Connections Series
Infrastructure and Construction

CREDIT SUISSE

Solving the concrete emissions puzzle primer

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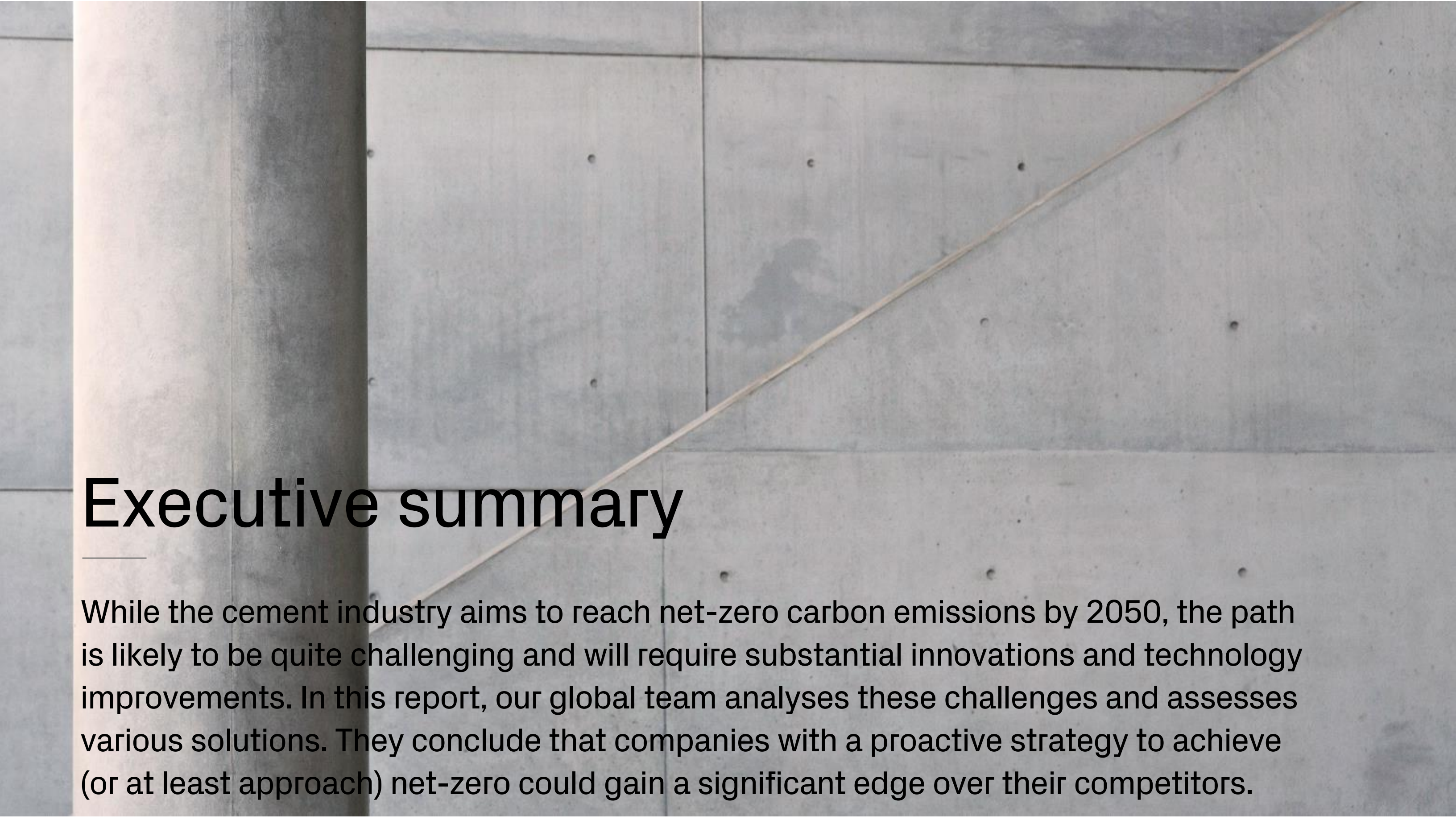


Executive summary

While the cement industry aims to reach net-zero carbon emissions by 2050, the path is likely to be quite challenging and will require substantial innovations and technology improvements. In this report, our global team analyses these challenges and assesses various solutions. They conclude that companies with a proactive strategy to achieve (or at least approach) net-zero could gain a significant edge over their competitors.

In this publication, our global team examines the current state of cement & concrete sector emissions, avenues for the decarbonization of this CO_2-intensive sector, and the challenges befalling this effort. We also discuss cement's outsized role in the construction sector's emissions versus its revenue share, the burden it places on cement producers, and the risks it poses for the construction sector as a whole. Finally, we assess various technologies and alternatives that could accelerate cement's decarbonization process. We also highlight country-level decarbonization initiatives, including a section on China's cement sector, the largest in the world.

A big problem

Concrete is the foundation of most construction activity and also a massive industry, as the second most consumed material by mass after water. Still, this industry faces significant pushback from investors, as the main material needed to produce concrete (cement) is the most emissions-intensive, man-made material relative to revenues, as per McKinsey. Owing to the extensive usage of concrete for most construction projects, the sector is responsible for at least 7% of man-made CO_2 emissions, which is similar to India's total country emissions.

In addition, the cement sector is difficult to decarbonize versus other man-made materials because most of its emissions are generated during the production process rather than in the consumption of power/fuels. This places the onus of cement's decarbonization on cement companies rather than on power generators or EV manufacturers, for example, as is the case for other sectors such as transportation or HVAC.

Limited construction industry focus on this subject

Our U.S./Europe Construction & Building Materials analysts identify little focus on materials' carbon emissions from construction companies. We believe this is explained by several factors. The most relevant is that construction materials are not included in Scope 2 emissions, which we understand are the most followed by ESG-cognizant investors. We believe this approach is not appropriate, as a recent study published in Climate Journal estimates materials would add nearly 30% to the lifecycle emissions of a given residential project vs. Scope 1-2 only, if incorporated (bear in mind that residential is the least cement-intensive type of construction).

In addition, we believe "green" building indexes provide very little demand-push incentives for low-emission construction materials. For example, "environmentally preferred" construction materials represent only 4 of 110 points in the LEED Residential Low Rise checklist. As such, homebuyers sensitive to environmental issues will likely pay little attention to cleaner construction materials in their purchasing decisions. This also fails to stimulate homebuilders to push for cleaner construction materials.

Still, the cement industry has set encouraging targets

The industry's main industry association (GCCA, whose constituents account for most of the world's cement production ex-China) has made aggressive pledges to reach net-zero concrete by 2050. Most of the cement companies under our coverage ex-China have added themselves to this pledge. These companies also have aggressive plans for reducing per-ton cement-related emissions by 15% on average in 2020-2030. With this, we estimate these companies will have reduced emissions per ton of cement by 32% from 1990 to 2030, mostly from implementing technologies that are already widely proven on an industrial scale, such as alternative cementitious materials and fuels, more efficient kilns, and renewable/clean power.

Still, we believe cement's carbon emissions will remain highly significant in 2030, by which these widely available technologies will have already been integrated into most cement production, where suitable. Further reductions in cement/concrete emissions to reach net-zero concrete will necessarily rely on technologies yet unproven/uneconomical at an industrial scale (chiefly CCU/CCUS, or carbon capture, utilization, and storage).

Concrete will be extremely reliant on CCU/CCUS technology improvements to reach these lofty goals

According to estimates shared by a leading building materials company, only a further 13% reduction in direct cement/concrete emissions is feasible in 2030-50, as "clinkerization" will continue to generate emissions even if one used 100% clean electricity/fuel. As such, the pathway to net-zero concrete relies on other solutions, and chiefly on carbon capture, which represents a massive 59% of the needed 2030-2050 reduction

in concrete emissions. As such, we see cement/concrete as one of the industries most levered to improvements in carbon capture technology to reach its lofty emissions targets.

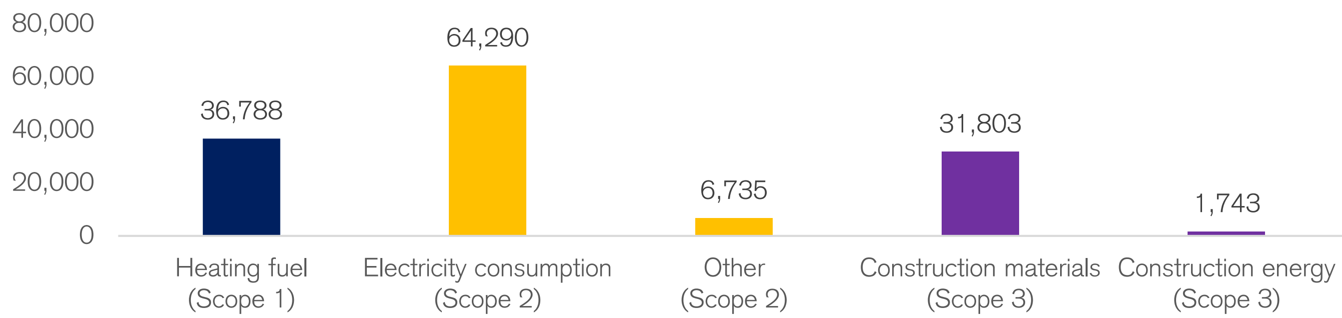
Our view: a sector-wide problem will require sector-wide efforts

After reviewing the problem from the angle of the cement producers and the construction industry more broadly, we consider whether the cement industry will bear the brunt of the emissions problem. Based on the way in which the share of emissions is reported, the cement industry's outsize share of emissions is causing investors to avoid the industry altogether and to bypass consideration of the lack of viable substitutes, cement's vital importance for construction activity, as well as its successful CO2 reduction track-record and ambitious targets.

We envision several scenarios that could develop in different regions/countries. In the absence of widespread carbon allowance systems in place, the cement and concrete industry could struggle to reduce emissions at a sufficient pace to reach net-zero concrete by 2050, as the costs per ton of carbon capture could be too high relative to profitability. Even if carbon allowances are implemented in a manner that leads to CCUS being economically appealing at scale (as is the case currently in Europe), cement pricing will need to reflect the incremental costs, something we understand is not happening fully in this region. Absent this, cement margins could deteriorate, leading to underinvestment in CCUS initiatives.

