COUNCIL OF ENGINEERS
FOR THE ENERGY TRANSITION

An independent advisory council to the
United Nations Secretary-General

OVERVIEW OF STRATEGIES FOR REDUCING CO_2 EMISSIONS IN CHINA'S CEMENT INDUSTRY

This document is written based on open literature, experience in the field and two reports by the China Building Material Academy (CBMA) sponsored by the Energy Foundation (EF): "Research on the Carbon Neutrality Path of China's Cement Industry," dated July 2023, and China Building Materials Federation (CBMF) "Carbon emission reduction technology guide for cement industry" report dated November 2022.[1] The China Cement Association (CCA) is collaborating with the Global Cement and Concrete Association (GCCA) to develop a new roadmap for the industry. This new development will be followed with interest.

Key Messages

- By 2050, China is projected to more than halve its annual cement consumption, currently responsible for 3.5-4.0 % of global carbon emissions.
- China's development was uniquely characterized by an extraordinary growth in cement consumption per capita,—more than 2.5 times the peak level of the most developed countries. In the coming decades developing countries which are expected to increase their consumption need to follow a much more modest path of clinker demand rather than that of China to keep the 1.5 °C climate goal alive.
- The anticipated contraction in China's cement and concrete sector could lead to a challenging business environment, potentially deterring cement companies from adopting emission reduction measures unless robust policies and incentives are implemented.
- The drastic downturn in cement demand could lead to an increase in clinker factor: The CBMA/EF report projections for 2060 would imply an increase in clinker factor (responsible for most of the CO_2 emissions) from 65.7% to 73.5%. This would be in sharp contrast to the expected trend in the rest of the world where the average clinker factor is expected to decrease to around 50%. However, recent industry feedback suggests skepticism about this increase in clinker factor. This divergence underscores the importance of targeted interventions to manage increasing carbon intensity in China's cement production.
- With cement demand declining and only 18% of China's plants meeting the highest efficiency targets, the government is likely to prioritize the closure of the least efficient plants, intensifying efforts to streamline industry operations. This presents a significant challenge for the industry, yet it also offers an opportunity to enhance overall efficiency by phasing out underperforming facilities.
- The decrease in demand will naturally lead to a strong decline in CO_2 emissions from this sector, but there is still further room for curbing emissions at low cost and minimal technological barriers. Methods include reducing clinker in cement, through replacement by supplementary cementitious materials; promoting low CO_2 concrete through industrialized concrete production (optimizing mix design with superplasticizers), and minimizing concrete overuse in structures, through good design.

- Emerging technologies such as calcined kaolinitic clays and optimized separate cement grinding offer a promising potential to significantly lower carbon emissions intensity. Meanwhile, alternatives such as calcium sulfoaluminate cements, low-heat silicate cement, and medium-heat silicate cement offer modest emissions reductions.
- Given the high costs associated with Carbon Capture, Utilization, and Storage (CCUS) technology, achieving substantial CO_2 reduction in cement production will likely require governmental support and incentives to make it economically feasible for companies in a contracting market.

Strategies for Reducing CO_2 Emissions in China's Cement Industry

As seen in the figure below, the demand for cement in China has been the main factor in the growth of cement production worldwide for the past three to four decades. China now produces more than 50% of cement worldwide, making it the third largest emitting industry in the country, following power and steel. The production of cement and concrete in China accounts for approximately 3.5-4.0 % of global carbon emissions. This situation is now changing dramatically. The 2009 IEA/CSI report (which is behind the forecast figures below) forecasts the annual consumption of cement in China to be **reduced by half** by 2050, but the more recent CBMA/EF report forecasts an even bigger drop from a peak in clinker production in 2020 of 1.577 billion tons to 419 million tons in 2060 (nearly a fourfold reduction). The report also forecasts, however, that cement demand will reduce from 2.4 billion in 2020 to about 570 million in 2060. This would imply an increase in the clinker factor (from 65.7% to 73.5%), which is contrary to current trends in the rest of the world and the trend needed to reduce the carbon *intensity* of cement. The Chinese Cement Association, however, contends that the clinker factor will not increase. They dispute the roadmap published by the CBMA/EF and intend to produce another roadmap shortly. This is surely much needed, as based on our research, the clinker factor worldwide by 2050 must be reduced to below 50%.

