Toward Net Zero: Decarbonization Roadmap for China's Cement Industry

Executive Summary

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About RMI

RMI is an independent nonprofit founded in 1982 that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and nongovernmental organizations to identify and scale energy system interventions that will cut greenhouse gas emissions at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing, People's Republic of China.

About China Cement Association

China Cement Association (CCA), established in 1987 in Beijing, is a social organization with independent legal status. CCA is a voluntary industrial organization consists of producers of cement and related products, research and engineering design enterprises, investment consulting enterprises, and other entities. With wide representation, CCA serves as a bridge between businesses and the government, and provides technical and policy consulting services for businesses, the government, and the whole society. We cooperate with businesses, the government, research and design institutions, and builders to promote the green, low-carbon, and sustainable development of the cement industry.

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Preface

The cement industry is a key factor in China's transition to carbon neutrality. China's cement production and consumption account for more than half of the respective global totals, and its cement carbon emissions are the third largest in the country, after those of power and steel, accounting for about 13% of the country's total carbon emissions. One challenge of decarbonizing cement is its massive process emissions, which require transformational technologies to substitute raw materials and ingredients on a large scale. Another challenge comes from switching from coal to low-carbon energy sources. In addition, given the young assets of the industry, the risk of stranded assets is high in a rapid transition. A relatively low concentration rate among top cement companies also impedes the scaling up of transition technologies.

Under its carbon-peaking and -neutrality goals, China is building a "1+N" policy system, which includes the production of carbon-peaking action plans for key industries, including the building materials industry, in which cement is a key component. The low-carbon transition of downstream industries such as construction, the continuation of environmental policies, and the growth of the nationwide carbon market will all accelerate the transition to carbon neutrality in the cement industry.

This report, which is coauthored by RMI and the China Cement Association (CCA), provides a thorough discussion of the net-zero transition of the cement industry. Our analysis shows that achieving carbon neutrality will require synergy among various approaches including demand reduction, fuel switching, cement chemistry changes, energy efficiency improvement, and CO_2 storage and utilization. The demand for cement is likely to decline in China because of slowing urbanization, weakening construction, phasing out of substandard production capacity, and improvements in building material efficiency. Alternative fuels will play an important role in reducing emissions, and some technologies are already showing early applications. Changes to cement chemistries — such as reducing the clinker-to-cement ratio, developing new low-carbon cements, and switching raw materials — are an important approach to reducing process emissions. Carbon capture, utilization, and storage (CCUS) could provide end treatment of the remaining carbon emissions; the location of storage options could influence the industry's future geographical distribution.

The cement industry's net-zero transition also requires the right pricing mechanism to ensure a cost advantage for low-carbon cement. The cement industry is closely related to upstream and downstream industries, most notably fuel, concrete, and construction; therefore, a systematic approach that integrates the whole value chain's net-zero transition is necessary. However, because of the uncertainties in supply and demand balance, technology development, and costs, this study focuses solely on China's cement industry. It reviews the industry's short-, medium-, and long-term decarbonization strategies, technology deployment, and economics, within the time frame delineated by China's decarbonization goals (2020–60), so as to provide potential guidance for policymakers and market participants.

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China is the world's largest producer and consumer of cement. In 2021, China produced 2.36 billion tons of cement, accounting for 57% of world production; its total cement consumption was 2.38 billion tons, accounting for more than half of the world's total. CO_2 emissions from China's cement industry totaled about 1.37 billion tons in 2020.[1] The industry accounts for 13% of the country's total carbon emissions, making it the third largest emitting industry, following power and steel. Therefore, decarbonization of this industry is crucial to achieving the country's goal of carbon neutrality.

The net-zero transition of China's cement industry faces substantial challenges. Cement production in China is highly dependent on fossil fuels, with potential alternative fuels still in the early trial stage. Even with completely zero-carbon fuels, cement production will still require technologies for reducing process emissions and sequestering CO_2. In addition, the industry has relatively young assets, and thus greater risk of stranded assets under a rapid transition. Furthermore, the lack of concentration of cement producers makes promoting collective market actions and new technologies challenging.

