's expected that the IAA will produce labels which can cover only the GHG emissions of products and not all the environmental parameters listed under Annex I of the ESPR (product parameters) or the Annex II (predetermined environmental essential characteristics) of the CPR.

While the IAA intends to kick start lead markets for low-carbon products in public procurement with these labels, it delegates the mandate to the ESPR and CPR for these labels. It is expected

that the ESPR and CPR will produce the product requirements, subsequent labels covering many environmental parameters by 2029, when the mandatory low-carbon requirements in public procurement is enforced by the proposed IAA.

The IAA has a special focus on EU origin requirements for strategic products, including steel and cement. The recently published proposal for the Act mandates at least 5% of the total volume of concrete and mortar used to be “low-carbon and of Union origin” which many stakeholders consider too low for creating lead markets for low-carbon concretes. But this view is contingent on the thresholds defining a low-carbon product which once again is defined by the performance classes for products, produced by the ESPR and the CPR.

A ‘Buy European’ requirement is best placed for products that are higher in sustainability, covering all social and environmental impacts of the product¹²⁶.

The EU should prioritise trade with partners who are committed to the Paris agreement, as well as other global conventions on biodiversity, pollution, resource consumption and social rights. Remaining open would allow the EU to benefit from additional innovation and an increased capacity to speed up the transition to a healthy climate, biodiversity and pollution-free environment.

This is also compatible with a “Made with the EU” framework which embeds the sustainability preference first, while enabling the EU to use market access and demand leverage to drive the reduction of environmental and social impacts of global trade and consumption.

An alliance with partners committed to protecting the climate, biodiversity, resource consumption and social rights to support a just transition can also keep global resource use within planetary boundaries.

3.7 Improving circularity of construction and demolition waste – Circular Economy Act and Waste Framework Directive

Construction and demolition waste (CDW) represented over one-third of all waste generated in the EU. It is composed of diverse materials, including concrete, bricks, wood, glass, metals, and plastics. CDW arises from the construction and demolition of buildings and infrastructure, as well as from road planning and maintenance activities. When excavated soil is excluded, the largest material fraction in CDW is the mineral fraction, which accounts for an average of 77%. This consists mainly of concrete (24.0%) and bricks (5%), followed by tiles and ceramics (1.2%), with mixed mineral waste making up 47%.¹²⁷

While EU Member States comply with the 70% recovery target for 2020 set out in the Waste Framework Directive (WFD) - with most already exceeding this threshold in 2016 - closer examination of waste management practices shows that CDW recovery is still predominantly based on backfilling and low-grade applications (“down-cycling”), such as the use of recycled aggregates in road sub-bases.¹²⁸

Moving towards more circular approaches for Europe’s largest waste stream holds significant potential for reducing CO₂ emissions. According to the European Commission, improving reuse and recycling of CDW (excluding excavated soils and dredging spoils) could cut emissions by around 48 Mt CO_{2eq} per year, while also generating net cost savings of approximately EUR 7.3 billion. These savings stem from prioritizing reuse over incineration, landfilling, and recycling.¹²⁹

For concrete alone, an analysis by the Joint Research Centre (JRC) of the European Commission estimates potential savings of 7.7 Mt CO_{2eq} annually under an improved reuse and recycling scenario. This assumes that 100% of waste concrete can be directed to either reuse/prepara-

tion for reuse (13%) or recycling (87%), compared to a 2020 baseline of 79% recycling and 10% recovery. If excavated soils and dredging spoils are also considered, the potential climate impact grows further: 51.5 Mt CO_{2eq} savings per year, alongside net savings of about EUR 19.5 billion.¹³⁰

The poor management of CDW not only creates a heavy environmental burden but also wastes valuable resources that could help decarbonise the cement industry. The decarbonisation potential lies in:

- Direct reuse and preparation for reuse of, e.g., pre-cast concrete elements, which reduces overall material demand.
- High-quality recycling, e.g., substituting or supplementing the need for Portland clinker in cement production (as recycled cement paste) and in concrete (as recycled concrete fines).

However, current EU policies have so far failed to unlock this potential. The WFD, in particular, has not delivered meaningful improvements in CDW management. Outdated provisions continue to act as barriers to progress.



The 2018 WFD sets a combined target of 70% for preparing for reuse, recycling, and other material recovery (including backfilling) to be achieved by 2020. Because the target is aggregated, it can be met largely through recovery operations and low-grade recycling/downcycling – approaches that do little to advance circularity and decarbonisation.

There is an urgent need to revise the target into separate, material-specific targets for reuse and high-quality recycling, calculated through a common methodology. Such a revision would help drive reuse and high-quality recycling, while contributing to the decarbonisation of the construction sector.

Importantly, Article 11(6) WFD already includes an evaluation clause requiring the European Commission to consider by December 2024 - reuse and recycling targets for CDW and its material-specific fractions, and to report to the European Parliament and Council – accompanied, where appropriate, by a legislative proposal. Yet, the Commission has not fulfilled this obligation (as of March 2026).

Another major gap in current legislation is the absence of concrete measures to facilitate the reuse and preparation for reuse of construction materials and CDW. Article 11(1) WFD merely stipulates that “Member States shall take measures to promote selective demolition in order to enable removal and safe handling of hazardous substances and facilitate re-use and high-quality recycling [...]”. This provision has proven insufficient, as the data above clearly demonstrate.

To achieve meaningful progress, more concrete and binding measures are required – such as a ban on demolition and wrecking of buildings and infrastructures without proper end-of-life planning. Such planning must include:

- Mandatory deconstruction planning, supported by pre-demolition audits,
- verification and enforcement mechanisms, and
- source separation of materials.

These steps are essential preconditions for enabling effective reuse and high-quality recycling. Such measures have been consistently called for by the recycling industry, cities, and civil society organisations¹³¹, yet they were not addressed in the latest targeted revision of the WFD, which focused only on food and textile waste.

The European Commission’s initiative to propose a Circular Economy Act by Q3 2026 – aimed at enhancing the EU’s economic security and competitiveness while promoting more sustainable production, circular economy business models, and decarbonisation – represents a key opportunity to implement these changes. This could be complemented by other measures such as introducing Extended Producer Responsibility for construction products, applying fiscal instruments such as green taxes to level the playing field between secondary and primary materials, green public procurement, and standardising secondary raw materials to strengthen their credibility.

3.8 State aid for cement/concrete decarbonisation

According to the DG Competition Case Search Tool, some state aid schemes have been awarded to projects specifically concerning the manufacturing of cement¹³². General schemes have been agreed by AT, PT, FR, DE and SK to support energy and emission-intensive industries and promote their transformation, but to understand to which extent they target cement production would require a detailed analysis of each decision, which is not in the scope of this paper.

The State aid frameworks aimed at supporting industrial decarbonisation (CEEAG and CISAF¹³³) include provisions that could be used for cement production, such as aid for the reduction of GHG emissions (paragraph 4.1 CEEAG), aid for resource efficiency and support circular economy (paragraph 4.4 CEEAG) and aid for the prevention or the reduction of pollution other than GHGs (paragraph 4.5 CEEAG), aid for the decarbonisation of industry (chapter 5 CISAF). CISAF also include specific requirements for supporting CCS projects (paragraph 5.2.3)

Outside the EU, Norway has generously supported a CCS project serving a Heidelberg Materials plant in Brevik, which took 20 years from planning to pilot runs and which has a CO₂ capture rate of only 50%¹³⁴ (about 400.000 t per year). The project has been extensively funded by the Norwegian government with 16,8 billion NOK¹³⁵, equivalent to 1,4 billion €.

The decarbonisation of cement manufacturing has been heavily supported by the Innovation Fund but only through CCUS projects and disregarding other cheaper and effective options. According to research made by Carbon Market Watch and WWF EU¹³⁶, from 2020 to 2022 more

than one third (2,5 billion €) of the total Innovation Fund budget went to financing CCUS projects, most of which were targeted to cement installations (11 projects worth almost 2 billion €).

It is unclear whether, at least, such projects included minimal conditions regarding, for instance, minimal CO₂ capture rates; remains the fact that the allocation of the Innovation Fund is far from being technology neutral and clearly prioritise the more expensive, energy-intensive and inefficient way to decarbonise the sector.

Furthermore, cement manufacturers benefitted from the so-called free allocation, meaning that they have basically been exempted from paying for their CO₂ emissions under the EU ETS Directive. According to the above-mentioned report, almost 60% (~60M tonnes) of CO₂ emissions of the sector are caused by 5 companies: Heidelberg Cements, Holcim, CRH, Buzzi Unicem and CEMEX. All their emissions (and even more in some cases) were covered by free allowances. This led to a substantial lack of progress in terms of decarbonisation.

The number of free allowances provided to cement manufacturers in the 2021-2024 period has been 96,7 million per year, equal to about 5,1 billion € in 2021, 7,7 billion € in 2022, 8 billion € in 2023 and 6,3 billion € in 2024.¹³⁷

Finally other impacts from cement production are not accounted for, such as through external damage costs generated due to air pollution and water quality, which is a cost for society. Only a very few countries apply pollution charges, such as in France (Taxe generale sur les activités polluantes) or the Norwegian NO_x charge system. The EEA highlights that the operation of the top 30 cement sites generated an air pollution damage cost worth 6.2 € billions in 2021.

Table 7: Top free allocation recipients among cement companies

Company	Location	Emissions (tonnes/CO ₂ _{eq} in 2023)	Free allowances (in 2023)	Ratio of free allowances to emissions
HeidelbergCement	Germany	20,124,083	21,329,441	106%
Holcim	Switzerland	16,440,097	16,683,826	101.4%
CRH	Ireland	10,896,621	10,437,536	95%
Buzzi Unicem	Italy	7,607,778	7,673,814	100%
CEMEX	Czech Republic	4,688,919	5,800,617	123.7%

3.9 Energy Performance of Buildings Directive and the Renovation Wave

The recast of the Energy Performance of Buildings Directive (EPBD) was the central legislative initiative of the European Commission’s 2020 Renovation Wave strategy and the key element of the “Fit for 55” package related to buildings. The final act entered into force on 28 May 2024. It needs to be transposed into national legislation by 29 May 2026. The main objectives of the recast are to at least double the annual energy renovation rate of buildings by 2030, increase the depth of buildings renovations, improve information on energy performance and sustainability of buildings, and ensure that all buildings will be in line with 2050 climate neutrality requirements.