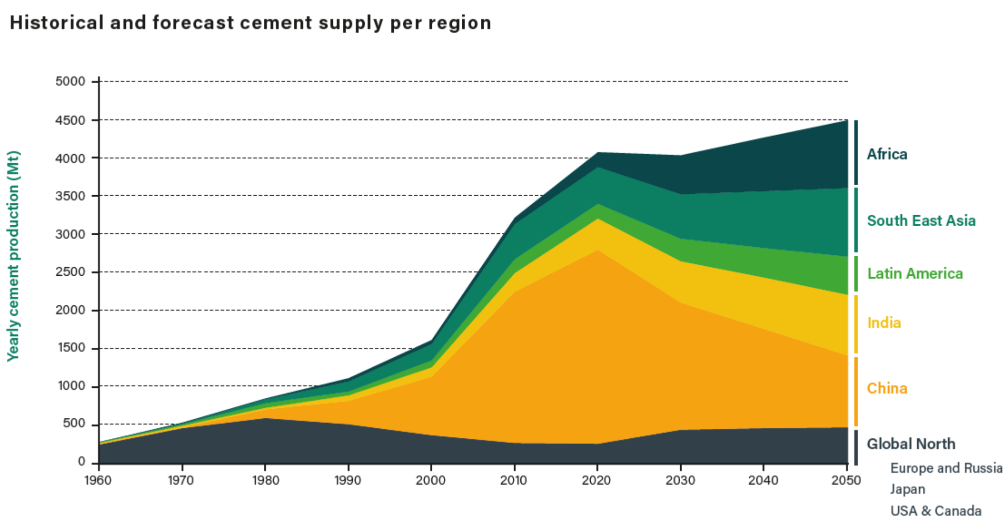

Figure 1. Historic and forecast cement supply per region. Graph redone by the author. Source: IEA, Cement Technology Roadmap: Carbon Emissions Reductions up to 2050, (Paris, IEA, 2009).[2]

Note: Forecasts are from 2009, but there is not more recent data for all regions. The updated projections for China are discussed below.

The likelihood of this demand reduction is believable if the consumption per capita is considered. Cement consumption per capita was only 20 kg per year in 1960 and 32 kg in 1975. This changed dramatically when Deng Xiaoping initiated his institutional reforms in 1978: cement consumption per capita immediately leap-frogged to 81 kg in 1980, passed 500 kg in 2000, and reached 1,590 kg in 2019, more than three times the average global consumption of 500 kg per capita, with many industrialized countries (e.g. France, Germany, UK, USA) having per capita consumptions below 300 kg. Even a reduction of production of cement in China by half will leave consumption at around 800 kg per capita—more than 2.5 times the level of the most developed countries. This growth in China corresponded to rapid urbanization and development of housing and infrastructure such as roads and high-speed rail. Such growth has enabled a large reduction of the levels of poverty, but now there is a deep crisis in real estate with many housing units standing empty.

The extraordinary growth in cement use in China is illustrated by figure 1, which has been compiled from the cement consumption per capita vs GDP per capita for all countries representing more than 2% of cement consumption. It is seen that all countries pass through a peak at a GDP per capita of around $30,000. However, the trajectory in China led to a peak around 3 times higher than that of most countries. In global terms, it would be desirable for developing countries to follow a more modest path of cement demand than that of China.