Stronger incentives for decision-makers (be it homebuyers, regulators, or architects) to prefer usage of cleaner cement could go a long way in allowing for this "green premium" to be paid. One of these incentives could be "green building" indexes incorporating low-emission materials in a more meaningful way. Another would be regulations favoring the usage of lower-clinker cement products (a trend already underway in the U.S., but that has recently reversed in China). But we believe the most impactful change could be the investment community more actively monitoring Scope 3 emissions of construction projects and companies. This could unlock premium pricing for lower-emission alternatives, in turn incentivizing and providing much needed capital for cement companies to accelerate decarbonization.

Figure 1: Construction materials are the third largest component of Scope 1-3 emissions for a housing development's lifecycle emissions



Source: Company data, Credit Suisse, Climate Journal

How to tackle the issue from an investing standpoint

We believe that, for cement companies, preparation for the long-term race to net zero is more important than mid-term targets. As our ESG team has argued, the world needs (and will likely see, at least in advanced economies) much higher global carbon prices to advance decarbonization. The average 14% 2020-2030 per-ton target reduction in CO2 emissions from companies in our coverage could provide little protection against the hefty incremental costs for cement companies if mandatory carbon markets grow as expected across the globe.

We believe companies with a proactive strategy to achieve (or at least approach) net zero could gain a significant edge vs. competitors in such a scenario, and also limits risks in the event full pass-through of carbon costs proves elusive. From our coverage, couple of companies are stand out, as they are going beyond 2030 targets to create a detailed roadmap for net zero, matched with a diverse set of carbon capture projects. The project portfolio and the resulting learning opportunities for early implementation could prove to be among the most important assets for cement companies in the long term, in our view.

“ Concrete is the most used material in the world by volume after water.

Cement and concrete: a brief primer

Most construction requires concrete. Concrete is the most used material in the world by volume after water. We estimate ~14.3bn cubic meters (m3) of concrete were poured in 2020.

…and concrete needs cement. Concrete is a liquid mix between water, aggregates (mostly sand and gravel) and cement. Cement is the binding agent for setting concrete, and is also produced on a massive scale (4,281bn Mt in 2021 as per IEA estimates). Concrete is mixed onsite or in ready-mix plants close to the construction site because concrete begins to "set" or dry as soon as it is not being mixed. Usually, it needs to be poured before 60-90 minutes have passed for the pouring and setting to be adequate.

Cement is made from limestone, gypsum, and other materials. To make cement, limestone is calcinated at high temperatures inside a kiln with aluminosilicates to produce clinker, which is then combined with other materials (usually gypsum) and ground to small particles to produce cement. One of the most important characteristics of cement is its "clinker factor": that is, the amount of clinker per ton of cement. This factor varies significantly between 55% and 90%, depending on construction regulations, client preference, as well as incorporation of other materials that serve as an alternative to clinker, such as pozzolan rock or fly ash.

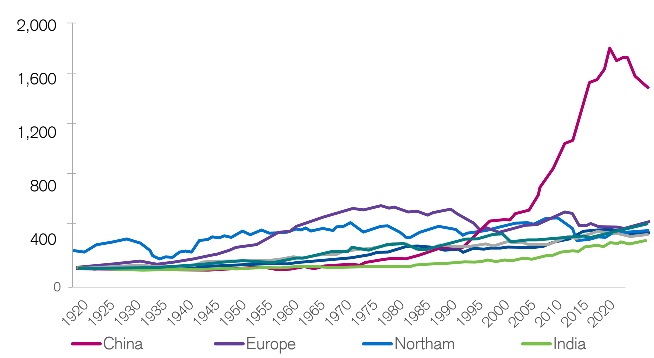
World cement demand has grown in recent years, but likely to remain stagnant in the medium term. Cement demand has grown at a 2.7% 2010-20 CAGR, albeit decelerating notably from 6.1% in 2010-14 to 0.5% in 2021. IEA anticipates that world cement demand during 2021-30 will remain stagnant, as China's demand is expected to decline, offset by growth in India and Africa, as well as the U.S. By far, China is the largest producer at 2,500 Mt in 2021 (58% of total), followed by India's 330 Mt, Vietnam's at 113 Mt and the U.S. at 92 Mt. U.S. is the largest import market, as consumption was 105 Mt according to PCA.

Notably, demand was strong through the pandemic. During the height of the pandemic, the cement industry was considered indispensable in most countries, as self-construction/home improvement demand increased materially as consumers could devote a larger share of wallet to these activities. We also saw infrastructure construction activities continue or even be stimulated by government, as this was seen as a way to limit the economic impact of lockdowns.

Per-capita demand is highly variable. Most countries have cement demand per-capita of 200-400kg/person, with developed countries at the high-end of the range and Latam/Asia/Africa in the mid to low-end. The outlier is China, with per-capita demand above 1,500kg/ton, which is expected to decline over time according to the IEA.

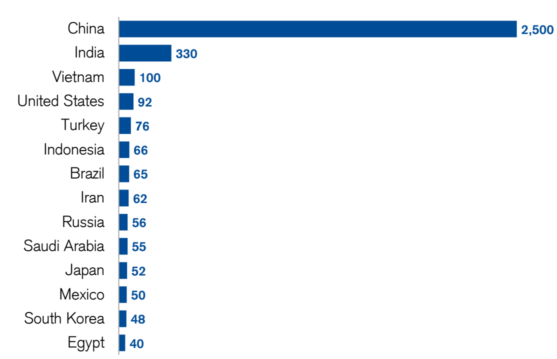
A very "local" commodity. Unlike other materials such as steel or copper, cement is very thinly traded among countries, with only US$12.4bn in trade in 2020 as per the OEC (vs. our estimates of a total market size of US$300-350bn). This is because cement's value per ton is relatively low (for example, US$120-130/ton in the U.S. in 2019, vs. steel at US$600/ton), and also because it is relatively difficult to transport/store, with expiration of 45-60 days after being packed, as it deteriorates gradually due to exposure to humidity.

Figure 2: Cement consumption per capita (kg/person)



Source: FICAM

Figure 3: Total cement production in 2021



Source: Statista

“ The buildings and construction industry accounts for 40% of total global energy-related carbon emissions.

Framing the concrete emissions challenge in buildings and infrastructure

Importance of concrete use in construction activity and emissions

Concrete is a relatively small industry within construction spending… From a revenue perspective, concrete sales are small relative to overall construction spending. In the U.S., we estimate US$48.9bn in concrete sales in 2021, representing 3% of the US$1,587bn annual construction spending in the year.

… but by far the most important from an emissions standpoint. We estimate cement alone represents 60%-plus of building materials and construction activities' CO2 emissions, which are estimated at 11% of world total. Furthermore, it is not feasible to immediately substitute concrete with a lower-GWP material, as most of the construction industry is dependent on concrete for foundations.

By IEA's estimates, cement generates 4.5% of world greenhouse gases' global warming potential (GWP) and 7% of man-made CO2 (11% by other estimates), while concrete (including cement) accounts for 8% as per McKinsey. Stand-alone, cement production emissions are only below that of the U.S., China and India in terms of total country emissions.

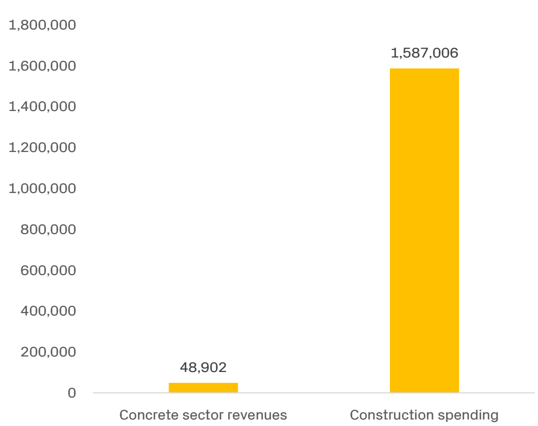
From our U.S. Multi-industry team led by John Walsh:

The buildings and construction industry accounts for 40% of total global energy-related carbon emissions. With governments worldwide committing to achieving net zero in the coming decades, there is increasing focus for building products companies and developers to adopt a net-zero mindset whereby the system would remove the same amount of carbon dioxide from the atmosphere as it emits, i.e., no net carbon dioxide is emitted. While three-quarters of carbon emissions are currently attributable to building operations, we estimate that the amount of embodied carbon will exceed operational carbon in a building by 2035. To reduce embodied carbon, building owners are typically willing to pay a 5-10% premium (up to potentially 30%) for green products.

Substitutes are very limited. We believe the most popular suggestions regarding possible concrete substitutes (e.g., wood, steel, compacted materials) do not take into account concrete's durability, malleability, ease of production on-site, among many other characteristics. Materials that can indeed replicate cement's binding properties for production of concrete closely such as fly ash, silica fumes or blast furnace slag, are all byproducts of other production processes (combustion of coal, production of steel, and silicon) which implies that they cannot be produced at will. Another "alternative" is pozzolan rock, which was used since the Romans in a similar fashion to cement. However, it is not widely available in all locations, and it takes far more time to "cure" as the binding agent than cement concrete.

Figure 4: Concrete represented a meager 3% of 2021 U.S. construction spending, by our estimates

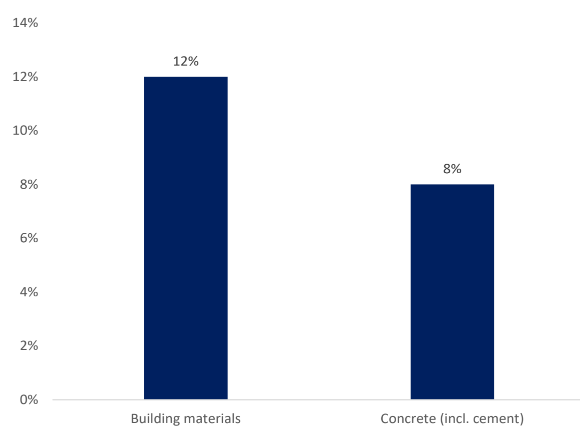
Nominal US$ in millions



Source: PCA, Credit Suisse

Figure 5: However, we estimate the cement and concrete industry accounts for ~67% of the construction sector's CO2 footprint

% of man-made CO2 emissions as of 2020.