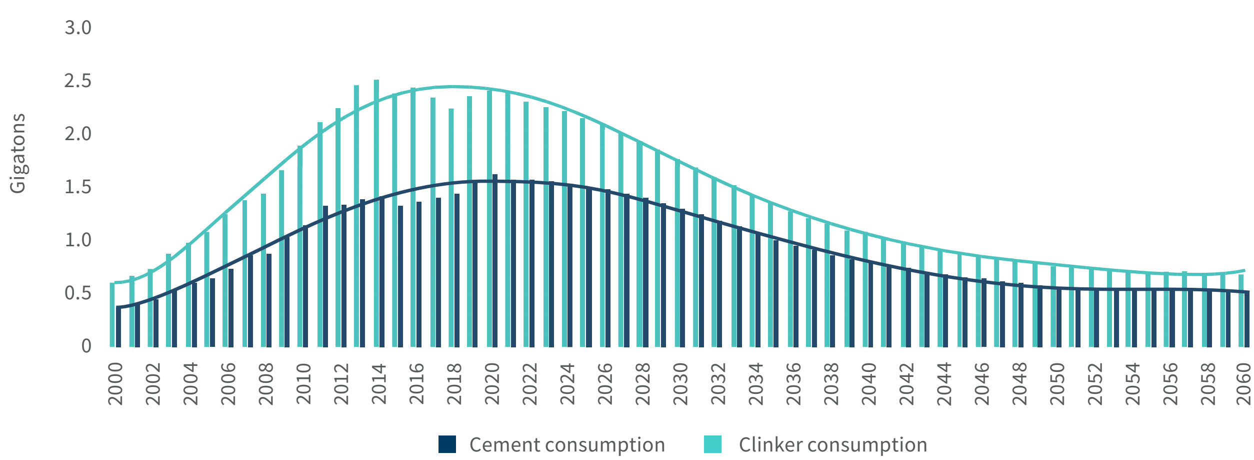
However, the industry also enjoys several opportunities to implement supply-side reform and take advantage of demand-side change to promote the net-zero transition. It has young technologies and equipment, an extensive market base, and innovative testing conditions, with a better-than-world-average energy-efficiency level as well as the experience and capability to innovate. As China's economy shifts from high-speed to high-quality development, the downstream construction industry is improving its low-carbon performance, which will benefit the low-carbon transition in the building materials industry, including cement, and help foster a robust low-carbon building materials market.

Outlook for Cement Supply and Demand

In the next decades, the slowdown of urbanization and infrastructure build-out will dominate cement demand trends. The main demand for cement comes from the construction industry, which is dominated by the housing and infrastructure sectors. As urbanization and the demand for housing drop in the long run, the scale of new housing development will decline. While China still needs to improve its infrastructure, the scale of infrastructure construction is gradually diminishing. With the slowdown in construction sectors including housing, roads, and railways, a decline in cement demand will be inevitable.

By 2050, China's cement clinker demand is likely to fall by two-thirds from current levels. With the adjustment of China's economic development model, the share of investment in construction engineering has gradually decreased, resulting in a continuous decoupling of GDP growth from cement consumption. Cement demand is expected to fall from 2.38 billion tons in 2021 to 750 million tons in 2050 (see Exhibit 1). Lower demand will drive down the industry's carbon emissions.

Exhibit 1 **Historical and projected trends of cement and clinker consumption in China**



Source: RMI and China Cement Association

Decarbonization Pathways

The decarbonization of the cement industry requires a multifaceted approach, including reducing cement consumption, developing low-carbon cement varieties, increasing the substitution of low-carbon energy sources for fuel and electricity, and promoting CCUS technology to offset process emissions (see Exhibit 2). At present, carbon reduction in the industry relies mainly on improving equipment and energy efficiency. Although these approaches can achieve some emissions reductions in the short term, they are unlikely to attain net-zero emissions using only existing technologies.