While the Renovation Wave and the EPBD target primarily the reduction of operational greenhouse gas emissions, the recast introduces the first steps to address Whole Life Carbon (WLC, referred to as “life-cycle GWP”) by introducing obligations to calculate and disclose WLC for new buildings (from 2028 for buildings with a useful floor area greater than 1,000 m² and from 2030 for all new buildings) and set limit values from 2030 on total cumulative WLC of all new buildings. It influences adoption of low-emission cement and concrete indirectly by motivating building owners and investors across all building sectors to identify and implement measures to reduce embodied carbon, with concrete representing the large single embodied carbon hotspot for priority attention.

According to Annex III of the Directive, the total life cycle GWP is to be communicated as a numeric indicator for each life-cycle stage expressed as $\text{kgCO}_{2\text{eq}}/\text{m}^2$ (of useful floor area) over a reference study period of 50 years. It should be calculated in accordance with EN 15978:2011 for the scope of building elements and technical equipment defined in indicator 1.2 of the Level(s) common framework. Where a national calculation tool or method exists or is required for making disclosures or for obtaining building permits, that tool or method may be used to provide the required disclosure. Other calculation tools or methods may be used if they fulfil the minimum criteria laid down by Level(s). Data regarding specific construction products calculated in accordance with the CPR are to be used when available.

However, it is important to note that since the national limit values and reporting will focus on the building level and be expressed as $\text{kgCO}_{2\text{eq}}/\text{m}^2$ (of useful floor area), it does not consider the number or space efficiency of new buildings constructed. This means that while this measure could lead to a reduction in embodied carbon per m^2 , the total carbon emissions of the buildings sector may continue to rise by an increase in overall construction. In addition, since WLC limits will be set at national level, they may lack ambition to drive reduction of embodied emissions (i.e. if they can be achieved only with energy efficiency improvements reducing operational emissions). To accommodate WLC limits that also encourage the lead markets for low-carbon binders, it could be useful to set limits for embodied carbon separately from operational GHG emissions. This is not difficult as the total WLC limits are derived from a lifecycle approach using the standard EN 15978 and this already includes the product stage (A1-A3 in EN 15978) and the operational stage and are a sum of internal limits across all life cycle stages. However, many member states have adopted a single limit value for WLC for ease of use.

A notable example for this approach is France's RE 2020¹³⁸, which has listed limits for construction products and the construction process, separated from operational energy use over a 50-year reference period.

As the carbon emissions of construction products are accounted only once over the 50-year reference period, their relative share of embodied emissions increases over time as operational energy use becomes less carbon intensive. Over a lifetime of 50 years, the materials used typically account for more than half of its whole life carbon emissions. Therefore, embodied carbon limits apart from operational limits are important, since the largest share of a buildings carbon footprint is locked in before it's ever occupied.

Tracking construction product emissions and setting separate limits help in sending a clear market signal on the adoption of low-carbon cements and facilitates the transition from 'nearly zero energy buildings' in 2020 towards the 'zero emission buildings' in 2050. This is already the case for green building certification agencies, who rank the embodied carbon separately.

3.10 Tools for tracking progress in cement transformation and pollution reporting systems

The existing tools for tracking progress in cement transformation and pollution prevention / reduction apply both at the manufacturing stage (cement kilns) level as well at the product (cement/concrete) level, however these tools are not yet fit for purpose on many counts.

Manufacturing stage level (e.g. Industrial Emissions Portal, EMAS):

The European Pollutant Release and Transfer Register (E-PRTR)¹³⁹ was established in 2004. The coverage is limited to a set of 91 pollutant (groups) of large-scale industrial activities, including cement production sites with clinker production above 500 tonnes per day. The current reporting is annual and focused on annual releases (in mass) of those pollutants to air, water and land as well as waste transfers.

Many reporting obligations also existed prior to the IED 2.0, and a better integration of both reporting systems is expected from various improvements introduced through the Industrial Emissions Portal Regulation' (IEP-R), which aims to enhance public access to information related to industrial emissions and facilitate public participation in environmental decision-making. The IEP-R was published in the Official Journal of the European Union on 2nd May 2024.¹⁴⁰

The main shortcomings of the current Industrial emissions portal (hereafter referred as portal or IEP) were:

- Does not allow EU-wide benchmarking of the environmental performance of industrial activities covered by the IED. The performance data formats are reported in annual tonnes for every site in the IEP, but the emission limits under the EU BREF benchmarks are mostly expressed in mass concentrations.
- The conditions listed in the permits in force or the compliance data are not directly integrated in the portal. The data are not comparable at the EU level for similar activities and require

acquiring national permit data, involving extensive efforts.

- Data related to inputs (e.g., water and energy consumption) are not made available.
- Information is not put in context: it is difficult for citizens to understand the scale of pollution and health and hazard relevance to which they might be exposed. Without a comparable performance data of the industrial site/ activity and their energy and water consumption data, it's difficult to assess the best efforts by operators on pollution prevention and reduction at source. Ensuring the availability of performance data would level the environmental playing field for the operators while making data more useful for various users.

The updated IEP-R¹⁴¹ addressed some of these issues to make environmental performance data comparable:

- The list of pollutants and current reporting thresholds were updated in 2025, with the aim to have at least a 90% capture rate and a "0" threshold for pollutants displaying a particularly high hazard to the environment or human health.
- The reporting on production volumes and operating hours is now mandatory for all installations. A 'voluntary' obligation existed so far as of 2023.
- Reporting on inputs, such as energy, water and 'key' raw materials are mandatory but actual reporting on the new system will only start from 2027. Various raw materials used in cement clinker will now have to be reported specifically.
- Other contextual information reported under the IED 2.0 will have to be integrated in the IEP, which is expected to be user-friendly, allowing extraction of data via query-based datasets.

Other instruments, such as the EMAS Regulation, are voluntary and require an annual reporting obligation on related key benchmark indicators (called core environmental performance indicators) on the Environmental Management Systems (EMS), sharing basic content as listed in the Annex IV of the EMAS Regulation¹⁴².

However, the reporting is not made at the installation level¹⁴³ and very few cement producers are registered under EMAS, e.g. Rüdersdorf cement, Cementos Portland Valderrivas El Alto Plant, Titan (Greece), Holcim (Spain)¹⁴⁴. The IED 2.0 strengthens EMS-related provisions and enhances the relevance and uptake of EMAS. At the least, ope-

rators of IED activities should provide a functional web link to the environmental report of the EMS (EMAS or ISO 14001) in a digital format to allow extraction of data by the EEA which manages the Industrial Emissions Portal.

If these positive changes are implemented and information is made transparently available in a user-friendly format, it would be possible to put pollution, input and consumption data into context of production volumes at the installation level. This enables data comparability on the performance of various operators on many parameters in standardised units for concrete or cement produced, improving the level playing field among operators. This approach would also promote benchmarking at the product level, especially because most of the pollution footprint occurs at the manufacturing stage of cement/concrete.

Product stage level (EPD / Construction Product Regulation):

Information at the product level covering the full environmental footprint of relevant stages of the life cycle stages of the concrete value chain is essential for benchmarking products and enabling smart procurement (about 40% of all EU concrete is purchased by public buyers). Reporting should thus be objective and non-discriminatory towards the policy objectives) pursued (e.g. pollution prevention, circular economy and climate neutrality). For construction materials like concrete, decarbonisation and circularity go hand in hand¹⁴⁵.

The revised European Construction Product Regulation (CPR)¹⁴⁶ mandates disclosure of environmental information through enhanced Environmental Product Declarations (EPDs). These follow LCA methodologies covering aspects beyond global warming potential, such as recycling, water use, toxicity, etc¹⁴⁷. Article 15 of the CPR requires the declaration of performance and conformity, which includes the product's environmental sustainability performance covering the essential environmental characteristics as listed in Annex II of the CPR. These cover various climate change effects, ozone depletion, acidification or eutrophication potential, abiotic depletion, water use, emissions such as particulate matter, eco and human toxicity as well as land use related impacts.

Article 16 of the CPR requires the EPD's to be human and machine readable, searchable and transferable without vendor lock-in and free of charge. The manufacturer should make this information available in a digital product passport. Requirements on the minimal content and format of the digital product passport are specified

in Article 75 of the CPR.

Initiatives such as Building Transparency¹⁴⁸ support openEPD¹⁴⁹, a free, open digital standard format for EPDs. Those are compliant with both ISO and EN standards and are available digitally, making EPDs interoperable between databases and usable at a global scale. A dedicated database of digital EPDs based on powerful search criteria has been set up on this basis¹⁵⁰.

Building level reporting (EPBD):

Whole life cycle targets (decarbonisation) are also set at the building level, through the EPBD or national regulations. Embodied carbon limits of buildings rely on sharing of disaggregated, robust and inter-operable environmental footprint information over the life cycle of the concrete value chain, similar to the data offered through installation level environmental performance data e.g. European industrial emissions portal.