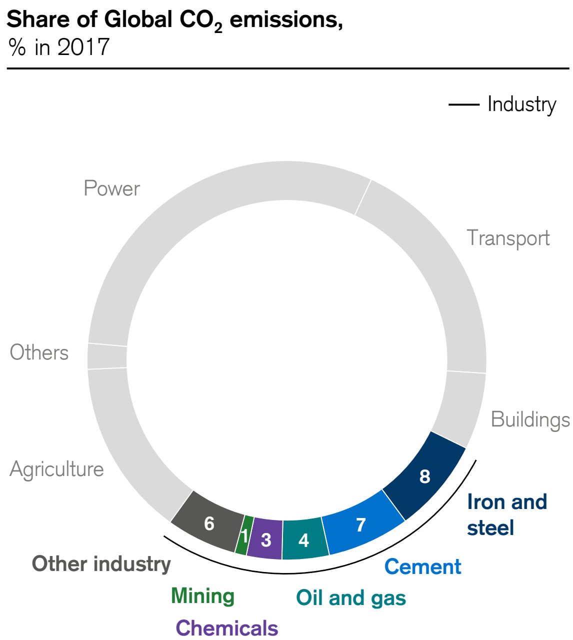
Source: McKinsey, GCCA, Credit Suisse

Substitutes are better suited for improving cement's carbon footprint and costs than for stand-alone utilization. All of these supplementary cementitious materials (SCMs) are used by cement companies to reduce the clinker needed in cement, which in turn reduces emissions per ton, while preserving the characteristics of cement virtually unchanged.

Cement intensity varies significantly by sector, with infrastructure ranking by far as the most demanding per dollar spent. PCA has estimated U.S. cement intensity per subsegment for the 1995-2015 period. Highways are the most intensive at 316.4 Mt per US$mn spent, with housing as the least cement-intensive at 19.8/8.7 Mt per US$mn. However, because residential construction spending is such a large proportion of overall spending (49% of total in 2021 vs. 6% of total for Highways and Streets), residential cement demand still accounts for 20-25% of total U.S. cement demand.

Figure 6: Cement represents 7% of global emissions, the second largest emitter within materials after iron and steel

% of global man-made emissions

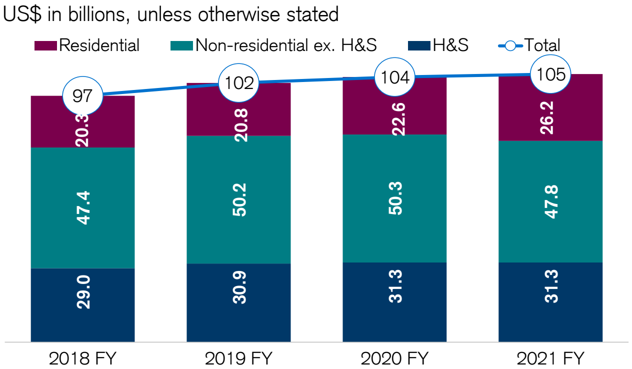


Source: Credit Suisse, McKinsey

Transportation refers to combustion of fossil fuels for transportation purposes, as it does for power. Buildings' consumption excludes power usage.

Figure 7: CSe U.S. cement demand by segment, 2018-21. Highways and Streets are a large segment of overall demand in the country, as most roads are made of concrete rather than asphalt

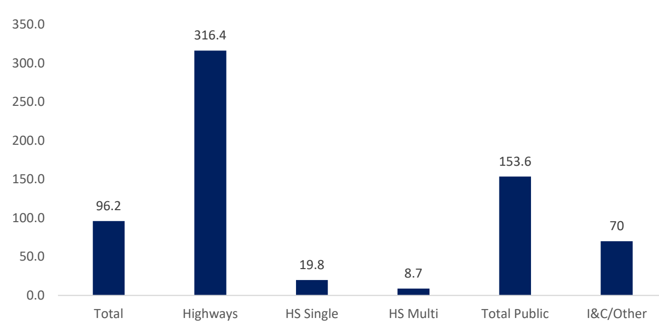
US$ in billions, unless otherwise stated



Source: PCA, Credit Suisse

Figure 8: U.S. cement intensity per US$mn of construction spending, 1995-2015 average

Tons of cement per US$mn spent.



Source: PCA, Credit Suisse

Even within lifecycle building emissions, construction materials' emissions are very important

Cement emissions are not included in traditional reporting from construction/infrastructure/building emissions. This is because emissions related to the production of materials acquired from third parties is considered within Scope 3, while most companies usually focus on Scopes 1 and 2, which are directly attributable to the company's operations. It is worth noting that some countries or environmental reporting standards do require Scope 3 disclosure. The SEC proposed a rule on 3/21/22 to disclose Scope 3 emissions if material, which could place heightened interest on construction materials-related emissions. The rule is currently open for comments until May 20, 2022; we are unclear on timing for enactment, albeit the proposed rule implies Scope 3 reporting would be required for FY 2024.

Lifecycle emissions are relevant, even for residential applications. A recent study of lifecycle emissions from a 3,000-home development project in Jeollanam Province, South Korea (Kim, K.-T.; Kim, I. The Significance of Scope 3 GHG Emissions in Construction Projects in Korea: Using EIA and LCA. Climate 2021, 9, 33), provides very cogent information on the impact of construction materials on overall project emissions. Including construction materials' production emissions into the project, the total carbon footprint of the project is increased by 30%. Worth noting, construction materials' emissions are generated upfront, while emissions related to power consumption could turn out to be lower as the electricity generation matrix becomes greener.

As is described in the paper, Korea's environmental impact assessments do not include Scope 3 emissions, which could underestimate total project emissions by 46-51% vs. EIA's that do include it. Most of the differential between Scope 2 and Scope 3 emissions is explained by construction materials (we believe mainly cement and steel).

Limited focus on Scope 3 emissions creates limited incentive to shift to lower-carbon concrete

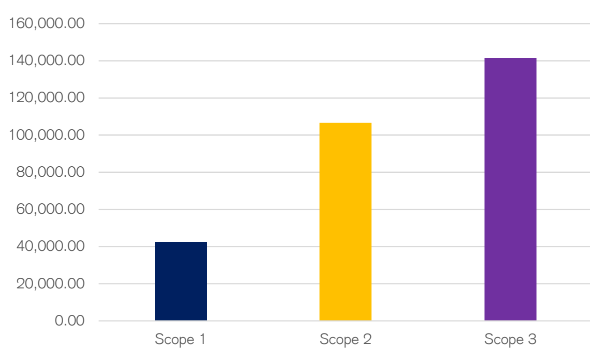
We argue that for the purpose of construction, focus on Scope 1 and 2 only creates limited incentive for using lower-carbon materials for construction companies. We believe construction companies such as homebuilders have more incentives to invest in appliances that reduce emissions for the final user (for example, modern HVAC/insulation that generates power/fuel savings for the final user) rather than optimizing for further reduction in lifecycle emissions.

As per our U.S. housing and building products' team, led by Dan Oppenheim, U.S. homebuilders have yet to focus on concrete as a "green" issue owing to metrics centered on post-construction building efficiency. While there has been significant focus in the U.S. on the issue of green building in the residential market, concrete is rarely mentioned as part of "green" building. We believe the primary issue is that the adoption of most green materials by consumers is based on energy savings or health issues, rather than due to emissions during the production of the material. In addition, an increasingly common metric viewed by buyers of new homes is the Home Energy Rating System (HERS) Index score, which primarily relates to energy efficiency, but is nonetheless viewed as a proxy for how "green" a new home is. The HERS does not mention concrete as one of items reviewed when developing an energy rating (HERS score) for a home. As a result, there is limited incentive or rationale for homebuilders to focus on this issue.

Also, the Green Home Checklist from the United States Green Building Council (USGBC) notes many areas to consider when assessing whether a home is green (location, size, design, building materials, insulation, windows and doors, energy efficiency, renewable energy, water efficiency, indoor environmental quality, and landscaping), but makes no mention of concrete. In addition, the Leadership in Energy and Environmental Design (LEED) makes only limited mention of concrete in the LEED Residential Rating System. In the LEED Residential

Figure 9: Lifecycle CO2 emissions for a housing development project in Korea. Including Scope 3 emissions (mostly construction materials) increases emissions by 30% vs. Scope 1-2, the primarily reported metric

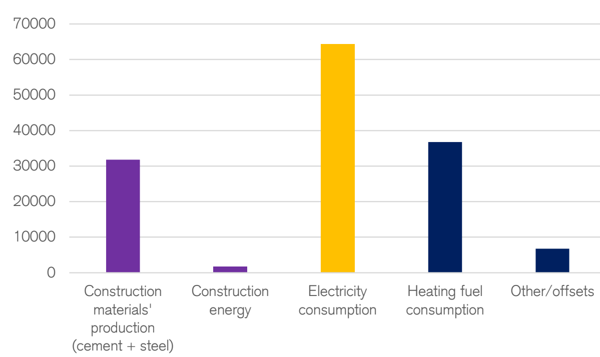
Equivalent CO2 emissions per year in tons.



Source: Climate Journal, Credit Suisse

Figure 10: Construction materials are the third largest component of Scope 3 emissions for the housing development's lifecycle emissions. Still, we believe focus from developers is centered on reducing Scope 1 and 2 emissions

Scope 3 equivalent CO2 emissions per year.



Source: Climate Journal, Credit Suisse

system, a builder can earn one point for utilizing concrete that consists of at least 30% fly ash or slag as a cement substitute and 50% recycled content or reclaimed aggregate. We note that this appears to us as a simplistic assessment of concrete's emissions profile, as there are many other ways of "greening" cement than only SCMs, as described throughout this report.

On this topic, our Europe Building Materials and Construction team, led by Emily Biddulph, highlights the following: The residential sector in Europe has to date largely focused on increasing the energy efficiency of the buildings in use, rather than the carbon intensity of materials. While regulation is increasing, it largely focuses on insulation and the efficiency of heating systems. However, in the long-run we expect the carbon intensity of materials production to fall into greater focus. Companies are increasingly focused on light and off-site construction, largely because it allows for a more efficient build process and reduces the need for skilled labor. Reducing the carbon intensity of materials is not the primary motivation of this step; however, we still expect off-site construction to increase the use of light materials and reduce the use of concrete and mortar.

Why the construction industry as a whole should pay attention to cement's carbon footprint

As argued above, our discussions with construction companies indicate limited "demand-pull" for green cement, with homebuilders in particular showing a greater focus on reducing carbon intensity post-construction (for example via advanced HVAC/insulation) than on reducing construction-related emissions. We believe this is ill-advised, as we believe this could be placing an overtly large burden on the cement and concrete sector vs. its revenue share of the construction industry. We envision the following risk scenarios for the construction sector as a whole:

- Isolated and insufficient efforts by the cement industry on this matter could lead to sudden increases in concrete/cement prices if aggressive carbon regulations were put in place (which would most likely lead to sharp price increases, as there are no clear substitutes for concrete at this point). Our discussions with cement companies in Europe already indicate a "carbon premium" being added to the cement price in certain countries by cement producers with carbon allowance deficits, following the recent sharp increase in EU carbon allowance prices recently (see Figure 13).