Exhibit 2 **Deployment timeline for key levers in the cement industry's transition to net zero**

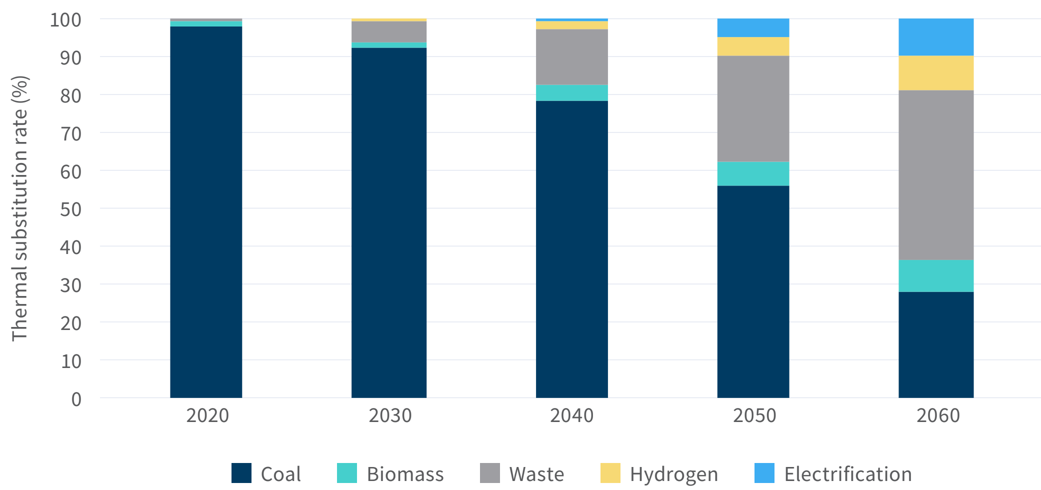
Levers	Actions	Deployment over time: 2020	2030	2040	2050	2060
1 Demand reduction	Reduce cement demand in building (mitigation effect)					10%
	Extend building lifespan (mitigation effect)					5%
	Recycle and reuse cement/concrete (recycling %)	40%				70%
2 Fuel substitution	Use solid-waste fuels (thermal substitution %)		5%	15%	28%	45%
	Use biomass fuels (thermal substitution %)					8%
	Use hydrogen and electrical kilns (thermal substitution %)			10%		25%
3 Energy efficiency	Apply clinker calcination energy-saving technologies (application %)	30%	60%	70%	80%	90%
	Apply grinding system energy-saving technologies (application %)		40%	60%	70%	80%
	Apply digitalization (application %)			100%		
4 Low-carbon cement composition	Reduce clinker-cement ratio			No higher than current national standard		
	Replace raw materials (substitution rate %)			15%		
	Develop low-carbon cement clinker (market share %)					10%
5 CCUS	Apply carbon capture (CO_2 captured %)		5%	10%	30%	90%
	Produce carbon-cured concrete			Commercialization		
	Make use of CO_2			Commercialization		

Source: RMI and China Cement Association

Demand reduction is the most important driver of carbon reduction in the cement industry. Cement clinker production is forecast to decline to 560 million tons per year by 2050, equivalent to a reduction of approximately 67% of total carbon emissions from the 2020 level. In the short term, the elimination of backward and excess capacity is the main approach to emissions reduction in the industry, helping the industry to peak its carbon emissions as soon as possible. In the long term, slowing urbanization and construction activity will be the main factors behind the decline in cement demand. To help reduce demand, efforts should be made to avoid waste of building materials, innovate building structures, and develop new cementitious materials.