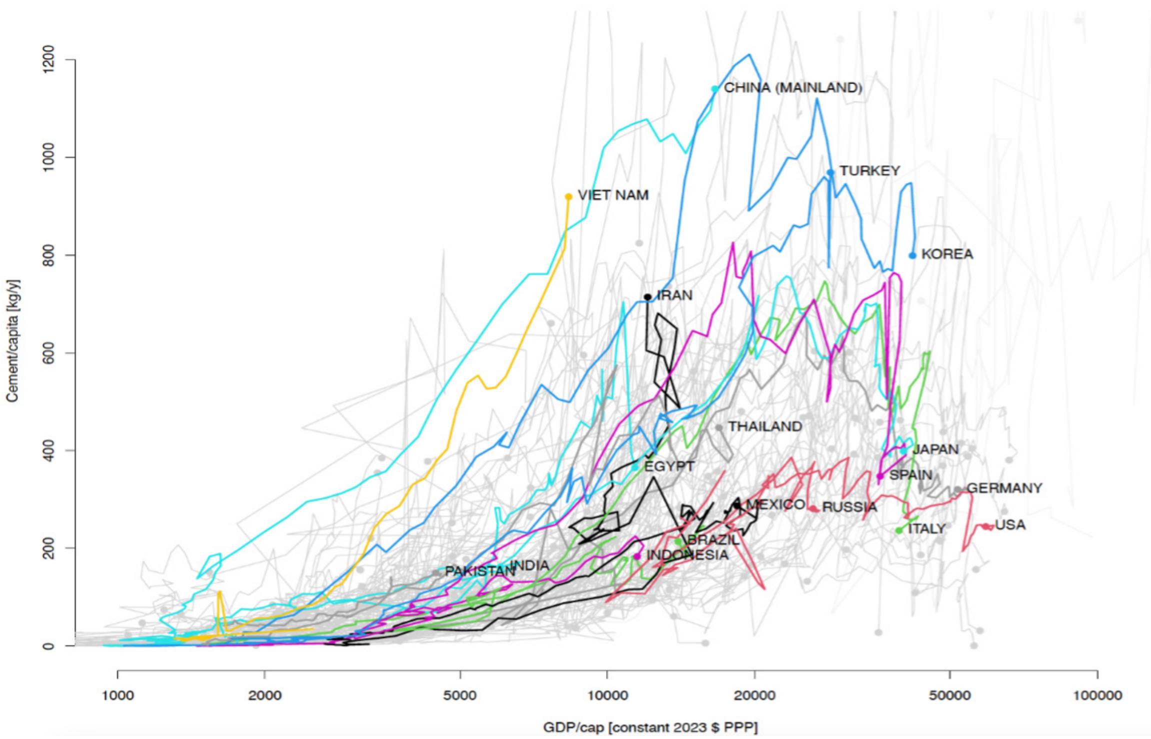

Figure 2. Cement per capita consumption as a function of GDP per capita for individual countries with some countries highlighted. Graph complied by Cyrille Dunant (University Cambridge) from Gapminder and World Bank data.

This drastic fall in consumption will be difficult for the industry, which will have to cope with rapidly declining sales. It will be challenging for the industry to introduce measures to reduce CO_2 intensity at the same time. However, we understand that the governmental pressure on all parts of the cement and concrete industry to decarbonize is extremely strong, and the majority of companies are partially or wholly government owned.

The rapid development of the industry means that not all cement plants are the most efficient. At the International Chemistry of Cement Conference in Bangkok in September 2023, Sui Tongbo of Sinoma (part of CNBM group) presented the targets for plant efficiency before 2030/2060, with three classes for energy consumption. He said only 18% of plants currently met the highest targets for production efficiency. In light of this, it is likely that the government will target closure of the least efficient plants.

As outlined in the **CEET Issue Brief, Decarbonizing the Cement and Concrete Sector**,[3] the CO_2 reduction measures that can be introduced most rapidly at the lowest cost with the least technological barriers are the following:

- **Reduce clinker in cement through replacement by Supplementary Cementitious Materials (SCMs).** Here it should be noted that the clinker factor in China is already one of the lowest in the world and has in fact increased recently due to restrictions on low-performance cement (32.5 MPa class). Nevertheless, there is still potential for CO_2 savings by the use of high reactivity replacement such as calcined kaolinitic clay and by better-optimized grinding (see points three and four in the following section of technologies identified by the CBMF).
- **Reduce cement in concrete, through industrialized concrete production, good mix design, and the use of superplasticizers.** The sale of cement in bags has already been banned in several urban centers, which is an important first step in this direction. In addition, targets should be set for CO_2 kg/m^3, which several studies (mainly outside China) have shown can be reduced to even 100 kg/m^3 from the current world average of around 300 kg/m^3.
- **Reduce overuse of concrete in structures, through good design.** At a recent workshop held at Tongji University in Shanghai, the high level representation from the government indicated significant interest in introducing CO_2/m^2 benchmarks in buildings.