Figure 11: Example of assessment of a green home in the U.S. Using concrete with certain "green" characteristics can garner only an improvement of 1 point out of 110, and 4 for environmentally preferred products, while construction materials have been estimated to represent up to 30% of lifecycle emissions of a residential development

LEED v4 for Building Design and Construction: Homes and Multifamily Lowrise
Project Checklist

Project Name:
Date:

Y	?	N			
			Credit	Integrative Process	2
0	0	0		**Location and Transportation**	**15**
Y			Prereq	Floodplain Avoidance	Required
				PERFORMANCE PATH	
			Credit	LEED for Neighborhood Development Location	15
				PRESCRIPTIVE PATH	
			Credit	Site Selection	8
			Credit	Compact Development	3
			Credit	Community Resources	2
			Credit	Access to Transit	2
0	0	0		**Sustainable Sites**	**7**
Y			Prereq	Construction Activity Pollution Prevention	Required
Y			Prereq	No Invasive Plants	Required
			Credit	Heat Island Reduction	2
			Credit	Rainwater Management	3
			Credit	Non-Toxic Pest Control	2
0	0	0		**Water Efficiency**	**12**
Y			Prereq	Water Metering	Required
				PERFORMANCE PATH	
			Credit	Total Water Use	12
				PRESCRIPTIVE PATH	
			Credit	Indoor Water Use	6
			Credit	Outdoor Water Use	4
0	0	0		**Energy and Atmosphere**	**38**
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Energy Metering	Required
Y			Prereq	Education of the Homeowner, Tenant or Building Manager	Required
				PERFORMANCE PATH	
			Credit	Annual Energy Use	29
				BOTH PATHS	
			Credit	Efficient Hot Water Distribution System	5
			Credit	Advanced Utility Tracking	2
			Credit	Active Solar Ready Design	1
			Credit	HVAC Start-Up Credentialing	1
				PRESCRIPTIVE PATH	
Y			Prereq	Home Size	Required
			Credit	Building Orientation for Passive Solar	3
			Credit	Air Infiltration	2
			Credit	Envelope Insulation	2
			Credit	Windows	3
			Credit	Space Heating & Cooling Equipment	4

Y	?	N			
				EA PRESCRIPTIVE PATH (continued)	
			Credit	Heating & Cooling Distribution Systems	3
			Credit	Efficient Domestic Hot Water Equipment	3
			Credit	Lighting	2
			Credit	High Efficiency Appliances	2
			Credit	Renewable Energy	4
0	0	0		**Materials and Resources**	**10**
Y			Prereq	Certified Tropical Wood	Required
Y			Prereq	Durability Management	Required
			Credit	Durability Management Verification	1
			Credit	**Environmentally Preferable Products**	**4**
			Credit	Construction Waste Management	3
			Credit	Material Efficient Framing	2
0	0	0		**Indoor Environmental Quality**	**16**
Y			Prereq	Ventilation	Required
Y			Prereq	Combustion Venting	Required
Y			Prereq	Garage Pollutant Protection	Required
Y			Prereq	Radon-Resistant Construction	Required
Y			Prereq	Air Filtering	Required
Y			Prereq	Environmental Tobacco Smoke	Required
Y			Prereq	Compartmentalization	Required
			Credit	Enhanced Ventilation	3
			Credit	Contaminant Control	2
			Credit	Balancing of Heating and Cooling Distribution Systems	3
			Credit	Enhanced Compartmentalization	1
			Credit	Enhanced Combustion Venting	2
			Credit	Enhanced Garage Pollutant Protection	2
			Credit	Low Emitting Products	3
0	0	0		**Innovation**	**6**
Y			Prereq	Preliminary Rating	Required
			Credit	Innovation	5
			Credit	LEED AP Homes	1
0	0	0		**Regional Priority**	**4**
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
0	0	0		**TOTALS** Possible Points:	**110**

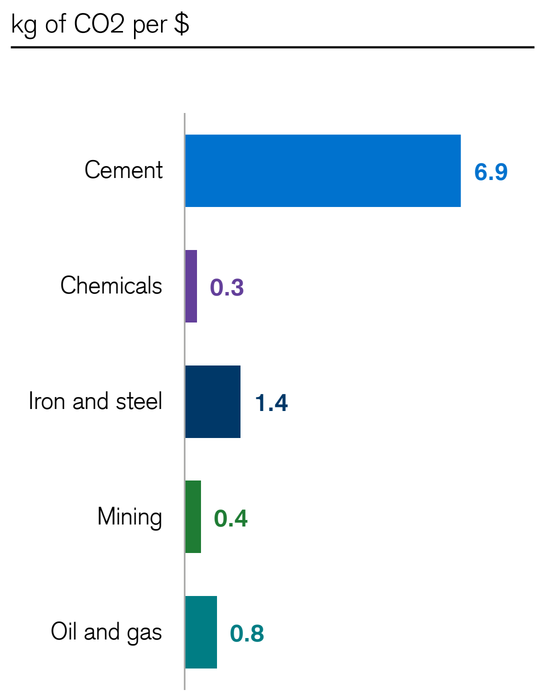
Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110

Source: USGBC, Credit Suisse

- Alternatively, there could be a scenario where cement companies are unable to pass through the carbon price to final consumers. Our discussions with cement producers also indicate the carbon premium being overlaid to EU cement prices is not fully covering the per-ton cost of carbon allowances. We understand this is not affecting all producers as several are still long carbon allowances from the initial free allocation process. However, we expect these allowances to be fully consumed eventually. If cement companies are unable to fully pass through carbon prices to final consumers, this could erode their margins, in turn limiting ability to invest in emission reduction initiatives. Also worth noting, granting of carbon allowances is expected to disappear gradually through 2021-30, implying that companies will have lower coverage over time (CX expects its carbon allowances' inventory in Europe to run out by 2025).
- Over time, there could also be a reputational risk for the construction sector's use of cement, leading to an aggressive pushback against concrete-intensive projects. In turn, this could force construction companies and homebuilders to radically change business models to depend less on concrete, which could affect their profitability and returns.

Figure 12: By McKinsey estimates, cement has by far the highest emissions within materials in terms of revenue generation. All else equal, this could place it at the highest risk of margin erosion, and limit its ability to invest in decarbonization absent a full price pass-through of carbon prices to clients

Kg of CO_2 per dollar of revenue



Source: Company data, Credit Suisse, McKinsey

Figure 13: Price of traded CO_2 allowances in Europe's ETS. For a discussion on carbon pricing and markets, as well as the recent hike in carbon prices in Europe, please see our ESG team's deep-dive into the topic (The Beginning of the Big Carbon Age, link)

Source: Company data, Credit Suisse, Refinitiv Datastream

“ Carbon capture is the key development to clean up cement.

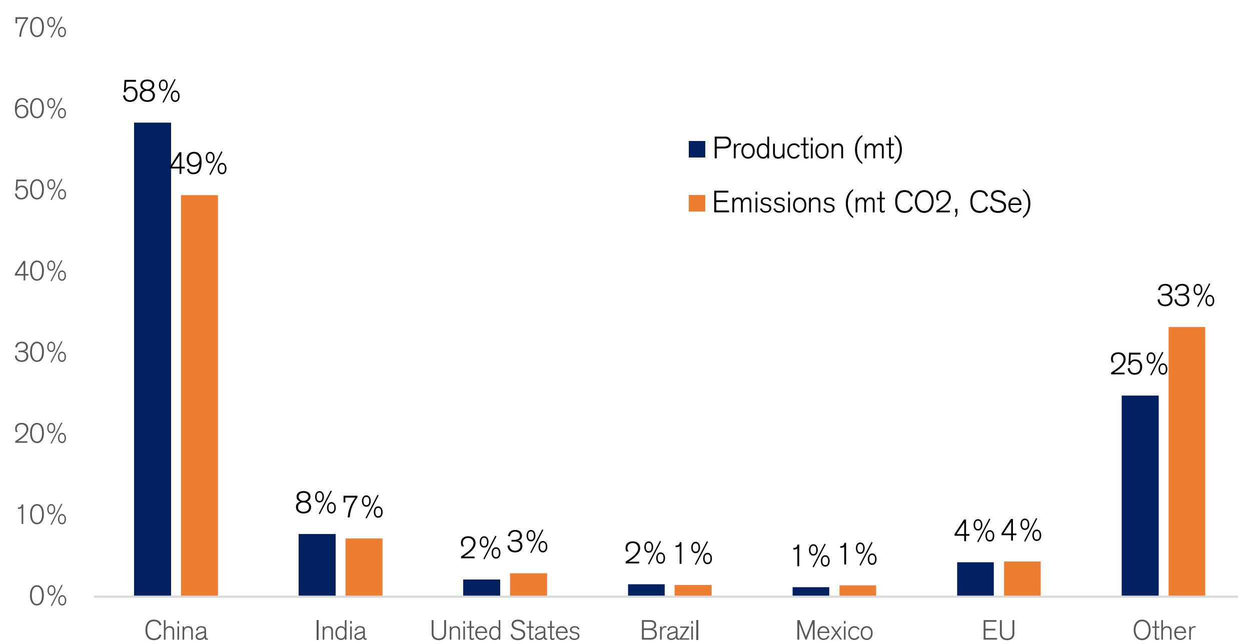
How to reduce cement's emissions: traditional and novel pathways

A breakdown of cement's emissions

A recap of what each emission scope means. There are three generally accepted calculations of company-level emissions of global warming potential gases, which we describe below.

- **Scope 1: Considers fuel combustion, company vehicles, and fugitive process emissions.** In the case of cement and concrete for example, it would include fugitive process emissions when calcinating limestone (which releases CO_2), combustion of fuels within the kiln, as well as diesel consumption for transporting ready-mix concrete to the construction site. For construction companies, it would mainly comprise diesel combustion of vehicles used in the construction process.
- **Scope 2 considers emissions generated from purchased electricity, heat and steam.** In most cases, electricity-related Scope 2 emissions are the most relevant. Usually a grid-wide or nation-wide emissions factor (CO_2 kg per MWh) is used, except if there are specific power supply contracts in place.
- **Scope 3 considers emissions for the production of purchased goods and services, employee commuting, waste disposal, distribution and supply chain, investments, among others.** To be clear, according to the EPA, this includes activities from assets not owned or controlled by the company, but that the organization indirectly impacts in its value chain. For construction companies, this would include cement-related emissions.