The development of alternative fuels in China is at an early stage, but it has great potential. Solid-waste fuels — which include tire-derived, solid recovered, and waste-derived fuels — and biomass are the best alternative fuels to support the energy transition, and are expected to be able to replace about 20 million to 60 million tons of coal in the future (see Exhibit 3). New energy sources such as hydrogen and green electricity can also be considered in the long term. However, the development of alternative fuels in China's cement industry is relatively laggard. Waste co-processing, which is a precursor of fuel substitution by waste-derived fuels, is the most frequently adopted technology. Policy barriers to waste utilization and to development of alternative-fuel supply chains need to be removed. At present, the thermal substitution rate in cement production is less than 2% in China, compared with rates of over 50% in other countries,[2] leaving a large space for improvement.

Exhibit 3 — Fuel substitution in clinker production under a carbon-neutral scenario



Source: RMI and China Cement Association

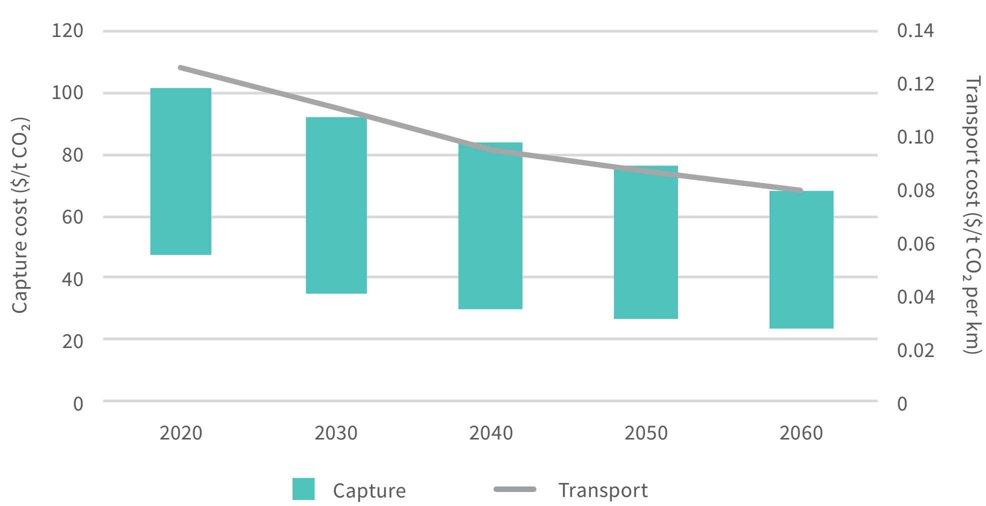
The energy-efficiency level of China's cement industry is above the world average, but there is still room for improvement. There are three types of energy-saving technologies in cement production, focused on clinker calcination, the grinding system, and digitalization. At present, the energy consumption per ton of clinker in China is between 2.6 and 4.0 gigajoules, which is equal to or better than the average in Europe and the United States.[3] However, there are still some substandard producers that cannot meet the national standard and are in urgent need of technical improvement. If the overall clinker energy consumption of cement production lines across the country can be upgraded from the current Level 3 to Level 1, it would be equivalent to reducing energy consumption and emissions by about 14%.

Changing cement composition and chemistry can reduce carbon emissions. There are three major strategies for this: clinker substitution that limits the clinker-to-cement ratio, therefore reducing the carbon intensity of cement; raw material substitution, which replaces part of the carbonates to reduce process emissions; and a non-Portland clinker system that is not based on calcium silicate. The current standard for cement products can be refined to include cement types with low clinker content where the quality and applicability of low-clinker cement can be met. Raw material substitution, which uses industrial waste to replace part of the limestone, can be a short-term measure to reduce the carbon intensity of clinker, considering the availability of industrial waste. New low-carbon clinkers — which are not based on calcium silicate and feature low calcium oxide (CaO) content, a low calcination temperature, and low carbon emissions — are expected to occupy a higher market share in the future.