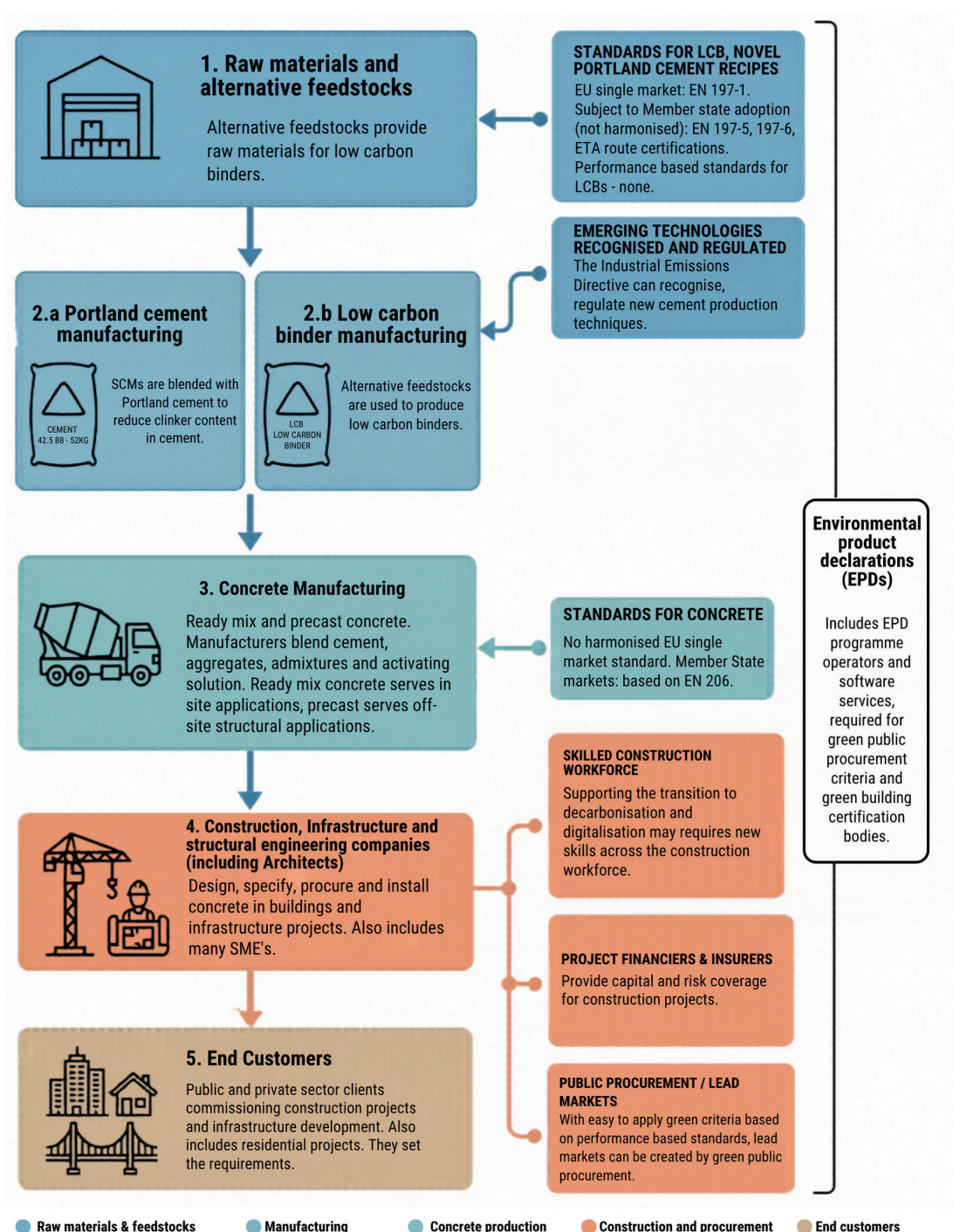
EPFL's Double Deck, a new teaching hub under construction in Lausanne, Switzerland — LC3 cement built into the very campus where the technology was invented. © LC3 / EPFL

Decarbonising the supply chain and creating lead markets via public and private procurement.

4.1 The cement/ concrete value chain

To decarbonise the use of cement, a full value chain approach is required. In the cement, concrete, and construction value chain, we can find the following actors: raw material/ feedstock providers, clinker producers, cement producers, manufacturers of cement derived products such as concrete, construction companies, engineering companies and architects, building and infrastructure owners and finally the end-users. All will have to adopt new practices, to enable full exploitation of the decarbonisation potential in the value chain.

Cement, concrete, and construction value chain



Actors in the value chain typically carry-out the following economic activities:

- Raw material suppliers source, extract, and prepare input materials to be used by cement producers, including in some cases the production of clinker. SCMs that can replace Portland clinker and reduce process emissions and hence produce low-carbon binders are also included here.
- Cementitious product manufacturers may produce their own clinker, produce cement, and if they produce concrete, they then blend the cement together with other materials such as aggregates and water. Depending on the product, concrete can be either produced in the construction sites or pre-casted in production facilities. A wide range of economic actors are involved in the production of concrete and most of them qualify as a small or medium-sized enterprise (SME). However, there are also large construction companies involved in the production of concrete. Moreover, most concrete producers operate independently, while several companies are vertically integrated into cement production value chains.
- The construction companies can be large or small and usually work for clients that can be private companies or public entities. Construction firms focus on practical delivery of a building or piece of infrastructure that meets client and end-user needs.
- The structural engineering bureau and architects design and propose projects to private and public customers. They are usually the link between the construction companies and the final client by providing a concept, design, that the construction company delivers to meet the client brief.
- Project financing and insurance services cover the investment and liabilities of projects. Their role in the deep decarbonisation of the value chain facilitates the risk management of the large investments required, also important for successful lead market creation.
- EPDs are necessary for tracking the carbon footprint of products across the value chain and for construction projects. Use of EPDs simplify the application of green criteria in public and private procurements as well as serve as the backbone for green building certification agencies.

- A LCB pathway as of now requires the recognition and regulation of new emerging techniques from the Industrial emissions directive and requires new harmonised standards for these binders to be used as cement or in concrete so that they can be available in the EU single market and become part of lead markets from public procurement.

Finally, it is important to highlight that there is a high degree of vertical integration throughout the above value chain. As pointed out by the Joint Research Centre: “many, if not most, cement companies [here referring to traditional Portland clinker producers] show a high degree of vertical integration and are consequently involved throughout the supply chain. The majority of cement companies own the quarries. Some producers also integrate downstream industries (i.e. concrete) and associated products (e.g. aggregate)”¹⁵¹. This trend is continuing in recent years, with a growing number of acquisitions from traditional cement companies in the construction and demolition waste sector, to strengthen their own position in the market. For obvious reasons, the above market structure has an important impact on the degree to which certain innovations on the supply side are promoted and taken up.

4.2 Analysis of decarbonisation roadmaps in the construction value chain.

Decarbonisation of entire industrial sectors require close collaboration across the value chain. The cement and concrete industries are no exception. Without the entire construction value chain adopting decarbonisation roadmaps covering their own operations as well as upstream and downstream stakeholders, the sector risks falling behind and losing the pace needed to transition competitively on a global scale.

The need for a synchronised sectoral decarbonisation approach is widely acknowledged. Industry-led global coalitions for demand creation exist like the First movers’ coalition¹⁵², Mission possible partnership¹⁵³, and intergovernmental efforts like Industrial Deep decarbonisation initiative¹⁵⁴. It’s also evident from coalitions created by civil society like Concrete Zero¹⁵⁵. The need to create lead markets for decarbonised industrial products is a top priority for Europe now, and it clearly follows a path and the need to retain competitiveness in the decarbonised industrial economy of the future.

This is also reflected in programmes like the big buyer’s working together¹⁵⁶ of the European commission, dedicated to increasing green public procurement. The announced revision of the Public Procurement Directive and the effort to fasten private procurement in the upcoming Industrial Accelerator Act are all aimed at creating lead markets and decarbonisation.

The following analysis provides insight into current efforts along the construction value chain and highlights gaps that need to be addressed to accelerate the transition. The analysis only includes five large cement producers and five large infrastructure companies, forming the second link in the fragmented and SME dominated value chain. With over 18 million direct jobs, nearly 9 % of the EU GDP and almost 95% of the enterprises being SMEs¹⁵⁷, the stakeholders must collaborate to drive faster decarbonisation, as they have the means and strategic as well as fiduciary interests to stay competitively ahead.

4.2.1 Methodology and sources

The list of cement companies is primarily derived from the Global database of cement production assets and upstream suppliers, published in 2023 by the Centre for Greening Finance and Investment at the University of Oxford¹⁵⁸. The database provides the ownership of plants and their parent companies along with the total cement production capacity (millions of tons). The list of infrastructure companies is derived from the CE 100 ranking conducted by KHL group LLP, published in their Construction Europe magazine and portal¹⁵⁹ published in fall 2024 providing a list of top 100 Europe headquartered companies by annual financial turnover.

The analysis covers the following companies:

Cement producers	Total cement production capacity in Europe (million tonnes)	Infrastructure company	Annual turnover in million euro	Rank in CE 100 list
Heidelberg Materials AG	78.6	Eiffage S.A.	22028	4
Holcim Ltd	75.96	STRABAG SE	17396	5
CRH public limited company	41.85	Acciona, S.A.	16761	6
Buzzi S.p.A.	25.71	Webuild S.p.A.	9148	9
CEMEX, S.A.B. de C.V.	21.7	Royal BAM Group nv	6174	17

The five cement companies chosen are the largest producers of cement in Europe, operate production facilities in most EU member states (except NL, MT, LT, LV, DK and PT) and cover almost 60% the production capacity in the EU 27. The infrastructure companies were chosen with consideration to operational presence in the country of the largest cement producers, geographic distribution across the EU while Royal Bam group nv being simply chosen as an example with an EU member state with progressive decarbonisation, green public procurement and circularity policies while not having Portland clinker production.



A treated water discharge tunnel built using ultra-low-carbon concrete pipes under the brand Exegy in Dugny, France. Carbon footprint < 100 kgCO₂/m³
Photo : Yves Chanoit, courtesy, Exegy

4.2.2 Analysis

We measured the progress of transition pathways based on the following efforts and measures:

1. On the presence of transition/ decarbonisation roadmaps for 2030 and 2050 and whether all scopes of emissions are covered in these plans and if they have been submitted to the Science Based Targets initiative (SBTi).
2. On efforts towards reduction of carbon emissions from cement/ concrete:
 - a. The blending of SCMs in the cement or recycled aggregates in concrete and whether there have been use of low-carbon alternative binders or concretes that have been developed using such binders.
 - b. Efforts towards circularity in their operations with special attention to construction and demolition waste and if they are valorised for use in low-carbon concretes.
 - c. Existence of dedicated partnerships with SCM producers or alternative low-carbon binders and any evidence of partnerships or supply or offtake agreements with those producers.
 - d. Efforts towards reduction of emissions from scope 3 upstream¹⁶⁰, covering raw materials suppliers as a proof of effort towards engaging in the decarbonisation efforts in the value chain.
3. On energy efficiency, electrification and use of renewable energy:
 - a. Existence of immediate efforts like energy efficiency or electrification of cement production and ancillary activities.
 - b. Existence of partnerships with renewable electricity providers or power purchase agreements with them.
4. Efforts towards carbon capture and storage or other carbon removals (except re-carbonation of concrete) for a comparison towards efforts on other decarbonisation levers.