Figure 14: Share of cement production and cement Scope 1 CO2 emissions (CSe) by country, 2021



Source: Statista, Global Efficiency Intelligence, Credit Suisse.

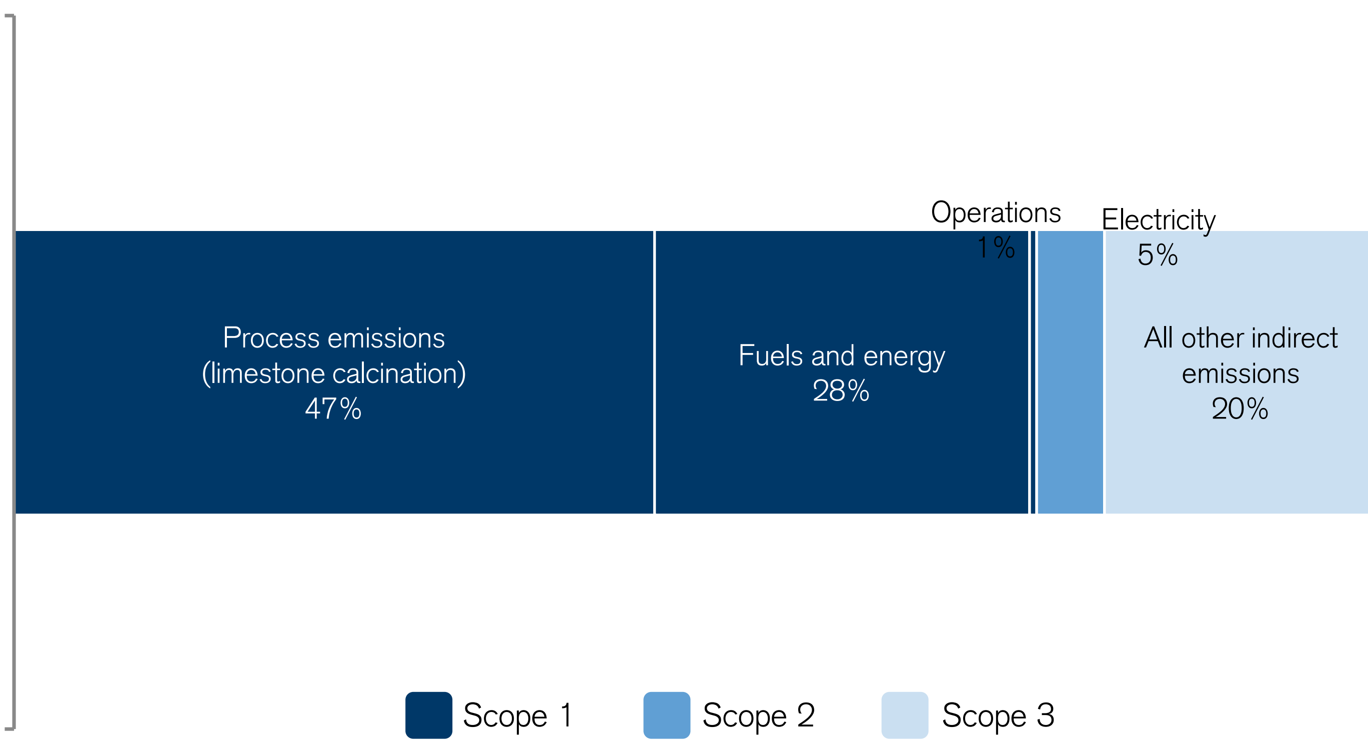
Note: We estimate cement emissions based on benchmarking analyses of emissions per ton.

We discuss below how cement's emissions are distributed between scopes, and alternatives for decarbonization of each.

- **Scope 1 cement emissions represent c.75% of total.** Fuel combustion from kilns and mining/transportation vehicles only account for 37% of Scope 1 CO_2. Most of Scope 1 emissions are produced as fugitive emissions when limestone is calcinated, producing clinker and CO_2. This process counts for over 60% of scope 1 emissions, or over 40% of total emissions for all three emission scopes.
  - Currently, the main levers to decarbonize this scope are via lowering clinker percentage within cement (be it due to lower requirements by clients/regulators, or usage of alternatives to clinker when available), as well as usage of net-zero fuels such as waste or biomass. Over time, it is expected that carbon capture and storage (CCS) will take on further importance by lowering both fugitive calcination and combustion-produced CO_2.
- **Scope 2 is 5% of total cement emissions.** Most cement companies are actively exploring usage of renewable power via Power Purchasing Agreements, where available. Still, given the limited importance of power consumption within total emissions, this could have a low impact on total emissions.
- **Scope 3 (20% of total cement emissions)** comprises mainly transportation of cement/materials by third parties, emissions related to the production of third-party sourced materials (for example aggregates consumed for concrete pouring if the company engages in ready-mix activities, or gypsum/aluminosilicates for cement production).
  - We have seen cement and concrete companies incrementally build capacity closer to end-markets, which can reduce transportation costs. We believe lowering clinker factors can also have a significant impact on this scope, as less gypsum/aluminosilicates would also be required for the clinker production process.

Recently, the industry's carbon footprint per ton has actually grown. IEA reports global direct CO_2/Mt of cement (Scope 1) increased 1.8% per year on average during 2015 to 2020, mainly due to an increase in the clinker-to-cement ratio in China, owing to changes in cement standards. Under IEA's Sustainable Development Scenario (SDS), IEA estimates a 3% annual decline in the direct CO_2 intensity of cement production is required to reach 450kg CO_2/t cement by 2030 and to get on track with the net zero emissions by 2050. IEA conducted a sector decarbonization review for the global cement sector in November 2021, and concluded it is not on track with the net zero emissions by 2050.

Figure 15: CO2 Scope 1-2-3 emissions by source of a global cement company



Source: Company data, Credit Suisse

A more difficult-to-decarbonize industry than most others. An important issue is that, unlike for other products, where most emissions are generated from the process of fuel and power consumption, 60% of cement's are generated from the process emissions of calcination, which cannot be reduced as the energy sector becomes less carbon-intensive by producing renewable energy or biofuels.

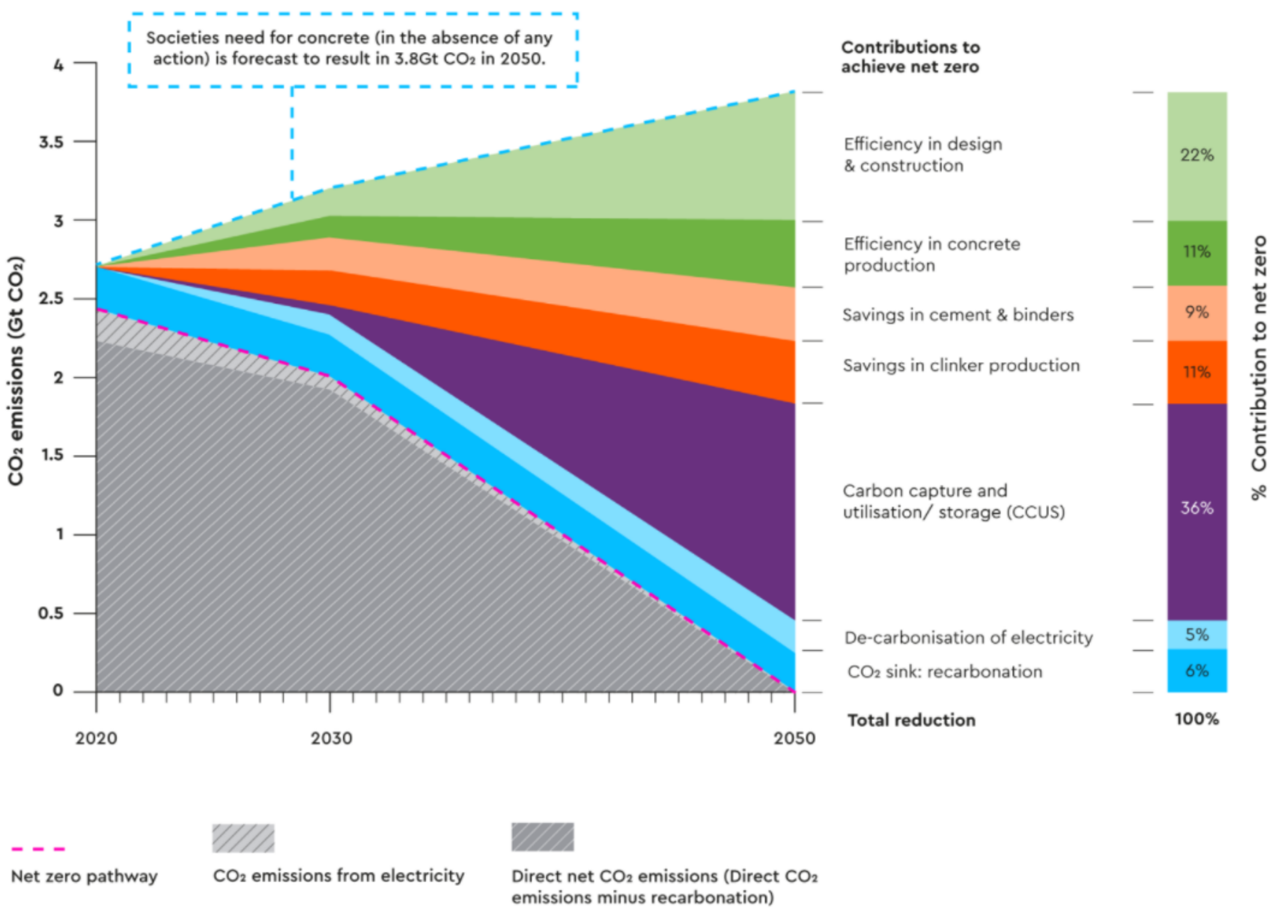
Steel is an interesting counter-example. We contrast this with steel, for example, which represents 7-9% of man-made emissions, but where progress toward net zero appears to be going much faster, with Sweden's HYBRIT targeting to produce the first fossil-free steel in the world by 2025, via a novel process to reduce iron ore using hydrogen rather than coal. Additionally, our Global Steel team believes a rising proportion of steel production looks set to shift toward recycled production, with steel scrap supply reaching 50% of total consumption, which could lead to a 20-40% reduction in steel-related emissions.