CCUS is a necessary technology for net-zero cement. Liquid absorption, calcium looping, second-generation oxy-fuel, and LEILAC (Low Emissions Intensity Lime and Cement) are feasible carbon capture technologies for cement. However, there are still challenges in adopting CCUS on a large scale. The geographical dispersion of cement plants increases difficulties in sharing CCUS facilities, therefore increasing the cost of CO_2 transportation. The concentration of CO_2 in the flue gas from a cement kiln is usually less than 30%, leading to high energy consumption and cost for carbon capture. As the technology matures and the scale effect unfolds, CCUS will become one of the core technologies to achieve carbon neutrality in the cement industry. CO_2 can also be used to produce mineralized building materials, and in geological storage, chemical synthesis, and other applications.

The zero-carbon premium is expected to fall. Currently, the premium of zero-carbon cement clinker production is 90%–480% due to the high cost of alternative fuels and CCUS technology.[i] In the future, the premium could fall significantly, thanks to the scaling up and cost reduction of alternative fuels and CCUS as well as the possibility of on-site CO_2 utilization. Our preliminary analysis projects that, with technological progress and large-scale development, the cost of carbon capture and storage per ton of CO_2 will decrease by about 40%, and the cost of green hydrogen and green electricity will fall by about 65% and 60%, respectively, bringing the premium of zero-carbon cement clinker down to 70%–240% by 2050 (see Exhibit 4).

Exhibit 4 Projected cost of carbon capture and transport in the cement industry



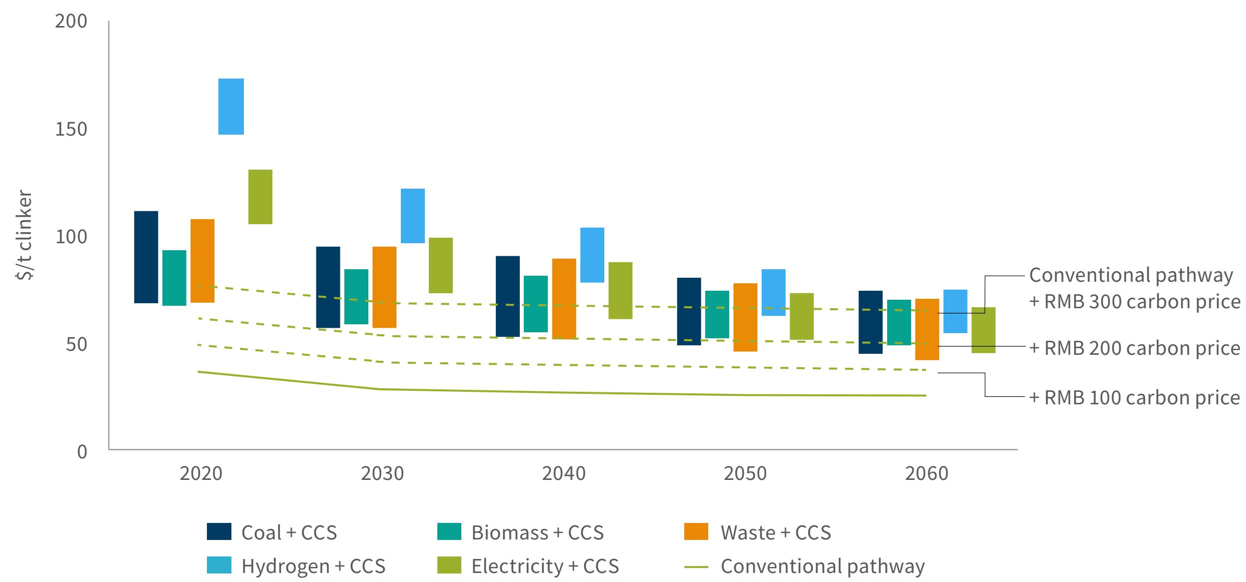
Source: RMI and China Cement Association

i The term "zero-carbon cement clinker" is used in this report to refer to clinker with near-zero carbon intensity. Carbon intensity in this context refers to net emissions (gross emissions minus carbon sequestered). When considering carbon emissions from cement production, we focus on Scope 1 and Scope 2 emissions — that is, direct emissions from cement production and electricity emissions. Emissions from the use of CCUS technology are not considered here because of unclear accounting boundaries.