4.2.3 Findings

1. Presence of transition/ decarbonisation roadmaps for 2030 and 2050 and whether all scopes of emissions are covered in these plans and if they have been submitted to the Science based Targets initiative. All companies analysed have a 2030 target while 2 of them haven't declared a 2050 target for decarboni-

sation yet. All except one company have included scope 3 emissions in their targets. This is quite an important factor for the infrastructure companies, as their scope 1 and scope 2 emissions are usually smaller than their scope 3 emissions.*

2. On efforts towards reduction of carbon emissions from cement/ concrete: In their pathway to decarbonisation, we expect many cement producers and infrastructure companies to adopt lower carbon cements and concretes while keeping R&D efforts in developing low-carbon alternatives to Portland clinker and producing novel cements and concretes. While the European standards EN 197-1, EN 197-5¹⁶¹ and EN 197-6¹⁶² allow a variety of SCM's to be used in Portland cements, it does not allow products which have a different share of Portland clinker (a different recipe) or new SCM's to be used (see also section 3.1). Consequently, these alternative cements/ binders are ought to affix the "CE mark" via the European technical assessment (ETA) route, by applying to the European Organisation for Technical Assessment (EOTA) to receive a European Assessment Document (EAD) which lists the characteristics and assesses the performance of the alternative binder. An ETA is received for a specific product based on the EAD. Under the revised CPR (2024/3110), a CE marking is permitted only after the EAD has been published in the OJEU. While it's common knowledge that these EAD approvals take years to get, the outcome is still imperfect. This because while EN 197-1 covers cements that can be used in concrete without additional testing or verification requirements, European concrete standards and its national annexes impose more restrictions on how these cements may be used in practice.
 - a. The use of supplementary cementitious materials in the cement or concrete used and whether there are alternative low-carbon binders or low-carbon cements or concretes using such binders or cements that have been developed.

All the cement producers analysed produce low-carbon cements and 4 of the 5 infrastructure companies also produce their own concrete and have a permanent production facility.

Among the cements and concretes used, we found very little low-carbon SCM's being used in their cements or concretes. Most of the SCM's used are the non-renewable granulated blast furnace slag from steel and fly ash from

coal while natural pozzolanas (including limestone), calcined clay, silica fumes are also widely used. However, few SCM's like recycled concrete fines (approved in EN 197-6), recycled mineral wool and reclaimed ashes (Holcim) were used in limited cases, as they are not harmonised.

We also checked these companies for their commitments towards reducing Portland clinker in their cements or concretes. The five cement companies had already listed their specific goal of reducing GHG emissions per tonne of cementitious materials with Heidelberg adopting the least GHG emissions intensity at 400kg/t of cementitious materials by 2030. Holcim had a target of 440 kg/t, while CRH reports a 33% gross intensity reduction from 2021. All others had a target equal to or slightly lower than 500 kg/ t of cementitious materials. Clearly, the declared targets for GHG intensity are incompatible with the 2030 target needed for a 1.5°C compatible pathway, which is at 270-360 kg CO_{2eq}/t¹⁶³ of cement. This was also compared against the efforts towards development and deployment of LCBs, which we find only one company taking the effort to do develop cements which replace Portland clinker or produce no CO₂ emissions (Mevocem from Material Evolution, piloted by CRH in the UK). A notable mention is the 100% recycled clinker cement from Holcim used in the Recy-génie project in Gennevilliers, France.

In comparison, four of the five infrastructure companies had pilot projects or trials of low-carbon concretes. However, only one of them, Eiffage, had used a LCB (no Portland clinker) based concrete during a 3 -year offtake agreement with Hoffmann Green Cement Technologies. Acciona is the only other company to have engaged with LCB based concretes as a part of a Horizon 2020¹⁶⁴ programme funded by the EU albeit not commercially deployed.

Alternative approvals of cements outside the EN 197 series:

Of the applications under the ETA route for cement approvals, we find it normal for cement companies to apply for novel cements and binders compared to infrastructure companies. In reality, we can expect an infrastructure company to have a partnership with a cement producer to develop LCBs or novel Portland cement recipes and concretes rather than applying for an EAD approval directly as it's not their domain expertise.

Of the 41 ETA route approvals¹⁶⁵ that have been provided for cements, 4 of the 5 cement producers covered in this analysis have received approvals for 14 novel cements so far and all of them have received approvals for non-Portland clinker cements. However, 3 of the cements can be considered as high-carbon alternative binders and are rather special cements with specific properties (fast curing, low alkali content, etc). Only one cement producer received approval for an alternative low-carbon binder (Solidia from Holcim), which offer some GHG emissions reduction as compared to CEM 1 Portland clinker cement.

There were only 2 cements that were among the 41 ETA route approvals which has over 60-70% carbon reduction- Ecocem act and Ecocem ultra, from Ecocem, a low-carbon cement company.

2 out of the 5 infrastructure companies haven't piloted or used any low-carbon alternative clinker cements/ concretes at all, and we can't find evidence on their plans to replace clinker completely. This includes the existence of any partnerships, offtake or purchase agreements between the infrastructure companies and SCM or low-carbon cement/ concrete producers.

- b. Efforts towards circularity in their operations with special attention to construction and demolition waste and if they are valorised towards low-carbon products.

Construction and demolition waste (CDW) can be utilised in three distinct ways: reused to produce aggregates and fillers for concrete; reused as recycled concrete fines as an SCM in cement/ concrete or reused as clinker recovered from the uncarbonated cement content in CDW, which can be used to reduce the share of Portland clinker. The use of CDW as aggregates or fillers are most common compared to its other options but are technically feasible. Some companies have even commercially launched products (Holcim's Susteno cement and Heidelberg^{166 167}).

Among the 5 cement companies, all of them have published efforts towards managing CDW by investing into collection, recycling systems and research.

Likewise, all except one of the infrastructure companies have taken the recovery and recycling of CDW more seriously with investments in new processing centres for CDW and

participating in circular projects^{168 169} using concretes with CDW aggregates. However, it's also evident that the infrastructure companies have not ventured beyond the use of CDW as aggregates and fillers rather than the more carbon rewarding approach of recovering cement paste or using treated recycled concrete fines as SCM's. Webuild has declared no measurable circularity targets for 2024 and is the only company to have not taken efforts on using concretes with CDW.

- c. Existence of dedicated partnerships with SCM producers or alternative low-carbon binders and any evidence of partnerships or supply or offtake agreements with those producers.

On the existence of a future commitment to purchase alternative low-carbon binders (including LCBs) we were looking for evidence of offtake agreements, purchase commitments for cements or concretes for such binders by infrastructure companies; and any dedicated agreements with SCM producers and alternative low-carbon binders including LCBs by cement companies. We also included any publicly announced investments (or acquisitions) in these alternate cement manufacturers.

One cement company and two infrastructure companies don't have any evidence of agreements or investments supporting any low-carbon cements or concretes based on those cements. However, three cement companies have had some partnership with LCB producers.

CRH, with its innovation fund CRH ventures, has partnerships with alternative low-carbon cement producers and SCM producers. The partnerships include Material Evolution¹⁷⁰, a UK based company piloting Mevocem, an alkali based LCB; with Sublime Systems¹⁷¹, a non-Portland cementitious binder producer (not classified as LCB) and acquired¹⁷² Eco Material Technologies, a major SCM supplier in the USA for fly ash.

Holcim also has an innovation funding arm, Holcim MAQER ventures¹⁷³, and has invested both in Sublime systems as well as Salt X (electric arc calciner) in Sweden. CEMEX ventures¹⁷⁴, launched in 2017 also has invested in Terra CO2, a USA based company which produces a cement -Opus Zero (LCB) and is in full concrete trials now. CEMEX has also invested in Synhelion (Switzerland), a solar synthetic fuel producer, to collaborate and produce Portland cement using solar thermal heating replacing fuel related emissions from the production of Portland cement. This was demonstrated in

Spain.

Eiffage had signed a cement supply contract for 3 years¹⁷⁵ with Hoffmann Green Cement Technologies, the company which produces H-UKR, a zero-clinker cement (classified as an LCB), commercialised in 2021. Heidelberg has been investing in their own facilities for low-carbon cements but has also investments in CDW based SCM's with Envicore¹⁷⁶, in Canada.

Perhaps the best example of such collaborative partnerships between cement producers and infrastructure companies could be the development of an ultra-low-carbon concrete, Exegy Ultra by VINCI construction and Ecocem based on Ecocem ultra (LCB), a collaboration lasting over 15 years¹⁷⁷. The concrete has been successfully used in segments of the Grand Paris Express¹⁷⁸ metro and the Olympics village¹⁷⁹ for the Paris 2024 Olympics.

- d. Efforts towards reduction of emissions from scope 3 upstream, covering raw materials suppliers as a proof of effort towards engaging in the decarbonisation efforts in the value chain.

Apart from any direct initiatives studied earlier, it's important to acknowledge the role of collaboration in catalysing decarbonisation efforts across the value chain. To make meaningful progress to reduce scope 3 emissions (upstream), it's vital for any company to engage with suppliers about low-carbon products. As a first step this must be reflected in the supplier code of conduct or supplier engagement policies of the company. It's obvious to state and yet: A scope 3 emissions of a company are essentially scope 2 emissions of many upstream companies.

For our case, we also explored the existence of partnerships between low-carbon raw material providers and off take or purchase agreements between infrastructure companies and low-carbon cement producers.

Six out of the ten companies in our list did not have a supplier engagement policy covering high emission raw materials like cement or steel, finetuned to influence the procurement of low-carbon cement/ concrete. One infrastructure company (BAM group) had an ambitious ask- of having their tier -1 suppliers to have an SBTi target but this fell short of specific requirements for procuring low-carbon materials.

Three companies (two cement producers and an infrastructure company) had policies that

included parameters which can distinguish low-carbon raw materials like environmental product declarations (EPD's) or life cycle assessments (LCA) of their products. One infrastructure company adopted specific requirements for low-carbon steel but set the threshold for cement based on the EU taxonomy benchmarks for cement¹⁸⁰, which unfortunately can't be considered aligned to a 1.5-degree pathway (based on the EU ETS benchmarks). Of those who considered LCA's or EPD's from their suppliers, the requirements were unfortunately restricted only to GHG emissions. Of the five infrastructure companies, we can consider four did not have a supplier engagement policy that is finetuned to influence the procurement of low-carbon cement/ concrete.

3. Existence of immediate efforts like energy efficiency or electrification of cement production and ancillary activities and the existence of partnerships with renewable electricity providers or power purchase agreements with them.

As almost all companies listed targets for their scope 2 emissions, efforts in energy efficiency and purchase of renewables were one of the common measures to reduce scope 2 emissions. For our case, we were looking for evidence of more investments into waste heat recovery, advancements in electrification of rotary kilns or power purchase agreements (PPA) with renewable electricity providers, as an indication of the company's commitments to long term investments towards greening the power grid. Of the 5 cement producers, Holcim and Heidelberg had evidence of research on electrification of Portland clinker production while some of the cement producers were also advancing on waste heat recovery systems. Heidelberg is a partner in the EU Horizon funded ELECTRA project¹⁸¹ with active research on plasma techniques in their Slite cement production facility. Holcim with its investment in SaltX's electric arc calciner¹⁸² (plasma technique) is aiming to establish world's first all-electric cement production. Buzzi's has recently commissioned¹⁸³ an ORC based waste heat recovery system in their Geseke plant (Dyckerhoff) recovering previously unused waste heat from clinker coolers. However, Holcim is the largest among the cement producers to have invested into waste heat recovery (WHR) systems globally while CEMEX is also actively expanding on WHR¹⁸⁴ across its global operations. PPA's for renewable energy (RE) were used by all except one cement producer. Most of the infrastructure companies had efforts to increase their overall RE share.