It must be stressed that all the above measures will further reduce clinker consumption and so exacerbate the problem of falling sales for cement clinker producers. Despite this, there seems to be a strong commitment from the government to decarbonize the industry.

In common with the rest of the world, the main remaining measure to deal with the CO_2 emissions from clinker production is carbon capture and storage (CCS). This requires a very high capital investment (around three times the cost of building a clinker plant) and has high operational costs that will increase the cost of clinker production by two to three times. This will be challenging for companies to install in a shrinking market without government intervention. (Other alternative clinkering methods, such as the use of hydrogen fuel and electrification, are quite far from industrial implementation at scale and still would not eliminate the process emissions for the limestone breakdown — meaning that CCS is still necessary)

At present the government is putting most focus on getting cement producers to adopt alternative fuels: many plants in Europe operate with less than 10% of fuel from primary fossil sources. This does not sustainably reduce CO_2 emissions of clinker (except insofar as biomass can be used), but it does reduce the demand for coal and safely disposes of wastes that might otherwise be landfilled, which would lead to other emissions (e.g. methane) and environmental problems.

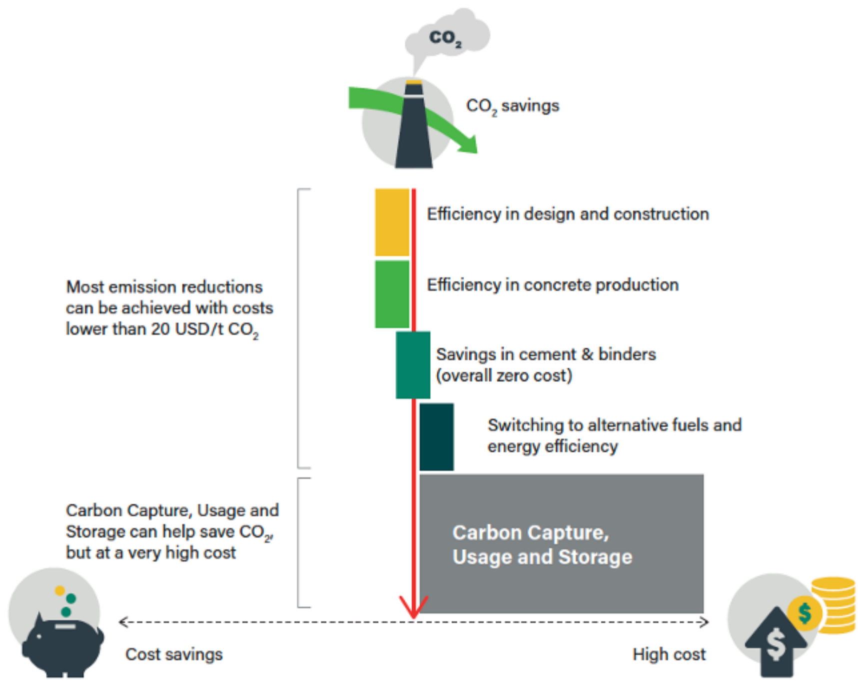

Figure 3. Schematic depiction of the different levers available to reduce CO2 emissions from cement related construction with their approximate costs. The top 4 levers are based on presently available technologies and could be implemented as relatively low cost leading together to savings even up to about 70%. The gap to zero will need to be filled by something like Carbon Capture and storage, but this has significant technological challenges and high cost. Designed by author.

The CBMF has published a “Carbon Emission Reduction Technology Guide for Cement Industry,” which is provided with translation in the annex. In addition to emphasizing the need to switch to alternative fuels, this guide identifies five low carbon cement technologies (apart from CCS), which are commented on here:

1. **High-belite sulfo-aluminosilicate (ferro-aluminosilicate) cement technology:** This technology is also known as CSA (calcium sulfoaluminate) cements. CSA cements have been produced in China since the 1970s and currently account for less than 0.1% of cement production. Growth in production is limited by several factors, but most importantly the lack of necessary raw materials with high alumina contents compared to silica. These raw materials, such as bauxite, are in high demand from the aluminum industry. Therefore, there is little potential for CO_2 reduction here.