Technological progress may narrow the cost differences between zero-carbon-cement pathways. When the costs of green hydrogen and electricity are low enough, the hydrogen- and electricity-based pathways will gradually become advantageous. According to our calculation, hydrogen-based cement clinker is likely to reach cost parity with solid-waste-based clinker when the green hydrogen price is lower than $840/ton, while the electricity pathway may reach cost parity with the solid-waste pathway when the green electricity price is lower than $0.02/kilowatt-hour (kWh).

Although the cost of zero-carbon cement is likely to become closer to that of traditional cement in the future, it can hardly reach cost parity without a proper carbon pricing mechanism. China's cement industry is well placed to be integrated into the national carbon trading market because of its good carbon data collection and accounting. Carbon price will play an important role in accelerating the industry's transition and making zero-carbon cement cost advantageous (see Exhibit 5).

Exhibit 5 Cost of cement clinker by different pathways to zero carbon



Note: Cost estimates are shown as ranges for new pathways due to uncertainties of CCUS cost. The cost projections shown in this exhibit assume constant coal and raw material costs and unchanged clinker composition. The clinker cost projection in this report contains the main, but not all, cost factors of clinker, and is used for comparison purposes only. In practice, clinker costs vary depending on production lines. CCS = carbon capture and storage.

Source: RMI and China Cement Association

Transition Timing and Regional Differences

The timeline for decarbonization in China's cement industry is as follows.

- In the near term (until 2030), the main focus will be demand reduction and efficiency improvement, helping the industry to achieve an early and high-quality peak in carbon emissions. The technology and standards of solid-waste fuels will gradually be established and improved. Clean electricity will account for about 40% of electricity consumption. By 2030, about 5% of the emissions in the industry could be captured.

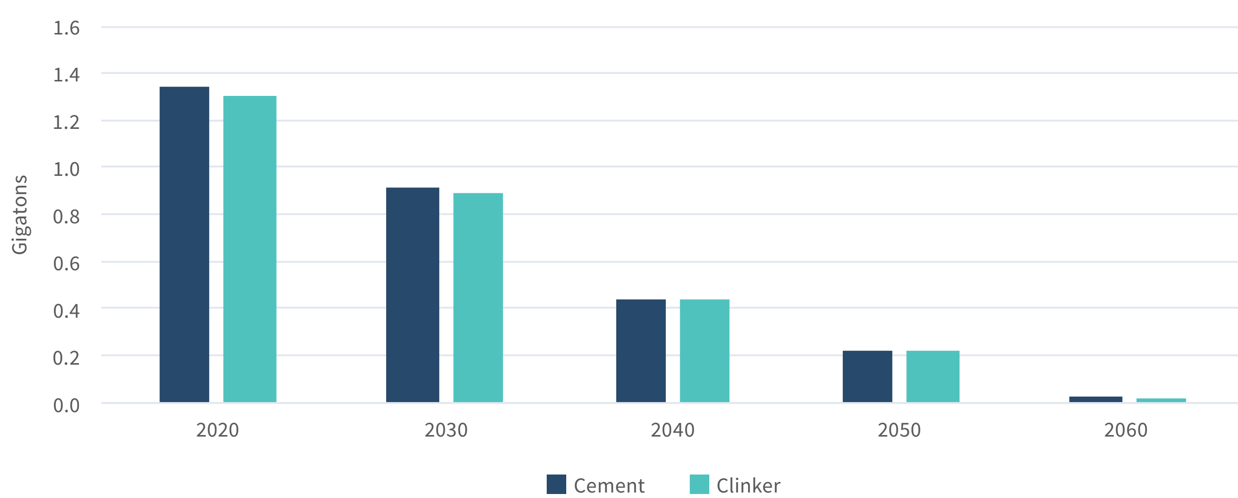
- In the medium term (2030–40), demand reduction, alternative fuels, and CCUS will work together to drive emissions reductions. The share of sustainable power in cement production will further rise to 55%. CCUS technology will be able to capture about 10% of industry emissions. Standardization and commercialization of solid-waste fuels will be established.