4. Efforts towards carbon capture and storage or other carbon removals (except re-carbonation

of concrete) for a comparison towards efforts on other decarbonisation levers.

Cement production is one of the few industrial sectors where existing production techniques need to transform completely to achieve the net zero goals for 2050. As stated earlier (section 2.4), The cement sector is characterised by an important amount of process CO₂ emissions due to Portland clinker production, the key constituent of cement. While carbon capture and storage solutions are marked by a prolonged incubation period of over 20 years to achieve a viable TRL score, its often also seen as a reason for early investments into CCS or CCU technologies.

Of the 5 cement companies, only CEMEX, CRH PLC and Holcim have invested or piloted LCBs. None have developed an LCB yet, and none have applied for an LCB under the ETA route, in comparison to their efforts on carbon capture systems.

This can also be seen as lack of evidence of collaboration in the sector with all cement production companies investing in pilots and advanced trials for CCS/U in their plants while 4 of the 5 infrastructure companies have no measures on CCS. Eiffage is the only infrastructure company to have done a pilot in their Haut Lieu lime plant¹⁸⁵ and an acquisition of HSM offshore Energy¹⁸⁶, an integrated engineering company specialising in offshore projects in The Netherlands.

4.2.4 Conclusions

Overall, based on the limited sample size of the assessment, we can conclude broadly,

1. While most of the companies have a transition plan, with all scopes covered, many of them focus on scope 1 and 2 emissions (operational emissions and purchased energy). This narrow focus affects the drive to decarbonise the entire value chain.
2. Most of the cement producers covered in this assessment have not ventured beyond the use of SCM's and recipes listed in the EN 197-1, EN 197-5 and EN 197-6 standards. While novel cement approval sought via the ETA route is not uncommon, none of the cement companies have applied for an approval for an LCB. In comparison among the 5 infrastructure companies, only 2 had pilot projects or trials of concretes using alternatives to Portland clinker.
3. CDW is considered as a resource by varying extent by the two largest stakeholders in the value chain. Cement companies are develo-

ping advanced recycling with CDW to produce Portland clinker alternatives while infrastructure companies have mostly used CDW as aggregates in their concrete. Both stakeholders consider the reduction and valorisation of CDW as an important measure towards circularity.

4. Evidence of offtake agreements or purchase commitments for low-carbon product procurement are low, with only one notable effort among infrastructure stakeholders by developing alternatives to Portland clinker concretes in collaboration with new low-carbon cement companies.
5. Supplier engagement is low and is a key factor for accelerating decarbonisation across the value chain. Six out of the ten companies in our list did not have a supplier engagement policy covering high emission raw materials like cement or steel as they are not finetuned to influence the procurement of low-carbon cement/ concrete.

Taken together, these findings reveal a value chain where transition plans have not translated into action. Cement producers have not ventured beyond EN 197-1 compliant recipes, infrastructure companies show limited evidence of offtake commitments or supplier engagement for low-carbon alternatives, and CDW valorisation remains largely limited to aggregate use rather than clinker substitution. The drive to decarbonise the entire value chain remains insufficient.

4.3 Lead markets via public procurement

Public procurement covers over 14% of the EU GDP and holds a crucial role in decarbonising key industries. In the EU, over 25% of the construction sector emissions are covered by public procurement¹⁸⁷. With 36% of steel and 50% of cement/ concrete emissions coming from the construction sector, it's clear that public procurement has a vast potential to finance and drive the decarbonisation in steel and cement industries.

The public procurement directive is being reviewed now¹⁸⁸, and the second consultation was completed in January 2026. The Commission is in the process of extensive consultations with all stakeholders, and a proposal is expected mid or late 2026.

While the existing directive (2014/24/EU) encourages contracting authorities to award the most economically advantageous tender using a price or a cost effectiveness approach, such as life cycle costs or a price -quality ratio which should include environmental and social criteria, it's clear

that despite this possibility, green public procurement is not common practice yet¹⁸⁹.

Green public procurement should become the norm rather than a special procurement procedure as it is now. The major barriers- lack of targets or climate neutral goals, voluntary and hence low application of environmental and social criteria in awarding tenders, poor monitoring and tracking systems to measure GPP impact and extensive capacity building and training programmes must be addressed in the review process¹⁹⁰.

While a complete transition to green public procurement helps the EU in reaching its climate, environmental and social goals, it can and should also be used to direct targeted procurement towards low-carbon products from GHG emission intensive industrial sectors, creating lead markets and providing incentives for the early adopters of low-carbon cement and concrete. This is where the lack of harmonised standards hurt, and the EN 197-1 standard being the only one formally recognised as a harmonised standard while the recently published EN 197-5 follows an old mandate and is technically not yet harmonised¹⁹¹.

As discussed earlier (section 4.2), the EN 197-1 standard restricts the harmonised cements to follow a few recipes of Portland clinker and selected SCM's and does not allow products which have a different share of Portland clinker (a different recipe) or new SCM's or an alternative to Portland clinker to be used. Even though a "CE" label is available for the low-carbon cements approved for safety and performance under the ETA route and have received a European technical assessment (ETA), it's specific to the product and valid only for the holder of the assessment. This makes contracting authorities having to use the technical specifications of the product (from the ETA) along with an option for "equivalent" specifications, to avoid being considered discriminatory¹⁹².

Since construction products are hardly bought directly by contracting authorities, the complication to introduce a technical specification with "equivalence" in an infrastructure project tender, participated by infrastructure or EPC¹⁹³ companies (who are not cement producers), makes it almost rare for LCB's entering normal public procurement procedures. Although there are many case studies across the EU for the use of low and ultra-low-carbon cements and concretes, very few are driven by standards, and most are driven by national or regional GPP programmes, or by national reduction targets for GHG emissions assigned to procurement departments while the

ultimate decision and associated legal risks falls on the contracting authority.

While authorities can wait for the ESPR and CPR to provide classes of performance for cement and/or concrete¹⁹⁴, it is important to highlight that today the MEAT (Most economically advantageous tender) principle is already mandatory¹⁹⁵ for authorities to follow. However, further improvements to the framework should be made to the framework to make it mandatory to include non-price considerations in MEAT to better promote procurement contracts of products, works or services with a high environmental impact and are of high value and longer duration-term procurements. GHG emissions are a priority, but other environmental impacts like pollution (SO₂, dust, VOC and NO_x) should be included as parameters to identify the most economically advantageous tender. A life cycle assessment (LCA)¹⁹⁶, following the ISO 14040 and 14044 standards, is an analysis of all environmental impacts from raw materials production to final disposal. It can be used directly or be used to arrive at shadow prices for various pollutants including GHG emissions.

Shadow price approaches (used by Germany and The Netherlands) for every pollutant and the use of Value of Statistical Life method to derive estimated health costs of pollutants can be a simpler solution to promote lead markets in prioritised procurement sectors (using CPV codes) as compared to a full LCA for every product in the tender or a detailed project level LCA. An LCA covering the full scope of environmental impacts from production to end of life (Module D) can also help in identifying circular products and promote its use. With specific pollutants to track, contracting authorities can directly include the requirements to disclose the specific pollution impacts of the products, works or services in the prior information notices, and evaluate the tenders using monetised costs. However, standardised methodologies for life cycle assessment and life cycle costing are necessary to measure environmental impacts for circular products to enable circular procurement. The shadow price for carbon should be set at 200-330 €/t CO_{2eq} (IPCC aligned for 1.5 °C pathway) and the results from LCA (or EPD's) can then be used in best price to quality ratio or life cycle costing methodologies to identify and award a tender considered to be MEAT.

The construction sector has a high share of waste in the EU (section 3.7). Circularity in construction may very well be one of the routes to achieve net zero in construction industry. Apart from circular cements¹⁹⁷ or low-carbon concretes made from CDW, a lot of potential exists for the reuse of structural and load bearing steel elements, hollow and open sections, trusses and sheet piles

from existing buildings and infrastructure which are marked for demolition or renovation. Like cement products, harmonised standards for reclaimed structural steel components that have been altered cannot have a "CE" marking since they are not harmonised under the CPR. Even concrete, a product which has a direct application in construction and for which procurement criteria could be easily set, also does not have harmonised standards at present. For example, while many member states have defined minimum re-use, recycling and recovery rates for CDW as a part of their public procurement requirements, some member states recommend recycling practices based on other documentation like demolition plans. This lack of coordination creates uncertainty for suppliers in the intra EU cross border market including procurement.

Circular procurement procedures, including rapid circular contracting¹⁹⁸, should be encouraged and should be incorporated along with existing legal procedures like dynamic purchasing systems (Article 34), Framework agreements (Article 33) and competitive procedures with negotiations (Article 29) and innovation partnership (Article 31) and joint procurements in the Public Procurement Directive.

Concrete GHG thresholds and whole life carbon limits (WLC) for buildings that can drive low-carbon binders:

While it's possible to set a range of CO₂ emissions per tonne of cements/low-carbon binders that can be applied to concrete and floor area of buildings, doing so does not translate directly into concrete or building level outcomes. A product specific benchmark at a clinker level or cement offers limited flexibility for the construction sector compared to a performance limits set at the concrete level (kg. CO₂/ m³) or building area (kg. CO₂/ m³).

By contrast, concrete or building area-based targets enable the levers for decarbonisation from building less, building circular and increasing material efficiency by optimising structural design.

As referred earlier in section 3.9, the whole life carbon limits for building area are best applied as twin benchmarks, separated by embodied carbon and the operational energy use of the buildings, usually referenced over 50-year periods.

A limit of 135 kg. CO_{2eq}/m³¹⁹⁹ (cradle to gate) for structural concrete of strength class C30/37 under typical exposure (XC) conditions can be taken as an indicative target for this purpose. It reflects an ambitious and technically achievable limit from materials consistent with net zero goals in

2050²⁰⁰. This reduction is possible through the following stacked levers : reduction of Portland cement content in concrete and a corresponding increase in SCM's, sourcing of lower carbon SCMs, and reduced electricity related carbon emissions, However, the first lever is constrained by the recipe based EN 206 standard for concrete which accepts only recipe based cements from the EN 197-1 cement standard.