Path to reducing carbon emission in cement sector

In 2021, GCCA released its decarbonization roadmap to net zero by 2050 for concrete, from the current global CO_2 emission in excess of 2.5 gigatonnes (Scope 1). According to GCCA, 3.8 gigatonnes of CO_2 emissions will need to be offset by 2050, using the following decarbonization levers: Carbon Capture & Utilization & Storage (CCUS, 36% contribution to net zero), improving efficiency in design & construction (22%), improving efficiency in concrete production (11%), savings in clinker production (11%), savings in cement & binders (9%), CO_2 recarbonation (6%), and decarbonization of electricity (5%).

We believe cement companies have been actively following GCCA's decarbonization roadmap, as many have set respective strategies and/or made investments toward decarbonization. Based on current technology readiness and investment focus, there are three key strategies that cement companies have adopted to reduce carbon emissions, including deploying CCUS, lowering the clinker-to-cement ratio, and switching to low-carbon fuel sources.

Figure 16: GCCA's decarbonization roadmap to net zero by 2050 for concrete



Source: GCCA

Existing levers currently being deployed at scale

Improving clinker production efficiency and using alternative materials are the most feasible decarbonization alternatives currently, based on IEA's technology readiness assessment. More specifically, lowering the clinker-to-cement ratio is the main strategy to cut CO_2 emissions. Calcined clay and alkali-activated binders are both in the early adoption stage and used as replacements for clinker in blended cements to lower the clinker-to-cement ratio. Under IEA's Sustainable Development Scenario (SDS), the clinker-to-cement ratio needs to fall by ~1% per year from the current global average of 0.72 in 2020 to 0.65 by 2030. However, IEA estimated the global clinker-to-cement ratio went up at an average of 1.6% per year between 2015 and 2020, which was the main reason for an increase in global direct CO2/Mt of cement (Scope 1) by 1.8% per year on average over the same period. Overcapacity in less developed markets is the main cause as it reduces the benefit from doing more blending to replace clinker, along with less stringent environmental industrial standards (as has been the case in China).

Switching to low-carbon fuel sources such as tires/disposed of materials is another important and popular strategy adopted by cement companies to reduce carbon emissions. Under IEA's SDS, fossil fuel consumed in clinker production needs to decline from 3.1GJ/t clinker in 2018 to 2.8GJ/t clinker in 2030, while expanding the biomass and renewable portions in clinker production. However, the cost of low-carbon fuel is the main barrier to this carbon emission strategy.

Technologies under development to reduce cement's carbon footprint

Bearing in mind GCCA's list of levers for the cement and concrete sector to achieve net zero by 2050, we believe the primary driver for enhanced industry decarbonization is the successful development of several technologies, some of which currently are not ready for industrial scale-deployment.

Figure 17: GCCA's decarbonization levers and their application in the cement and concrete sector

Decarbonization Lever	Contribution to net zero	Application
Carbon capture and utilization/storage (CCUS)	36%	- Only becomes significant beyond 2030 when commercial viability and necessary infrastructure have been established - Utilization of captured CO_2 includes injection into wet concrete, curing of hardened concrete and in the manufacturing of aggregates from waste products
Efficiency in design & construction	22%	- Ensure reduction of CO_2 emissions becomes a design parameter in addition to the current parameters. For example, through the choice of concrete floor slab geometry and system, choice of concrete column spacing and optimization of concrete strength/element size/reinforcement percentage - GCCA expects improved design and construction to reduce CO_2 emission in the sector of 7% and 22% in 2030 and 2050, respectively
Efficiency in concrete production	11%	- Moving from small project site batching of concrete using bagged cement to industrialized processes offers significant CO_2 emissions due to adherence to mix specifications and quality control - Utilization of admixtures, improved processing of aggregates are good opportunities for CO_2 emission savings - GCCA estimates optimization of concrete production in terms of binder utilization can lead to binder demand reductions of 5% and 14% in 2030 and 2050, respectively
Savings in clinker production	11%	- Use of decarbonated raw materials, energy efficiency measures, use of sustainable waste materials to replace fossil fuels and innovations such as hydrogen and kiln electrification - Alternative fuels are derived from non-primary materials (e.g., waste or by-products). Supply chain logistics and infrastructure, permitting and waster policy to reduce/eliminate waste to land fill are required to increase the use of alternative fuels - GCCA estimates global alternative fuel to increase from the current 6% to 22% and 43% by 2030 and 2050, respectively
Savings in cement & binders	9%	- Fly ash, ground limestone and other materials can be added to deliver concretes with reduced CO_2 emissions but still with the required performance - GCCA expects to reduce the global clinker binder factor from current 0.63, to 0.58 and 0.52 by 2030 and 2050, respectively - GCCA forecasts alternatives to Portland clinker cements will be 1% and 5% of cement in 2030 and 2050, respectively
CO2 sink: recarbonation	6%	- Recarbonation is a natural process of CO_2 uptake by concrete. Recently it has been considered in carbon accounting (i.e., IPCC 6th Assessment Report published in August 2021) - GCCA estimates recarbonation effect of 20% of the theoretical maximum carbonation possible for a tonne of clinker (525kg CO_2/tonne) - i.e., 105kg CO_2/tonne clinnker
Decarbonization of electricity	5%	- Reduction of emissions from generation of electricity used in cement and concrete production - Demand for electricity from the sector will increase until 2030 in-line with increased cement and concrete production and also in 2030-2050 primarily due to electricity demand of carbon capture solutions

Source: GCCA, Credit Suisse

In November 2021, IEA assessed technologies readiness for decarbonization in the cement sector. As we expected, most decarbonization technology focused on the production phase, but only a few of these (calcined clay, alkali-activated binders, among others) have entered the early adoption level, including utilizing alternative materials and recycling, CO_2 sequestration in inert carbonate materials (as an approach to utilize captured CO_2), and advanced grinding technologies to improve production efficiency.

Compared to the last assessment in 2020, while most technologies stayed at the same level, hydrogen technology advanced from the concept level to small prototype, benefiting from the global trend of green investment in the technology, especially under the EU Green Deal that identified hydrogen as the key to a clean and circular economy.

Carbon capture: the key development to clean up cement

IEA expects carbon capture to be a relevant factor in the process of reducing total CO_2 man-made global emissions… IEA estimates carbon capture could offset as much as 5Gt per year by 2050 versus the 2020 man-made emissions of ~35GT. As such, IEA believes CCU/CCUS alone can represent 14% of the global net-zero emissions reduction target (20.8% of the 2030-2050 net-zero scenario reduction target).

…but for concrete in particular, CCS/CCUS is the biggest factor by far for reaching net zero. A leading global building materials company headquartered in Mexico estimates that it will reach net emissions per m3 of concrete of ~200 (including Scope 2 and Scope 3) by 2030, a 41.1% reduction vs. 2020 levels of 340, mostly explained by the reduction in cement emissions from 800 to 475 $kgCO_2$/ton. However, to reach net-zero concrete, the contribution of traditional emission-reducing cement mechanisms will have been mostly exhausted. Excluding CCU/CCUS implementation, we estimate that cement emissions could only decline another 13% in 2030-50 (22kg CO_2/m3 concrete). According to the European Cement Association, even assuming 100% clean electricity and fuel as well as minimal clinker factor, emissions per ton of cement would still be 280$kgCO_2$/ton, owing to the clinkerization process alone, which highlights the need for CCUS for the cement & concrete sector to reach net zero.

The remainder will have to be achieved via lower concrete-related emissions (for example electric ready-mix trucks), carbon capture measures and recarbonation of concrete. In 2030-50, it is estimated by one of the global cement companies, that carbon capture/recarbonation will represent 59% of the needed reduction in emissions to reach net zero. Similarly, another global cement company expects CCUS to represent 50% of its 2020-2050 needed reduction in emissions per m3 of concrete to reach net zero.

As such, we see cement/concrete as one of the industries most levered to improvements in carbon capture technology to reach its lofty emissions targets.

Significant difficulties still exist for CCUS implementation. GCCA expects CCUS to become significant only beyond 2030 when commercial viability and necessary infrastructure have been established. Likewise, UK Mineral Products Association (October 2019 - Options for switching UK cement production sites to near zero CO_2 emission fuel: Technical and financial feasibility) stated that CCUS is required to achieve net negative emission in the cement sector and meet UK's target of net zero by 2050.

Figure 18: Technology readiness for decarbonization in the cement sector

Readiness level	Technology	Step in value chain	Importance for net-zero emissions
Early adoption	Raw materials > Alternative cement constituents > Calcined clay	Production	High
Early adoption	Raw materials > Alternative binding material > Alkali-activated binders (geopolymers)	Production	Moderate
Early adoption	Curing > CO_2 sequestration in inert carbonate materials (mineralization)	Production	Moderate
Early adoption	Unhydrated cement recycling	End-of-life	Moderate
Large prototype to Early adoption	Grinding > Advanced grinding technologies	Production	Moderate
Demonstration	Raw materials > Alternative binding material > Carbonation of calcium silicates	Production	Moderate
Demonstration	Cement kiln > CCUS > Chemical absorption, partial capture rates (less than 20%)	Production	Moderate
Demonstration	Cement kiln > CCUS > Calcium looping	Production	Very high
Demonstration	Cement kiln > CCUS > Chemical absorption (full capture rates)	Production	Very high
Large prototype	Cement kiln > CCUS > Oxy-fuelling	Production	High
Large prototype	Cement kiln > CCUS > Direct separation	Production	Moderate
Large prototype	Cement kiln > CCUS > Novel physical adsorption (silica or organic-based)	Production	Moderate
Large prototype	Concrete fines recycling	End-of-life	Moderate
Large prototype	Cement kiln > Direct heat from variable renewables > Concentrated solar power-generated heat for industrial processes	Production	Moderate
Small prototype	Cement kiln > Electrification (direct)	Production	Moderate
Small prototype	Cement kiln > Partial use of hydrogen	Production	Moderate
Concept	Raw materials > Alternative binding material > Magnesium oxides derived from magnesium silicates	Production	Moderate
Concept	Cement kiln > Electrolyzer-based process for decarbonating calcium carbonate prior to clinker production in the kiln	Production	Moderate