- In the long term (2040–50), alternative fuels and CCUS will play a larger role in reducing emissions. With the carbon pricing mechanism, zero-carbon cement will show a cost advantage. About 30% of the CO_2 emitted by the cement industry will be captured. About half of the fuel for calcination will be provided by sustainable energy sources. The carbon intensity of cement and clinker will fall by about 50% from current levels.

- In 2050–60, when China is approaching the realization of its carbon neutrality goal, new alternative production technologies, such as hydrogen and green electricity, will mature and become commercialized. The industry-wide fuel substitution rate will reach 70%, and 90% of CO_2 produced by the cement industry will be captured. Total CO_2 emissions from the industry, and the carbon intensity of cement products, will be close to net zero.

Exhibit 6 shows the drop in emissions that is projected to result from these steps.

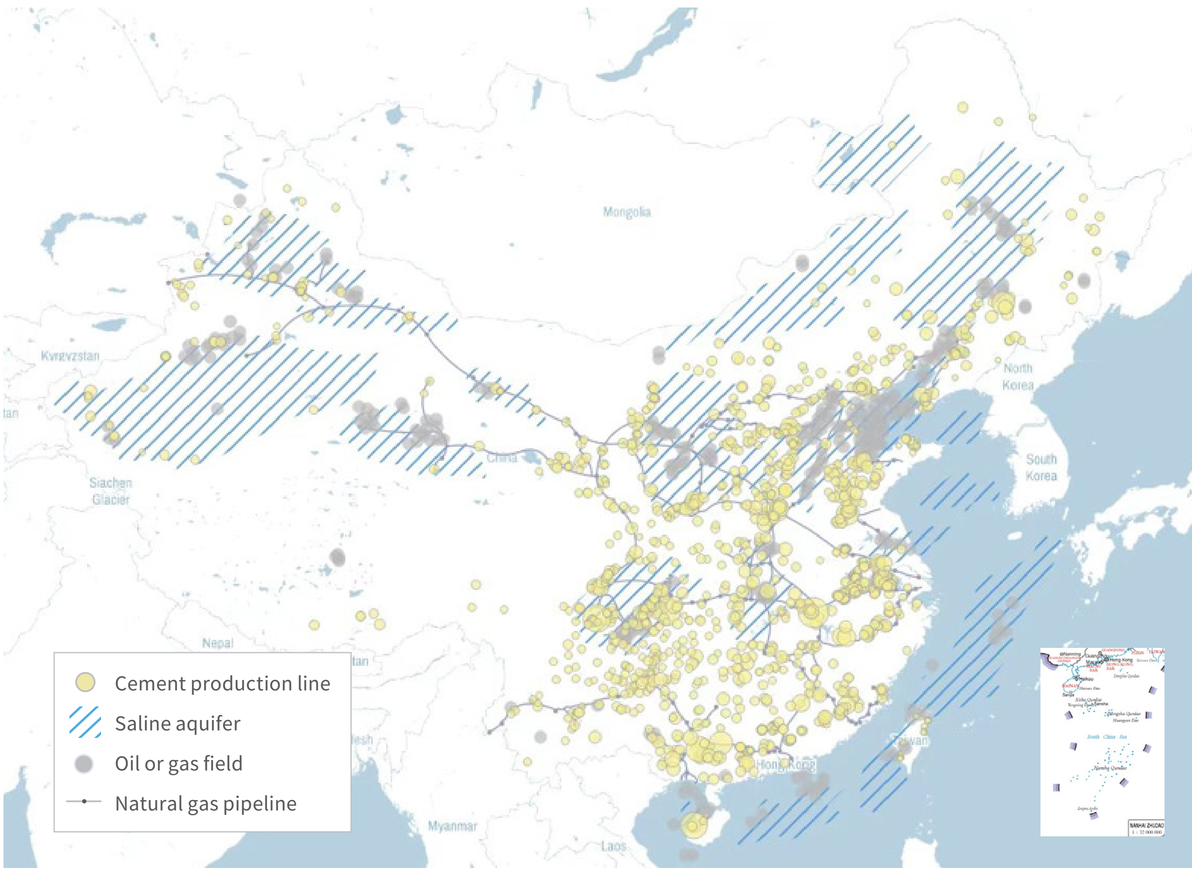
Exhibit 6 **Historical and projected carbon emissions of cement and clinker production after CCUS**