To arrive at an equivalence in WLC thresholds involves assumptions about the carbon emissions from reinforcement steel used²⁰¹ and other material contributions to the overall carbon footprint involved in one square meter of building area. If the indicative concrete GHG emissions at 135 kg CO_{2eq}/m³ are used, the total embodied emissions covered in the WLC limit values can be arrived at around 225 kg CO_{2eq}/m². We recommend, this as an indicative limit for all embodied emissions covered in the WLC limit values derived from a lifecycle analysis using EN 15978 standard. To arrive at an equivalence in WLC thresholds involves assumptions about the carbon emissions from reinforcement steel used and other material contributions to the overall carbon footprint involved in one square meter of building area. If the indicative concrete GHG emissions at 135 kg CO_{2eq}/m³ are used, the total embodied emissions covered in the WLC limit values can be arrived at around 225 kg CO_{2eq}/m². We recommend, this as an indicative limit for all embodied emissions covered in the WLC limit values derived from a lifecycle analysis using EN 15978 standard.

4.4 Lead markets via private procurement

While Public procurement remains as a versatile tool in the policy maker's toolbox for creating lead markets, it's also necessary to ensure that industrial production techniques are upgraded to match the pace needed for decarbonisation. Lead markets can be created via corporate procurement as well. In the EU, the process of setting performance requirements for all construction products and production installations are through regulations like the ESPR, CPR and the IED. While policy measures on changing the industrial production techniques are underway, economic operators should proactively take measures to engage, encourage and support in decarbonising their supply chain.

Supply chain engagement is necessary for successful decarbonisation of any industrial value chain since scope 3 emissions, are usually²⁰² larger than direct emissions. According to SB-Ti's guidance for supplier engagement, scope 3 emissions should be included in the targets of a company, if they are above 40% of total GHG

emissions and the targets set for scope 3 must cover a minimum of 67% of Scope 3 emissions. An ideal supplier engagement policy should prioritize stakeholders according to the GHG emission intensity of the purchased products and services. However, as seen earlier in the assessment in section 4.2, 4 of the 5 largest infrastructure companies don't have a supplier engagement policy that can target high emission raw materials, while all of them had a scope 3 target.

LCAs or EPD's, which are widely used in the construction sector in Europe should cover all environmental impacts (cradle to grave), compared to the narrow scope 2 emissions (cradle to gate) that are usually covered. This greatly improves the ability to distinguish the full scope of emissions involved and makes it easier for shadow pricing methods to be used for an environmentally friendly product.

Construction, Infrastructure and structural engineering companies, who are the second largest stakeholders in the construction value chain and primary users of cement products, should progressively move their supply/purchase agreements to ultra-low-carbon cement and SCM producers. They should also move to ultra-low-carbon cements approved by the ETA route for use in their concretes. This is an important step, since the low-carbon cements in the market, largely compliant with EN-197-1 standards, may be unavoidable in public procurement contracts but can be used without any legal barriers in corporate procurement. The existence of ETA certified ultra-low-carbon cements demonstrate two important things: the cement is economically feasible and structurally safe, and the effort by the holders of the ETA indicate the existence of a market demand for their product. These ETA route approvals are a precursor to the eventual inclusion of such cements in harmonised standards.

Building certification schemes also play an indirect role in creating lead markets for the cement industry. The most common building certification schemes used in Europe are: BREEAM²⁰³, DGNB, HQE, Minergie (Switzerland), Verde and LEED apart from the LEVEL(S) framework for building certification produced by the Commission. All the schemes are voluntary and are widely used by the construction sector. Most of these schemes are based on a whole life carbon methodology covering all embodied emissions which will indirectly reward the use of low-carbon cements/concretes which can help improve the overall green score of the building projects. Infrastructure companies should aim for a larger share of their project under the highest certification levels

in their schemes, which can be attainable if low or ultra-low-carbon cements can be utilised. National building codes have been successful in increasing the low-carbon building stock by setting minimum environmental performance thresholds for new construction and increasingly incorporating whole-life carbon requirements.

The indicative thresholds listed for public procurement (section 4.3) whether expressed per m³ of concrete, per m² of floor area, or as embodied carbon limits within whole-life carbon benchmarks — can equally serve as voluntary reference points for private procurement actors, who can adopt them ahead of any binding regu-



Summary of EU policy recommendations

The below policy recommendations are a non-exhaustive list of impactful actions and levers for supporting the transformation of the construction value chain at EU policy level, focused on cement decarbonisation. Focus is made on policy opportunities that are either overdue or actionable within a max 5-year timeframe to deliver impact (see EU policy avenue).

5.1 Sufficiency, circularity and material efficiency measures

Circularity strategies, including sufficiency, material efficiency and product/material lifespan expansion, should be the first priority for decarbonising the use of cement and concrete in buildings and infrastructure.

Reducing demand for new construction

- Prioritising the higher utilisation, renovation or adaptation of existing buildings in reducing demand for new construction over the decision to construct, including measures to efficiently use existing spaces, assess the feasibility of using existing floor area through regional building stock analyses and extend the lifetimes of building using renovations and retrofitting.

Policy avenue: European Affordable Housing Plan, Energy Performance of Buildings Directive, implementation via National Building Renovation Plans, Public Procurement Directives.

Reducing demand for cement and concrete

- Full or partial replacement of concrete in individual buildings and structures by alternative low-emission materials, such as timber and other bio-based materials, where such materials are available from sustainable sources.
- Reduction in the amount of concrete used in buildings and concrete structures through digitalisation, waste prevention and materially efficient structural design and material specifications.
- Reduction of the cement-to-concrete ratio in concrete (in production and end-use applications)

Policy avenue: Energy Performance of Buildings Directive. Implementation via national GWP limits for new construction. Revision of harmonised standards under the Construction Products Regulation.

Lifetime expansion (extending end-of-life value for materials)

- Extended producer responsibility for construction products, green taxation measures to bring price parity among secondary and primary materials.
- Swift adoption of separate reuse and recycling targets for CDW, as required under Article 11(6) of the WFD.
- Binding measures such as mandatory deconstruction planning supported by pre demolition audits, at source separation of materials and appropriate verification and enforcement mechanisms;
- Development of minimum requirements for reused, refurbished, repaired and recycled products for public procurement in the EU, starting with industrial sectors with high environmental impact.

Policy avenue: The proposed Circular Economy Act, Waste Framework Directive (WFD) review (Article 11(6) and implementation. Public Procurement Directives, CPR – Minimum GPP criteria for construction products and the EU Taxonomy regulation– Environmental Delegated Act.

5.2 Moving to performance based and zero pollution ambition-oriented standards.

Cement and concrete standards

- The recipe-based standardisation approach, setting out prescriptive Portland clinker content, should move towards performance-based standards which satisfy essential technical functions as well as high level of environmental and human health protection and climate neutrality ambition as its core criteria.
- The Commission should speed up the standardisation request to CEN/TC 51 to harmonise Alkali activated cements (scheduled for Q4 2027).
- Follow this up with a standardisation request for the harmonisation of EN 206 to CEN/TC 104 under a performance-based approach, which legally supports the inclusion of low-carbon binders into concrete and secure sufficient resources to the drafting process.
- Balance the composition of standardisation bodies / EU BREF expert groups in terms of interest groups represented, with the aim of promoting innovation towards future proof best practice instead of protecting the status quo of industry incumbents (laggards).

Policy avenue: The Construction Products Regulation and EU standardisation bodies, notably CEN/TC 51 for EN 197-1, EN 197-5, EN 197-6 and CEN /TC 104 for EN 206. Industrial Emissions Directive (IED) — BREF guidance rules.

Recognition and regulation of low environmental impact production techniques

- A swift review of the outdated Cement, Lime and Magnesium dioxide (CLM) BREF, fostering a transitioning away from Portland clinker-based / high polluting processes.
- Conclusions on Best Available Techniques (BAT) shall support alternative production techniques for low-carbon binders that don't generate process CO₂ emissions and minimise other environmental impacts to prove climate proof production methods. This requires a shift towards an outcome-oriented approach in BAT determination, setting the best ratio of no/lowest pollution impacts per tonne of cement material produced.
- Current outdated BAT-AE(P)Ls must be tightened e.g. daily averaged dust levels <5mg/Nm³, NO_x emissions <200 mg/Nm³ and mercury levels <10µg/Nm³ to promote technologies with less emissions intensity. Ambitious GHG BAT-AELs shall be set, which may be complied through the use of CCS or alternative low-carbon binders.
- CCS shall be clearly the last resort option as a transitional “last resort Available Technique”, due to its negative cross media effects and questionable cost-effectiveness ratings, unless applied to mitigate residual emissions that cannot be addressed through changes in chemical pathways or the use of circular and low-carbon feedstocks. Minimal capture rates (>95%) and safe and permanent storage requirements shall be integral part of the revised BAT ambition.

Policy avenue: Industrial Emissions Directive (IED) — CLM BREF review process.

More information in this report: Section 3.2, Section 2.4, CCS Reality Check: Risks and Priorities-European Environmental Bureau (2025), Fast-tracking cement decarbonisation: From underperforming to performance-based standards-. Alliance for Low-Carbon Cement and Concrete (2023).

5.3 Support for scaling up: procurement led lead markets.

The EU policy toolbox aimed at scaling up, lead markets or fostering uptake of the shift towards displacement of high concrete use by (more) sustainable concrete alternatives can be supported through various ways. Various stakeholders do have a role to play in the value chain, from producers, to big users (private/public) to procurement authorities (public or private).

Public procurement

- Public procurement must become fully climate neutral by 2045, and it should be based on roadmaps established by Member States. At the very least, this should be implemented for procurement of products, works and services covering GHG intensive industrial products with the goal to create lead markets.
- Environmental and socially responsible procurement criteria must be mandatory in all procurement contracts to prevent the practice of lowest price-based procurement. Only products with the highest-rated sustainability and performance requirements, as defined in relevant sectoral / product legislations may be awarded for procurement.

Policy avenue: Public Procurement Directives.

Concrete lead markets

- Procurement contracts must be awarded to products, works or services with the lowest environmental impact. Contracting authorities should support ETA route certified low-carbon binders by adopting ambitious criteria.
- An indicative reference for encouraging low-carbon binders can be set based on 135 kg CO_{2eq}/m³ (cradle to gate) for C30/37 for concrete, to encourage lead markets for low-carbon binder-based concretes in public procurement tenders. An equivalent WLC limit for all embodied carbon in building floor area, 225 kg CO_{2eq}/m² (over a 50-year reference period), can be used as a basis for setting WLC limits in limits in the national building renovation plans under the EPBD as well as criteria for buildings in public procurement contracts.
- Taxonomy regulation (2020/852): The Technical Screening Criteria (TSC) for substantial contribution to climate mitigation for the manufacture of cements must be updated to provide specific investment incentives for clinker-free low-carbon binders. The TSC criteria for all other infrastructure and buildings should also add a minimum substantial contribution threshold for concrete to drive investments into low-carbon concrete in large infrastructure projects.