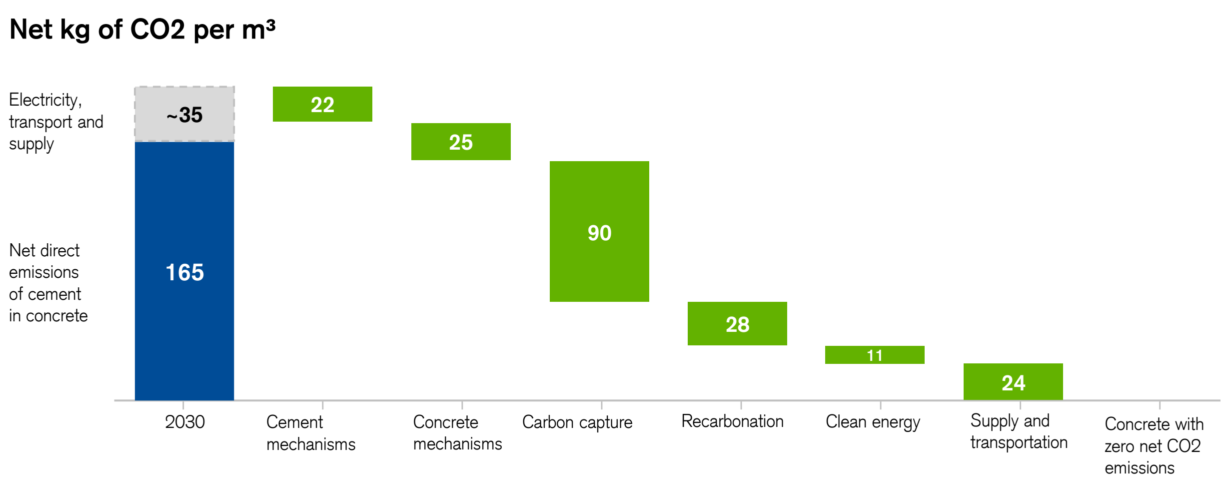
Source: IEA, Credit Suisse

At the company level, two global cement majors are among the most active in terms of CCUS projects, with both engaged in a wide range of pilot CCUS projects worldwide. However, current CCUS technologies are still expensive. Additionally, some cement plants may not have enough space on site for a capture plant, or facilities to store or transport CO_2. BCG has estimated CCUS facilities cost $35-155/Mt of CO_2 for cement production, depending on the concentration of CO_2.

Solution lies in the details. A recent discussion we had with one of the global cement majors on CCUS provided some interesting thoughts regarding implementation on the ground. This company has a multi-technology, multi-region portfolio of seven CCUS projects, mostly focused on amines/membranes, one of which is combined with solar clinker production and indirect calcination. The projects are for the most part receiving partial government funding, and are at pilot industrial stages, with start-up expected for 2025-30. The company believes some of these projects could reach costs close to US$50/ton of cement at scale. This would imply a breakeven carbon cost of US$80.6/tCO2 versus an EU carbon allowance price of US$85.6, which implies the projects could become cost-neutral in Europe once deployed.

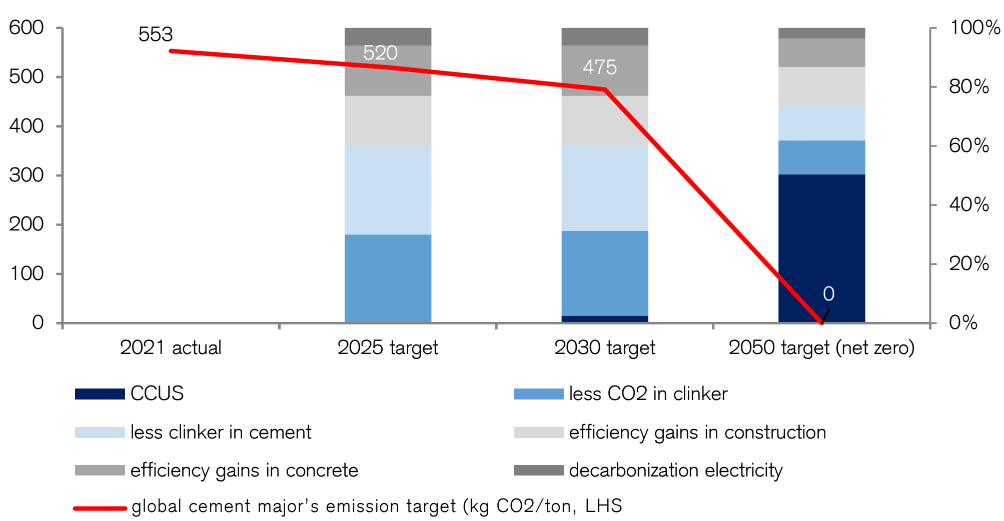
Also, as per our Canada Infrastructure team, one of the major limitations of CCS deployment is the appropriate geology required for safe and effective capture of carbon. The team's broader work has highlighted the regions that can practically deploy larger scale CCS; however, Canada is one region with considerable deployment potential (CX also highlighted the North Sea's national gas infrastructure and geology as an attractive region). The main area of focus for these initiatives is the energy heartland in the Province of Alberta. Yet, CCS in the cement industry is being used in Richmond, British Columbia by one of the companies on a pilot basis with a design to capture 1.5m tons of carbon per year.

Figure 19: Roadmap to concrete with net-zero CO2 emissions, shared by one of the global cement companies



Source: Company data, Credit Suisse

Figure 20: Roadmap to concrete net zero emissions in 2050, shared by another global cement major



Source: Company data, Credit Suisse

Some key CCS Canadian context appears in the bullets below:

- One of the companies has the CO2Ment Project in Richmond, BC, that captures flue gas from the facility using a private carbon capture company's equipment;
- Another company is involved in a broader-based initiative on the capture and transportation of carbon dioxide in the Edmonton area for 780,000 Mt of CO_2 per annum with a potential 2025 in-service date along with the International CCS Knowledge Centre's CCS study.
- More broadly, in Canada we note the federal government, the Cement Association of Canada (CAC), and the broader cement sector have a partnership to "support the development and implementation of a "Roadmap to Net-Zero-Carbon Concrete" by 2050 (Joint statement: Canada's Cement Industry and the Government of Canada announce a partnership to establish Canada as a global leader in low-carbon cement and to achieve net-zero carbon concrete - Innovation, Science and Economic Development Canada). Some key points include the following:
  - The Canadian government estimates potential to reduce more than 15 Mt of greenhouse gas (GHGs) cumulatively by 2030 along with ongoing reductions of 4 Mt annually;
  - Some of the stated objectives are to "position Canada's cement and concrete industry as a competitive global leader in the production of, and technologies related to low-carbon cement and concrete"; and
  - To help build a framework to explore "innovative opportunities while supporting and validating the development and evaluation of next generation technologies, products, and processes for commercialization that further reduce carbon content in cement and concrete."

“ China’s cement sector is the most efficient in terms of CO2/cement ton, while the U.S. is the least efficient.

Who is leading and who is lagging?

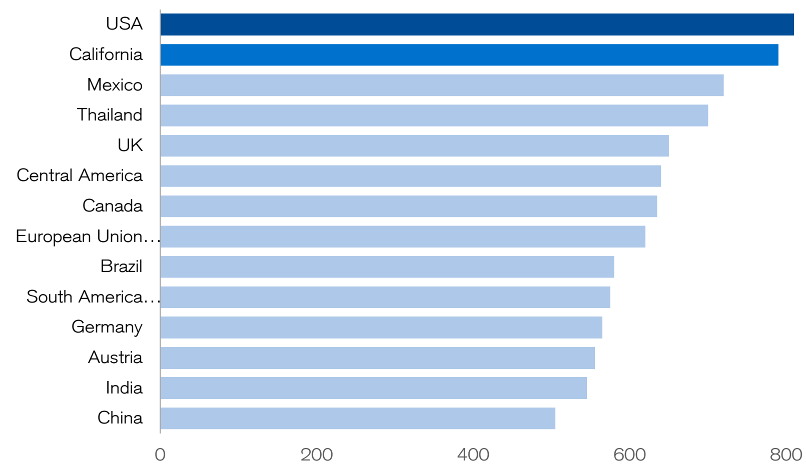
On a country basis, the U.S. is the laggard (albeit on an improvement path)

Regional differences are significant. Benchmarking studies from Global Efficiency Intelligence and the EPA show that China's cement sector is the most efficient in terms of CO_2/cement ton, while the U.S. is the least efficient, as per 2015. This is explained mainly by a higher clinker content, as SCMs are added at cement production sites in other countries and at RMC production sites in the U.S. Plant ages and more sophisticated versions of cement production facilities also play a role.

Why is the U.S. so far behind? Our understanding is that the elevated emissions per ton of cement for the U.S. are mainly explained by very high clinker factors. According to a leading cement equipment company, clinker factors across the world are usually 70-80% (which can be reduced further with the use of SCMs). However, in the U.S., current standards for Portland cement require 95% clinker. This is offset somewhat because ready-mix producers usually apply SCMs as well.

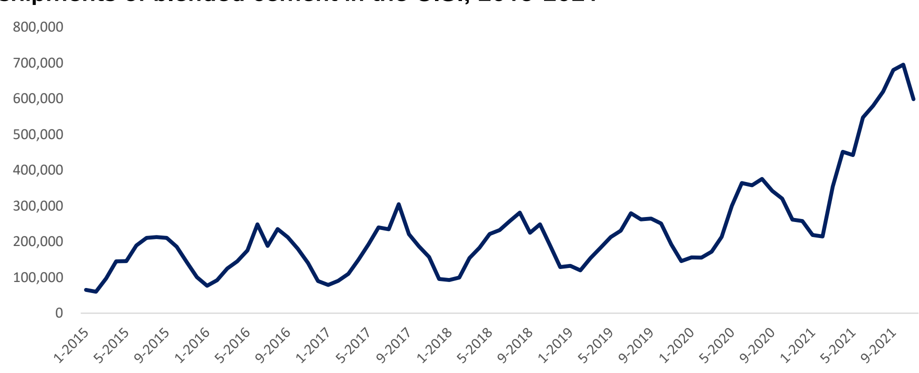
Figure 21: Estimated CO2 intensity per ton of cement produced by country. The U.S. is well above the rest, mostly explained by industry standards

CO2 emissions per ton of cement



Source: Company data, Credit Suisse, Global Efficiency Intelligence.