2. **Low-heat silicate cement, medium-heat silicate cement, and their preparation technology:** Such cements were developed for the large dam building program (e.g Three Gorges dam). Increasing the amount of belite in clinker only gives a modest reduction in CO_2—about 10%. In addition, high-belite clinkers do not produce as much calcium hydroxide as high-alite ones, which means that the possible level of SCM addition (clinker substitution) is much lower. SCMs make it easy to achieve CO_2 reductions of 30-40%, so it is difficult to see how high-belite clinkers can achieve higher levels of decarbonization. Use of SCMs also lowers the heat rise, which makes these blended cements very suitable for massive structures such as dams. In such applications, pozzolanic SCMs also dramatically lower the risk of alkali silica reaction, which is not the case for high-belite cement.

   The current production of these “special cements” featured in examples 1 and 2 is currently only 50 million tons, or 2% of total production (2% of total) (CBMA in Climate Imperative Seminar, Nov 21, 2023).

3. **Optimized separate cement grinding technology:** This is a very promising route to maximize the performance from the clinker component by finer grinding, thus increasing the potential level of substitution by SCMs. As a rough estimate, this could reduce CO_2 emissions intensity of cement by around 20%, but will also reduce demand for clinker. Optimized separate cement grinding technology is a potential solution worldwide.

4. **Calcined kaolinitic clays to produce low-carbon cement:** This is basically the LC3 technology developed by École Polytechnique Fédérale de Lausanne in Switzerland; it has a very high potential for CO_2 reduction on a short time scale. Again, the deployment of this technology will exacerbate the fall in demand for clinker. Many companies are saying that China does not have suitable clays. Our assumption, however, is that this results from a misunderstanding of the materials needed: the low-grade materials suitable for calcination (approximately 30%-50% kaolin content) are not ceramic grade "clays" and so do not compete with ceramic applications; they may often be obtained from waste streams, such as dredging sediments, aggregate washing, coal gangue, or mine tailings.

5. **Industrial by-product gypsum to sulfuric acid cogeneration cement technology:** This is a route being worked on by several researchers worldwide. The amount of sulfuric acid consumed annually is about 15 times less than the amount of cement produced, but the sulfuric acid can be reused in the process of phosphate extraction. The two biggest sources of by-product gypsum are phosphogypsum (300 Mt/y worldwide and 85 Mt/y in China) and flue gas desulfurization (FGD) gypsum (176 Mt/y worldwide as of 2019) mainly from the treatment of emissions from coal-fired power stations (this should decrease as coal is phased out). Sinoma, who are the world's largest producer of equipment related to cement production, recently showcased a full-scale plant they have constructed and are in the process of commissioning. This announcement dramatically increases the Technological Readiness Level of this technology to around seven to eight. They also claim to be able to recycle the acid produced into the process of extracting phosphates. Despite the now-proven viability of this route, it will only be able to supply a few percentage points of the calcium oxide current found in the cement production.

   This analysis indicates that two main technologies are likely to deliver substantial CO_2 savings in the next few critical decades: grinding (example 3) and calcined kaolinitic clays (example 4).

Roadmap Published in the CBMA/Energy Foundation report

The figure below shows the path to zero presented in the CBMA/Energy Foundation 2023 report, which is fully in line with the government's double target: peaking in emissions in 2030 achieving net zero by 2060. Current emissions are estimated at around thirteen hundred million tons. The biggest part of reduction, at the top, is the reduction in demand, which is forecast to account for about 60% of the emissions reduction. At the bottom is installation of CCUS capacity, forecast to give 18% reduction. The other reduction levers are low-carbon cement carbon reduction (3%), energy efficiency improvement (9%), energy substitution (9%).

The improvement in energy efficiency can be achieved relatively easily by shutting the low efficiency plants and keeping the more efficient ones. Energy substitution will come from replacing coal with waste fuels and biomass.