Policy avenue: Energy Performance of Buildings Directive, Public Procurement Directives and EU Taxonomy regulation.

More information in this report: Section 3.5, 4.3 and European Environmental Bureau (2025), Green Public Procurement: Recommendations for the EU Public Procurement Directive.

Private procurement

- Construction and Infrastructure companies should include targets for their contribution towards decarbonising the entire value chain. Targets for decarbonisation should include all emissions covering raw material supply and production (scope 3 upstream) for 2030 and 2050, driving the lead markets for low-carbon binders and concrete.
- Long term offtake agreements or purchase commitments for low-carbon products should be encouraged by the Construction and infrastructure companies.

Policy avenue: No specific EU policy.

Cement producers

- Cement producers opting for the CCS option should be covered by private funds or resources generated through rigorous enforcement of the polluter-pays principle. The swift phase out of free allocations under the EU ETS review should be maintained.
- Cement producers in the EU should lead the research on low and ultra-low-carbon cements by applying for ETA route certification for receiving a CE label, encouraging more infrastructure stakeholders to use such products and accelerate the performance-based standards for low-carbon binders.

Policy avenue: EU ETS Directive revision (Directive (EU) 2023/959).

Specific to investors and insurance companies

- Investors and Insurance companies should provide financial support, guarantees and risk management services to low-carbon binder production installations and infrastructure projects using concretes based on such binders, if the binders are certified under the ETA route and have received a 'CE' marking.

5.4 Cross cutting policies: Tools for tracking progress in cement transformation and pollution prevention

Key features

- Operators of IED installations should provide a functional web link to the Environmental Report of the EMS (EMAS or ISO 14001) in a digital format so to enable data interoperability.
- Allow comparability of permit conditions in force and integration of data related to inputs (e.g. water, raw materials and energy consumption) as well as production data to allow benchmarking of and comparability of performance at installation level.
- Open source and centralised EPD database should allow comparability of environmental sustainability performance at cement/concrete product level over its life cycle covering the essential environmental characteristics. These should be available digitally and make EPDs interoperable between databases and usable at a global scale.
- Monitoring and reporting frameworks for procurement contracts must be improved, with lower thresholds and track progress on green public procurement.

Policy avenue: Industrial Emissions Portal Regulation and digital EPDs, Public Procurement Directive, Digital Product Passport to be developed under the Construction Products Regulation. More information in this report: Section 3.10.



Annexes

Table 1: Cement production installations and production capacity by country in the EU

Cement production installations and production capacity by country in the EU, 2023			
Country	No of installations*	Capacity in Million tonnes	share of EU capacity
Germany	41	76.15	19.6
Spain	31	60.49	15.6
France	25	58.66	15.1
Italy	40	53.31	13.7
Poland	95	23.10	5.9
Greece	6	15.80	4.1
Romania	7	14.15	3.6
Belgium	7	10.40	2.7
Portugal	6	9.62	2.5
Austria	8	9.40	2.4
Ireland	4	9.00	2.3
Czechia	6	7.90	2.0
Slovakia	1	1.50	1.7
Bulgaria	7	5.40	1.4
Hungary	3	5.40	1.4
Croatia	9	4.71	1.2
Sweden	3	3.10	0.8
Finland	2	3.00	0.8
Denmark	1	2.95	0.8
Cyprus	1	2.85	0.7
Latvia	1	1.60	0.4
Luxembourg	1	1.50	0.4
Slovenia	9	6.60	0.4
Lithuania	2	1.20	0.3
Estonia	1	0.75	0.2

*Production of Portland cement clinker in rotary kilns exceeding 500 tonnes
Source: Number of production installations: Industrial Reporting under the Industrial Emissions Directive 2010/75 and European Pollutant Release and Transfer Register Regulation (EC) No 166/2006 - ver. 14.0 Mar. 2025
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Table 2: The 27 products in the family of common cements- EN 197-1 standards

Main types	Notation of the 27 products (types of common cement)		Composition (percentage by mass ^a)											Minor additional constituents
			Main constituents											
			Clinker	Blast-furnace slag	Silica fume	Pozzolana		Fly ash		Burnt shale	Limestone			
			K	S	D ^b	natural P	natural calcined Q	siliceous V	calca- reous W	T	L	LL		
CEM I	Portland cement	CEM I	95-100	—	—	—	—	—	—	—	—	—	—	0-5
CEM II	Portland-slag cement	CEM II/A-S	80-94	6-20	—	—	—	—	—	—	—	—	—	0-5
		CEM II/B-S	65-79	21-35	—	—	—	—	—	—	—	—	—	0-5
	Portland-silica fume cement	CEM II/A-D	90-94	—	6-10	—	—	—	—	—	—	—	—	0-5
	Portland-pozzolana cement	CEM II/A-P	80-94	—	—	6-20	—	—	—	—	—	—	—	0-5
		CEM II/B-P	65-79	—	—	21-35	—	—	—	—	—	—	—	0-5
		CEM II/A-Q	80-94	—	—	—	6-20	—	—	—	—	—	—	0-5
		CEM II/B-Q	65-79	—	—	—	21-35	—	—	—	—	—	—	0-5
	Portland-fly ash cement	CEM II/A-V	80-94	—	—	—	—	6-20	—	—	—	—	—	0-5
		CEM II/B-V	65-79	—	—	—	—	21-35	—	—	—	—	—	0-5
		CEM II/A-W	80-94	—	—	—	—	—	6-20	—	—	—	—	0-5
		CEM II/B-W	65-79	—	—	—	—	—	21-35	—	—	—	—	0-5
	Portland-burnt shale cement	CEM II/A-T	80-94	—	—	—	—	—	—	6-20	—	—	—	0-5
		CEM II/B-T	65-79	—	—	—	—	—	—	21-35	—	—	—	0-5
	Portland-limestone cement	CEM II/A-L	80-94	—	—	—	—	—	—	—	6-20	—	—	0-5
		CEM II/B-L	65-79	—	—	—	—	—	—	—	21-35	—	—	0-5
		CEM II/A-LL	80-94	—	—	—	—	—	—	—	—	6-20	—	0-5
		CEM II/B-LL	65-79	—	—	—	—	—	—	—	—	—	21-35	0-5
	Portland-composite cement ^c	CEM II/A-M	80-94	<----- 6-20 ----->										0-5
		CEM II/B-M	65-79	<----- 21-35 ----->										0-5
CEM III	Blastfurnace cement	CEM III/A	35-64	36-65	—	—	—	—	—	—	—	—	—	0-5
		CEM III/B	20-34	66-80	—	—	—	—	—	—	—	—	—	0-5
		CEM III/C	5-19	81-95	—	—	—	—	—	—	—	—	—	0-5
CEM IV	Pozzolanic cement ^c	CEM IV/A	65-89	—	<----- 11-35 ----->					—	—	—	0-5	
		CEM IV/B	45-64	—	<----- 36-55 ----->					—	—	—	0-5	
CEM V	Composite cement ^c	CEM V/A	40-64	18-30	—	<----- 18-30 ----->			—	—	—	—	0-5	
		CEM V/B	20-38	31-50	—	<----- 31-50 ----->			—	—	—	—	0-5	

a The values in the table refer to the sum of the main and minor additional constituents.

b The proportion of silica fume is limited to 10 %.

c In Portland-composite cements CEM II/A-M and CEM II/B-M, in pozzolanic cements CEM IV/A and CEM IV/B and in composite cements CEM V/A and CEM V/B the main constituents other than clinker shall be declared by designation of the cement (for example see clause 8).

(source: EN197-1, better known as the harmonized European cement standard)



Glossary and list of abbreviations used in this report.

Definitions used in this report:

Cement blending: Reduction of clinker content in Portland cement using supplementary cementitious materials (SCM's such as slag, fly ash, limestone, or recovered cement paste), thereby lowering the clinker share of the final cement and its overall GHG emissions.

Clinker substitution: Replacement of primary clinker share in Portland based cements with supplementary cementitious materials or alternative binders, thereby lowering or eliminating process CO₂ emissions from calcination.

Alternative binders: Binder systems that do not rely on Portland clinker chemistry as the primary hydraulic phase and instead use different chemical reaction pathways to achieve strength and durability. They can be high or low-carbon depending on the process CO₂ emissions generated from the production process.

LCB: Low-carbon binders are defined in this report as cementitious systems where process CO₂ emissions resulting from chemical pathways or the use of circular and low-carbon feedstocks are not hard to abate, with the aim to achieve deep decarbonisation of the binder production process. They are a specific subset of alternative low-carbon binders.

Recycled Aggregates: Substitution of virgin sand or gravel in concrete with recycled materials as aggregates derived from construction and demolition waste to reduce primary raw material extraction and associated emissions.

RCF: Recycled Concrete Fines. Fine particle fraction recovered from crushed concrete CDW; used as a supplementary cementitious material or filler in cement and concrete under EN 197-6.

RCP: Recycled Cement Paste. Hydraulically active fraction recovered from recycled concrete fines, containing residual unhydrated clinker particles; can substitute for fresh clinker in cement production.

Abbreviations used in this report:

AAC: Alkali-Activated Cements. Binder systems using alkali activators to react with aluminosilicate precursors such as slag or fly ash, without Portland clinker.

ARM: Alternative Raw Material

ASTM: American Society for Testing and Materials. US standards development organisation.

ATR: Autothermal Reforming. Hydrogen production process combining partial oxidation and steam reforming; used in low-carbon hydrogen pathways.

BAT: Best Available Techniques Under Directive 2010/75/EU as amended by 2024/1785/EU (Industrial Emissions Directive).

BAT AEL: BAT-Associated Emission Level. Emission limit values associated with the application of BAT (under directive 2010/75/EU as amended by 2024/1785/EU).

BAT AE(P)L: BAT-Associated Environmental Performance Level. Environmental performance benchmarks linked to BAT application (under directive 2010/75/EU as amended by 2024/1785/EU), covering performance parameters such as energy and material use.

BF: Blast Furnace. Iron-making furnace producing pig iron; a source of blast furnace slag used as an SCM in cement production.