Figure 22: Monthly shipments of blended cement in the U.S., 2015-2021



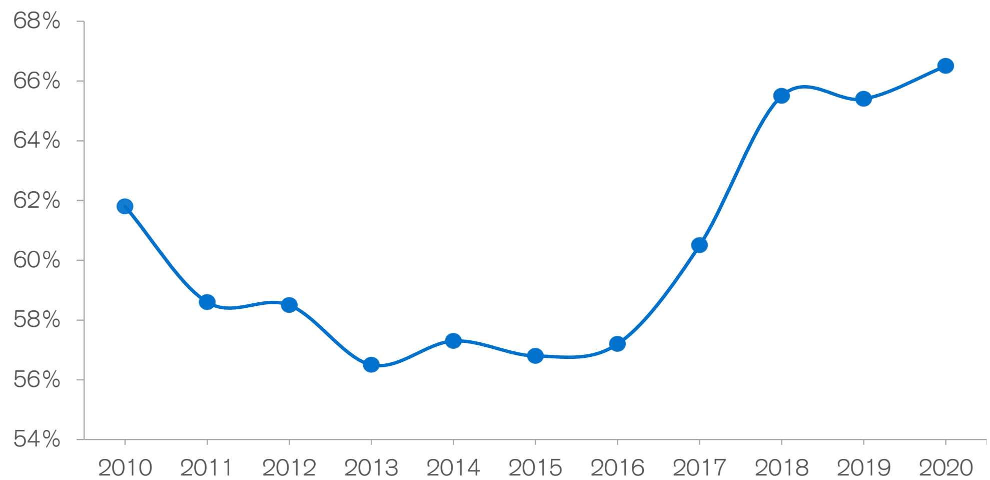
Source: Company data, Credit Suisse, USGS.

U.S. emissions trending the right way. Recently, we have seen several plants in the U.S. be converted from producing Portland cement to Portland-Limestone Blended (PLC) cement. The standard for this version allows for replacement of clinker with limestone of up to 15%, allowing for a 7-10% reduction in per-ton emissions.

Will China's recent deterioration in per-ton emissions turn around? Global per-ton emissions have increased 1.8% p.a. in 2015-2020, mostly explained by a 1.6% annual expansion in the global clinker-to-cement ratio. IEA attributes this mostly to a rapid increase in China's clinker-to-cement ratio (from 57% to 66% in this period), as overcapacity has reduced momentum for blending, as well as changes to standards that eliminated a grade of composite cement. As our China Cement team argues in detail, the Chinese government is implementing a wide range of decarbonization initiatives which could allow this trend to reverse.

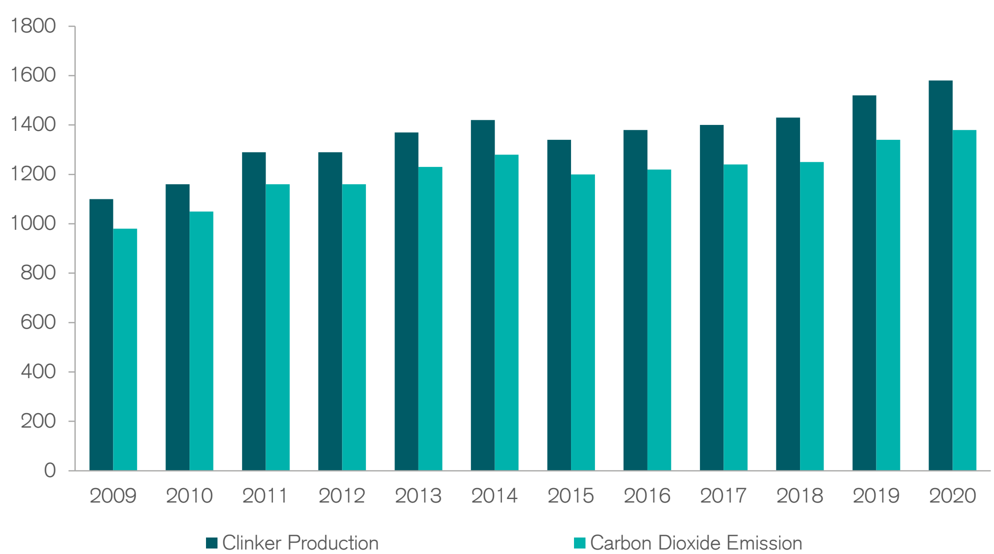
Australia's progress at this stage being driven by industry and customers, rather than policy and standards. Some grant funding for CCUS: At present, the increased consumption of low carbon concrete has been led by customers and industry, due to the absence of a broad-based emission government policy. Through the Carbon Capture Use and Storage Development Fund ('CCUS'), the federal government provided grants to two separate construction materials projects. Government funding was provided for a series of other projects in addition to these under the CCUS initiative, with total funding available of A$50mn and each project being eligible to receive A$500K to A$25mn. A Credit Suisse proprietary Survey of ready-mix concrete suppliers in Australia indicates increasing demand for low carbon concrete within the market, with the majority of survey participants citing an increase in customer requests for low carbon concrete in the last two surveys (78% in the Jan-22 survey, 70% in Jul-21 survey).

Figure 23: Clinker factor in China cement production, 2010-2020



Source: WorldCement, Credit Suisse.

Figure 24: China cement sector clinker production and CO2 emissions, 2009-20



Source: WorldCement, Credit Suisse

China's cement sector in focus

China produced 57% of the world's cement, as of 2016. On the other hand, benchmarking studies show that China's cement sector is the most efficient in terms of CO_2/cement ton. China produces nearly 60% of the world's cement and it also emits more than half of the total carbon emissions of the global cement industry.

Domestically, China basic materials sector, including cement, steel, coal, and aluminum industries, contributed ~38% of total carbon emissions in China in 2020, which is the second largest next to the power sector (~40% in 2020).

The cement sector is the second largest carbon producer in the industrial sector after steel. According to the China Cement Association, carbon emissions from the cement sector hit 1.38 bt in 2020, accounting for ~14% of the total carbon emission in China. Early in 2021, the China Building Materials Federation proposed a carbon agenda to achieve peak emissions by 2025 for the whole building materials sector. In particular, a more aggressive target was proposed for cement sector – "to peak the emissions by 2023."

For more on China's overall action plan for reducing CO_2 emissions, please see our ESG team's note on the matter in The Carbon Cycle Series.

Feasible ways to achieve the decarbonization target

Feasible ways to achieve the decarbonization target may include 1) to participate in the carbon trading system, 2) stricter restriction on newly added capacity, 3) technological improvements in production and the upgrade to large-tonnage production lines, 4) use of alternative fuels and raw materials, and 5) carbon capture technology.

Our CQi cement panel has highlighted some major measures to reduce carbon emissions in the next five years, and only a third of the cement panels believe that participating in carbon trading will be a key means for the sector to reduce carbon emissions. However, from our point of view, we expect carbon trading to be the focus in the future. (1) More than 90%of the CQi cement panel plans to reduce carbon emissions by upgrading its production process in next five years. (2) In addition, about a third of the panel expects to replace its outdated capacity with more environmentally friendly and energy-efficient equipment. (3) More than ~70% believe lifting the capacity threshold will be a key method to reduce carbon emissions for the whole sector.

We believe the following key aspects related to cement capacity, production, carbon trading schemes, and other policies will help the sector to achieve its decarbonization goal.

To reduce output via capacity cuts

At the end of 2020, the China Building Materials Federation issued guidance on eliminating outdated capacity. Under the guidance, clinker production lines with capacity below 2,000t/day should be eliminated by 2021 and capacity below 2,500t/day should be eliminated by 2022. This measure was originally aimed at reducing oversupply in the sector and curtailing pollution during the winter heating season. It is now being aimed at controlling carbon emissions.

Capacity swap

The first issue for cement's carbon emissions is the peaking of total output. Hence, capacity cuts remain a key method to achieve the decarbonization goal. According to our CQi team, over 70% of cement plants on its panels expect their output to peak by 2023, amid slowing growth in infrastructure and property investment.

On July 20, 2021, the Ministry of Industry and Information Technology (MIIT) unveiled the revised rule on cement capacity swap, to raise the amount of old capacity that producers need to retire as they proposed to build new facilities and close the loophole in the previous draft version. The new rule has been effective since August 2021.

Under the previous draft, for cement plants to be constructed after an M&A, the swap ratio will be set at 1:1. Hence, in order to get rid of a higher swap ratio, some cement manufacturers could take advantage of this via M&A. This loophole was closed in the revised version.

Key changes under the new and tougher rule:

- In areas classified as environmentally sensitive, cement producers must retire 2 metric tons of outdated capacity for each metric ton of newly built capacity, up from the previous swap ratio of 1.5:1. In non-environmentally sensitive areas, at least 1.5 metric tons of obsolete capacity should be eliminated for every metric ton of new capacity added, up from 1.25:1.
- To intensify the efforts to reduce inefficient cement capacity. For the capacity being classified as "restricted capacity" (lines with capacity<2000/day) and for capacity swap across provinces, the ratio should not be lower than 2:1.
- To encourage the comprehensive utilization of solid waste. For cement plants in Hubei, Guizhou and other three provinces, if the cement produced by using phosphorus (titanium, fluorine) gypsum, then the swap ratio could be set at 1:1.

In the long run, we believe the higher capacity swap ratio could gradually relieve the pressure of overcapacity in the cement industry. This will also promote industry standardization and environmental protections. In addition, compared to the old line to be replaced, new lines are more intelligent and efficient, with lower energy consumption and carbon emission.

Carbon trading system: We expect more cement producers to be included in China's carbon trading market in the foreseeable future. The national carbon trading system was launched in July 2021 and so far only power companies have participated. After IPPs were included in the carbon trading market, the market expected cement and aluminum producers to be the second wave to participate. The cement industry is an energy-intensive industry and one of the key carbon emission industries. Previously, carbon emission rights trading involving the cement industry had been piloted in Guangdong and Hubei. We expect inclusion in the carbon trading system to help the cement industry to speed up achieving its emissions reduction target via technological improvement. We believe this is conducive to supply-side control. Moreover, we believe the gap in the level of technology and environmental protections to accelerate the differentiation between small and large cement manufacturers to the benefit of leading cement enterprises.

Alternative fuels and raw materials

Currently, coal is the main fuel source for limestone calcination in the country. Nearly ~95% of cement is produced using coal. Although the likelihood of coal being completely replaced is low because of its relatively low price, it should continue to lose share as the fuel mix improves.

- **Biomass:** Biomass is currently heating less than ~1% of the cement production. It is considered a clean resource with no emissions. However, due to the short supply and high demand by many other industries, not many companies in the industry use biomass as a heating source.
- **Waste:** Waste is a potential resource for carbon reduction, currently heating ~5% of cement production. Organic waste could be used as fuel, and by using solid waste as the raw materials, it could reduce the use of limestone, further reducing carbon emissions. At the same time, waste usage has favorable policies in China.
- **Power:** For cement production, electricity is not very feasible in terms of technical requirements (requiring higher temperature and power), equipment transformation, or operation economy; thus, it may not become an important means of future emissions reduction.