Source: RMI and China Cement Association

In the future, cement production facilities throughout the country will choose their optimal transition pathways according to local resource advantages (see Exhibit 7). Cement production lines in China's north, northeast, and northwest will be able to introduce solid-waste and biomass fuels along with carbon capture and storage (CCS) technology in the near future, and to develop clean production based on green hydrogen or green electricity, using wind and solar photovoltaic, in the long term. Cement production lines in southwest and central China will be able to introduce solid-waste or biomass fuels, or use hydropower to develop green hydrogen or green electricity, and use a saline aquifer for CO_2 sequestration. CCS resources in east, southeast, and south central China are limited. There, cement plants should consider biomass and wind energy, while using natural gas pipelines for long-distance CO_2 transportation, storing CO_2 offshore, or utilizing it locally.

Exhibit 7 Distribution of major cement production and carbon storage sites



Source: RMI and China Cement Association

Recommendations

Include the cement industry in the national carbon trading market, leveraging the carbon price mechanism to drive the industry's net-zero transition.

Low-carbon production is likely to increase cement production costs, and the green premium is likely to remain prominent in the near and medium terms. Therefore, carbon pricing and trading mechanisms will be important enablers of the industry's low-carbon transition. A proper carbon market and pricing mechanism should be established, and cement producers should prepare now to take action when the industry is included in the carbon market.

Promote demand-side transition through carbon-linked green procurement policies.

One of the important drivers of cement decarbonization is change on the demand side, including steps such as improving structural efficiency, saving construction materials, recycling construction waste, and purchasing low-carbon building materials for construction projects. At present, the waste recovery rate is low in China's construction industry, and the procurement policy for green building materials is not linked to carbon emissions, so there is still room for improvement on the demand side. Efforts could be made, starting with government procurement projects and leading real estate companies, to encourage procurement of and nurture the market for low-carbon cement products and building materials.

Use green finance tools to support cement producers' transition.

Technical upgrading of the cement industry is in urgent need of investment, but existing green financial instruments cannot effectively meet the transition needs of carbon-intensive industries. Therefore, it is important to devise finance tools to support the transition of heavy industries, including cement. A finance framework, standard, and tools should be introduced to provide the policy foundation for the transition.

Promote a circular economy to achieve mass production and application of solid-waste fuel.

Solid-waste fuel can become an important alternative to coal in the cement industry, but a standardized system for the collection, sorting, pretreatment, and processing of solid waste needs to be established. The current system needs to be refined, and a solid-waste fuel industry should be established and developed with financial incentives from the government. Cement producers can participate in the standardization process as the major users of waste-derived fuels. They can also integrate part of the waste-fuel value chain and produce standardized alternative fuel products.

Endnotes

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2. International Finance Corporation, *Increasing the Use of Alternative Fuels at Cement Plants: International Best Practice*, 2017, **https://documents.worldbank.org/en/publication/documents-reports/documentdetail/563771502949993280/increasing-the-use-of-alternative-fuels-at-cement-plants-international-best-practice**.
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