BOF: Basic Oxygen Furnace. Steelmaking process using pure oxygen to convert pig iron to steel.

BREF: BAT Reference Document. Technical reference documents under directive 2010/75/EU as amended by 2024/1785/EU setting out BAT conclusions for specific industrial sectors.

BSI: British Standards Institution. UK national standards body.

CCS/ CCUS: Carbon capture and Storage. Carbon capture and use or storage.

CDW: Construction and Demolition Waste.

CE: Conformance Européenne. CE marking indicates a product meets EU harmonised standards and can be placed on the EU market; required for construction products under the CPR.

CEEAG: Climate, Energy and Environmental Aid Guidelines. European Commission guidelines governing state aid for climate, energy, and environmental objectives.

CEM: Cement type designation under EN 197-1

CEN: European Committee for Standardisation. European standardisation bodies responsible for developing EN standards, including the EN 197 series for cement and EN 206 for concrete.

CISAF: Climate and Industrial State Aid Framework. Adopted June 2025, complements the CEEAG and replaced the Temporary crisis and Transition Framework (TCTF), governs public support for industrial decarbonisation and climate investments.

CLM BREF: EU BREF on Cement, Lime and Magnesium Oxide Production. Sector-specific BAT Reference Document under directive 2010/75/EU as amended by 2024/1785/EU covering industrial emissions from cement, lime, and magnesium oxide manufacturing.

CO_{2eq}: equivalent CO₂ emissions of all GHG gases.

CPR: Construction Products Regulation. Regulation 2024/3110/ EU (recast) governing the placing of construction products on the EU market; mandates EPD requirements from January 2027.

CPV: Common Procurement Vocabulary. Standardised classification system for public procurement established by regulation 2002/2195/ EU and used in public procurement.

DRI: Direct Reduced Iron. Low-carbon alternative to blast furnace iron production; can use hydrogen as a reducing agent, enabling near-zero-emission steelmaking when combined with an EAF.

EAD: European Assessment Document. Technical document issued by European Organisation for Technical Assessment (EOTA) defining the assessment method and essential characteristics for a construction product seeking a European Technical Assessment.

EAF: Electric Arc Furnace. Steelmaking furnace using electrical energy to melt scrap steel; lower-emission route compared to the BF-BOF pathway.

EEA: European Environment Agency

EMAS: Eco-Management and Audit Scheme. Voluntary EU scheme under Regulation 2009/1221/ EC for organisations to evaluate and improve and publicly report environmental performance.

EMS: Environmental Management System. Framework for managing an organisation's environmental impacts; formalised under standards such as ISO 14001 or EU schemes such as EMAS.

EPBD: Energy Performance of Buildings Directive. EU Directive (recast 2024/1275/EU) setting minimum energy performance requirements for buildings.

EPD: Environmental Product Declaration. Standardised document quantifying the environmental impacts of a product across its lifecycle, based

on a life cycle assessment (LCA) in accordance with ISO 14025 and, for construction products in the EU, under EN 15804+A2.

EOTA: European Organisation for Technical Assessment. Europe-wide association of Technical Assessment Bodies (TABs) for construction products, established under the Construction Products Regulation; provides the framework for the European Technical Assessment (ETA) of construction products to ensure consistent product performance information throughout Europe.

ERMCO: European Ready Mixed Concrete Organisation

ESPR: Ecodesign for Sustainable Products Regulation (2024/1781/EU).

ETA: European Technical Assessment. Documented assessment of the performance of a construction product for its essential characteristics issued by a Technical Assessment Body (TAB) under Regulation 2024/3110/EU (CPR recast) on the basis of a European Assessment Document (EAD); provides a voluntary route to CE marking for products not covered by a harmonised standard.

EU ETS: EU Emissions Trading System, Directive 2003/87/EC.

EUA: European Union Allowance as defined under the EU ETS (Directive 2003/87/EC); one EUA entitles the holder to emit one tonne of CO₂ equivalent and can be traded. Issued through auctions or as free allocations to eligible installations.

E-PRTR: European Pollutant Release and Transfer Register. Publicly accessible EU-wide register under Regulation 2006/166/EC, implementing the UNECE Kiev Protocol on Pollutant Release and Transfer Registers. Replaced by the Industrial Emissions Portal regulation (2024/1244/EU) from 1 January 2028.

FA: Fly Ash. By-product of coal combustion with pozzolanic properties; used as an SCM in blended cements and concrete to partially replace Portland clinker.

GBFS: Granulated Blast Furnace Slag. Also referred to as Ground granulated Blast furnace Slag (GGBS); hydraulic material produced by quenching molten blast furnace slag and requires chemical activation to become cementitious; used as an SCM or clinker substitute in cement production.

GCCA: Global Cement and Concrete Association

GHG: Greenhouse Gas

GPP: Green Public Procurement.

GWP: Global Warming Potential. GWP usually covers GHG impact of a material over a defined time frame (typically 100 years) used in LCA and EPDs to quantify climate impact.

IAA: Industrial Accelerator Act.

IEA: International Energy Agency.

IED: Industrial Emissions Directive. Directive 2010/75/EU as amended by 2024/1785/EU, governing emissions from large industrial installations; sets BAT obligations for cement plants.

IED 2.0: Recast Industrial Emissions Directive. Directive 2024/1785/EU.

IEP-R: Industrial Emissions Portal Regulation. Revised legislation repealing the E-PRTR (2006/166/EC). Will be in force from January 2028.

IPCEI: Important Projects of Common European Interest

IPCC: Intergovernmental Panel on Climate Change.

ISO: International Organisation for Standardisation.

LC3: Limestone Calcined Clay Cement.

LCA: Life Cycle Assessment. Methodology for quantifying the environmental impacts of a product or system across its full lifecycle; governed by ISO 14040/44.

LEVEL(S): EU Framework for Sustainable Buildings. European Commission voluntary framework providing common metrics for assessing and reporting on the sustainability performance of buildings across their full lifecycle. It is the basis for whole life carbon assessments in the EPBD (2024/1275/EU).

MEAT: Most Economically Advantageous Tender. Award criterion under the public procurement directive (2014/24/EU); allows contracting authorities to evaluate tenders on quality, environmental, and social criteria beyond price alone.

OJEU: Official Journal of the European Union.

ORC: Organic Rankine Cycle.

PPA: Power Purchase Agreement.

PAC scenario: Paris compatible scenario

RDF: Refuse-Derived Fuel. Fuel produced from non-hazardous municipal solid waste.

RE: Renewable Energy

SBTi: Science Based Targets initiative. Initiative providing companies with a framework for setting greenhouse gas reduction targets aligned with Paris Agreement temperature goals.

SCM: Supplementary Cementitious Material. A material used to complement clinker in cement production that contributes to strength development in concrete, partially replacing Portland clinker; includes fly ash, GBFS, calcined clay, and silica fume.

SMR: Steam Methane Reforming. Conventional hydrogen production process using natural gas and steam; produces significant CO₂ unless combined with carbon capture.

SRF: Solid Recovered Fuel. An RDF standardised under EN 15359 to be used as an alternative fuel in cement kilns.

STEP: Solar Thermal Electrochemical Process

TP: Transformation Plan under Directive 2024/1785/EU (IED 2.0), a mandatory plan requiring industrial operators to outline steps towards net-zero production by 2050.

TRL: Technology Readiness Level. Scale from 1 to 9 used to assess the maturity of a technology; TRL 9 = commercially deployed; TRL 1-3 = early research.

TSC: Technical Screening Criteria published under EU Taxonomy Regulation 2020/852.

VSL: Value of Statistical Life. Valuation method used in cost-benefit analysis to monetise the economic value of reducing mortality risk.

WFD: Waste Framework Directive. Directive 2008/98/EC as amended by Directive 2018/851/EU and Directive 2025/1892/EU; establishes the EU legal framework for waste management.

WHR: Waste Heat Recovery. Capture and reuse of surplus thermal energy from industrial processes.

WLC: Whole Life Carbon. Total greenhouse gas emissions associated with a building or infrastructure asset across its full lifecycle. An equivalent term to refer to the lifecycle Global Warming Potential (GWP) as defined in revised Energy Performance of Buildings Directive (EPBD, Directive 2024/1275/EU).

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 200 Higher strength classes require proportionally higher embodied carbon limits. An expected 10-15 kg CO_{2eq}/ m³ increments for every concrete strength class has been applied in voluntary industry classifications (BY Low-carbon Classification, Finland). Performance is subject to full conformity with EN 206 based standards in Member States.
 201 Reinforcement steel is assumed to be at 0.5 t CO_{2eq}/ t of steel, reflecting a feasible limit for scrap-based EAF steel with low-carbon electricity in the EU today. Concrete intensity is assumed to be around 0.4m³/m² and reinforcement steel intensity is assumed at 50 kg/m², which can be reduced further with structural design efficiencies. The remaining stages apart from the B6 (operational emissions) included in the WLC life cycle assessments, specifically B2 (Maintenance), B4 (replacement) and C (end of life) stages are usually in the order of 10-15% of the embodied emissions in European housing archetype studies.
 202 By 11.4 times , SBTi <https://files.sciencebasedtargets.org/production/files/Supplier-Engagement-Guidance.pdf>
 203 <https://bregroup.com/products/breeam/> , <https://www.dgnb.de/en>, <https://www.hqegbc.org>, <https://www.minergie.com/en/>, <https://gbce.es/sistemas/verde/> and <https://www.gbci.org/europe> (LEED)



About the EEB

The European Environmental Bureau (EEB) brings together citizens' groups from across Europe. Our 190 members from 41 countries have more than 30 million individual supporters.

Vision

A better future where people and nature thrive together.

The next generation deserves a healthy planet. We believe in a world where equal, just, peaceful and democratic societies can prosper. A world with rich biodiversity and a safe climate. A world where laws and policies promote health and wellbeing while respecting nature. We believe that Europe has a crucial role to play in building this future.

Mission

We are the largest and most inclusive European network of environmental citizens' groups – and the only one that works on such a broad range of issues.

We advocate for progressive policies to create a better environment in the European Union and beyond.

Our Values

The EEB stands for sustainable development, environmental justice, global equity, transparency and participatory democracy. We promote the principles of prevention, precaution and 'polluter pays'.

- Democracy: We are a representative and inclusive organisation
- Fairness: We are committed to justice, equality and non-discrimination
- Respect: We provide an enabling, nurturing work culture that inspires excellence
- Integrity: We advocate policies based on science and communicate with honesty
- Sustainability: We strive to practice what we preach, applying green principles to our work.