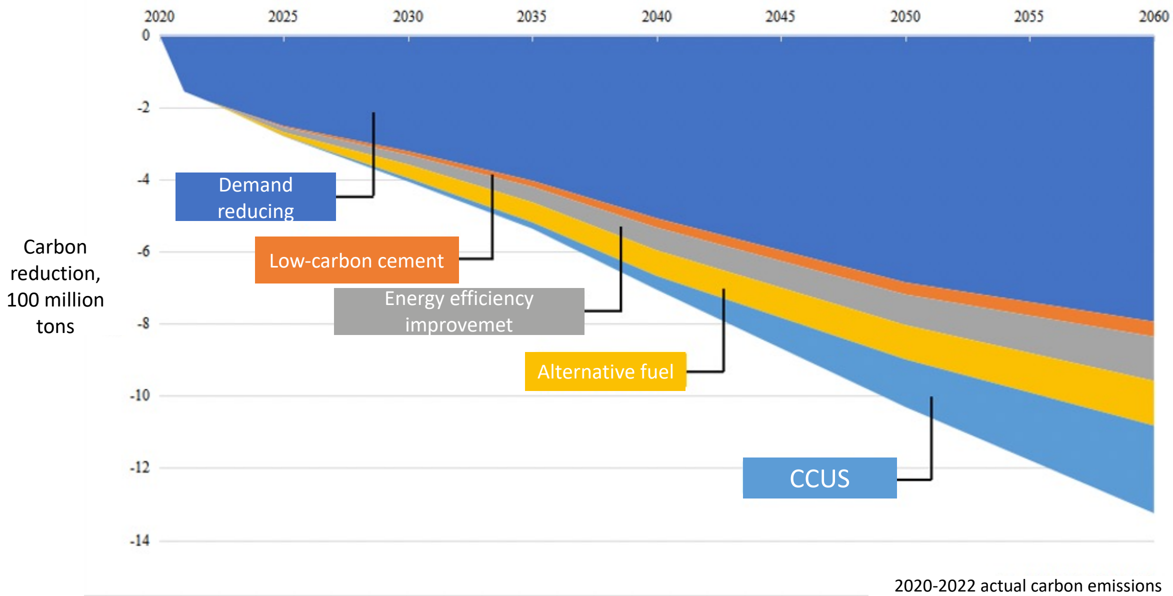

Figure 4. Levers for reduction of cement related CO2 emissions in China: from "Pathways of China's Cement Industry" China Building Materials Academy co, Ltd, July 17 2023 (link in Bibliography). Translation added.

The 3% reduction from low-carbon cements is extremely small, considering more efficient production of concrete and more efficient production of cement (lower clinker factor) are considered to be able to reduce 20% of emissions in the GCCA roadmap.[4] This reduction could increase substantially if the full range of clinker substitutes, including calcined clay, are considered. The potential of clinker substitutes is well appreciated by contacts in China, who assure that it will be better considered in the forthcoming roadmap to be carried out by the Chinese Cement Association.

As with other roadmaps around the world, the figure deemed necessary from CCUS is really just the difference between what is estimated as possible from other sources and the total needed. The CCS capacity for cement given in this report is roughly the same value as in another report: "CCS progress in China – A Status Report."[5] We have no further information about the possibility to realize this level of CCS.

Conclusions

China will achieve substantial reductions in CO_2 emissions from the cement and concrete sector simply from the falling demand and the shutting of small inefficient plants. This will create a very challenging business environment for cement companies. For example, the profits of the largest cement and construction related company CNBM fell by 60% last year, and the current market price of cement hardly covers production costs.

In light of this, some producers are reluctant to apply the rapidly accessible measures of decarbonization: reduced clinker in cement, reduced cement in concrete and more efficient use of concrete in structures, which could reduce emissions even further. A substantial part of the reduction is foreseen to come from carbon capture and storage, and the difficulties of realizing this globally (not only in China) are well recognized. However, the Chinese government's commitment to the decarbonization of the industry remains strong. This coupled by the fact that many companies are at least partially state owned indicates that strategies will be found to achieve higher levels of reduction on the levels of cement, concrete and buildings than shown in the CBMA/CBMF report. The upcoming new roadmap to be done by the Chinese Cement Association is eagerly anticipated in this regard.

Notes

1 He Jie, Cui Jingxuan, Nie Qing, Xiao Ying, and Ni Yaling, "A Study on the Carbon Neutrality Pathways of China's Cement Industry." China Building Materials Academy Co., Ltd., July 17, 2023, https://www.efchina.org/Attachments/Report/report-cip-20230913/%E4%B8%AD%E5%9B%BD%E6%B0%B4%E6%B3%A5%E8%A1%8C%E4%B8%9A%E7%A2%B3%E4%B8%AD%E5%92%8C%E8%B7%AF%E5%BE%84%E7%A0%94%E7%A9%B6, and "Cement Industry Carbon Emission Reduction Technical Guidelines, Flat Glass Industry Carbon Emission Reduction Technical Guidelines," cbmf.org, November 20, 2022, http://www.cbmf.org/c/2022/11/20/12796.shtml

2 IEA, "Cement Technology Roadmap: Carbon Emissions Reductions up to 2050," (Paris, IEA, 2009).

3 Karen Scrivener, "DECARBONIZING THE CEMENT AND CONCRETE SECTOR," Sustainable Development Solutions Network, December 8, 2023, https://files.unsdsn.org/202312CEETConcreteBrief.pdf.

4 GCCA, "Concrete Future: The GCCA 2050 Cement and Concrete Industry Roadmap for Net Zero Concrete," Global Cement and Concrete Association, October 12, 2021, https://gccassociation.org/concretefuture/wp-content/uploads/2022/10/GCCA-Concrete-Future-Roadmap-Document-AW-2022.pdf.

5 Xian Zhiang, Xiaoliang Yang, and Xi Lu, "CCS Progress in China - A Status Report," The Global CCS Institute, March 17, 2023, https://www.globalccsinstitute.com/wp-content/uploads/2023/03/CCUS-Progress-in-China.pdf.

Bibliography

"Cement Industry Carbon Emission Reduction Technical Guidelines, Flat Glass Industry Carbon

Emission Reduction Technical Guidelines." cbmf.org, November 20, 2022. http://www.cbmf.org/c/2022/11/20/12796.shtml.

GCCA. "Concrete Future: The GCCA 2050 Cement and Concrete Industry Roadmap for Net Zero

Concrete." Global Cement and Concrete Association, October 12, 2021. https://gccassociation.org/concretefuture/wp-content/uploads/2022/10/GCCA-Concrete-Future-Roadmap-Document-AW-2022.pdf.

IEA. "Cement Technology Roadmap: Carbon Emissions Reductions up to 2050." (Paris, IEA, 2009).

Jie, He, Cui Jingxuan, Nie Qing, Xiao Ying, and Ni Yaling. "A Study on the Carbon Neutrality

Pathways of China's Cement Industry." China Building Materials Academy Co., Ltd., July 17, 2023. https://www.efchina.org/Attachments/Report/report-cip-20230913/%E4%B8%AD%E5%9B%BD%E6%B0%B4%E6%B3%A5%E8%A1%8C%E4%B8%9A%E7%A2%B3%E4%B8%AD%E5%92%8C%E8%B7%AF%E5%BE%84%E7%A0%94%E7%A9%B6.

Scrivener, Karen. "DECARBONIZING THE CEMENT AND CONCRETE SECTOR." Sustainable Development Solutions Network, December 8, 2023. https://files.unsdsn.org/202312CEETConcreteBrief.pdf.

Zhiang, Xian, Xiaoliang Yang, and Xi Lu. "CCS Progress in China - A Status Report." The Global CCS Institute, March 17, 2023. https://www.globalccsinstitute.com/wp-content/uploads/2023/03/CCUS-Progress-in-China.pdf.

CEET SUBJECT MATTER EXPERT

Karen Scrivener,
Professor at École Polytechnique Fédérale de Lausanne and
Council of Engineers for the Energy Transition Member

CONTACT

Council of Engineers for the Energy Transition (CEET)

475 Riverside Drive | Suite 530
New York NY 10115 USA
+1 (212) 870-3920
ceet@unsdsn.org

Vienna International Centre
Wagramer Str. 5
P.O. Box 300
A-1400 Vienna, Austria

MORE INFORMATION AT

https://www.unsdsn.org/our-work/ceet/