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Minnovation™

Greening Cement Making: The Paths of Progress (Part-1)

Sustainability

Sustainable use of natural resources and effective waste utilization in green concrete is becoming increasingly necessary as natural resources become more limited. Further, the exponentially demand of individual habitation has led to increased demand for new construction. Cement industry is considered to be one of the most carbon intensive sectors, accounting for about 25% of CO_2 emissions of global industrial sectors (excluding power sector). The cement production has a high volume of energy consumption and carbon emissions, both ranking among the top three in all types of industrial sectors. Nominally, up to 8.0% of the total energy consumption in any cement producing country is consumed by cement production, which in turn produce about 12–15% of total CO_2 emissions of the whole country. Meanwhile, large amounts of pollutants are also generated along with cement production, of which dust emissions are the highest in industrial sectors and nitrogen oxide emissions ranking the third after power generation and vehicle exhaust. Therefore, it is significant to explore the green transition pathway of the cement industry in response to mitigating environmental problems.

There are five types of measures to promote green transition and sustainable development of the cement industry in the existing researches: (1) improving energy efficiency, (2) reducing the ratio of clinker to cement, (3) implementing carbon capture and carbon storage (CCS), (4) switching to alternative fuels, and (5) using alternative raw materials for cements. Among them, improving energy efficiency is the basic strategy, which reduces the energy intensity and CO_2 emissions by deploying advanced technologies (e.g., large-size new dry kiln and waste heat power generation technology). Reducing the ratio of clinker to cement means adding more mixtures like fly ash besides clinker to reduce the energy consumption as well as CO_2 emissions of per ton of cement. Implementing CCS technology is direct and efficient to reduce CO_2 emissions, and there have been some CCS pilot studies in cement industry worldwide. Compared with conventional fossil fuels, alternative fuels like garbage can reduce CO_2 and pollutants emissions effectively. Limestone as the raw material will decompose a large amount of CO_2 emissions at high temperature, therefore some companies use alternative raw materials with lower carbon intensity (e.g., industrial solid waste calcium carbide) to produce cement.

Most of the research in the field focus on the measures of improving energy efficiency, but the types of advanced technologies involved in their research are not comprehensive enough, and the specific effects of various technologies are not clearly quantified. What's more, regarding how to perform the green transition, most existing studies do not propose how to implement specific and feasible technology layouts, however, it is necessary to point out what the proportions of certain measures/technologies need to be promoted in the future. Furtherly, the evaluation on the corresponding cost for implementing technology layouts should be considered.

To better explore the green transition pathway of cement industry, as many green transition measures/technologies as possible should be discussed in a more comprehensive way to simulate and fit the actual development of the future cement industry. Furthermore, the technology layout of multiple green transition measures/technologies should be clearly proposed, to clarify how they should be implemented in each production process and give the specific roadmap of different measures/technologies. On this basis, assessing how much energy saving and emission reduction potential can be realized by these measures/technologies as well as how much costs will be paid, so as to provide reference and basis for policy makers.

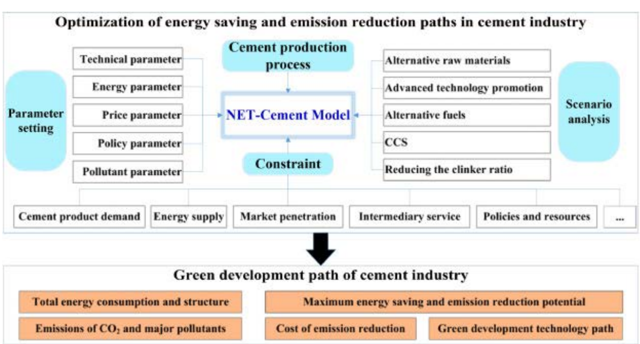


Figure: Transition pathway of cement industry

To improve energy efficiency of cement production, it is suggested to promote advanced technologies and carry out energy saving renovation of backward technologies so as to perform green production. To be specific, before the raw materials enter the large-size or medium-size new dry kiln for burning, energy consumption can be effectively reduced by developing the pre-sintering furnace technology, multi-channel combustion technology and preheating and decomposition with high solid gas ratio technology, and the penetration ratios of these three technologies are suggested to reach 65%, 85%, 35% in 2035 and 75%, 100%, 45% in 2050.

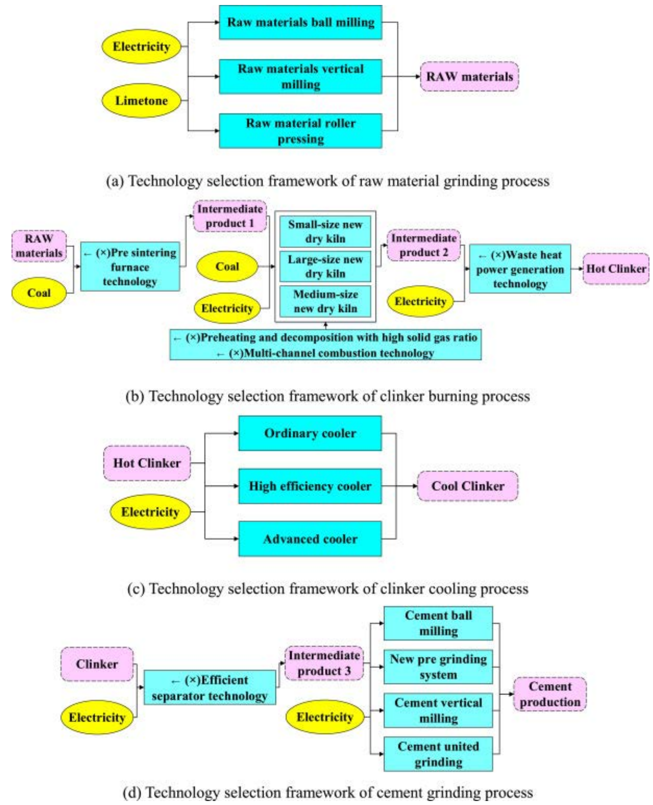


Figure. Technology selection framework of cement production. (a) Technology selection framework of raw material grinding process. (b) Technology selection framework of clinker burning process. (c) Technology selection framework of clinker cooling process. (d) Technology selection framework of cement grinding process.

Furthermore, when the clinkers are made into cement products, the efficient separator technology is suggested to be 90% and 95% in 2035 and 2050 because of its good effect on improving the energy efficiency of cement grinding. In addition, waste heat power generation technology should be increased to 100% by 2050 to realize the recycling and utilization of energy. Besides, using new pre-grinding system technology to improve backward ball milling technology is a direct way to save energy and reduce cost, which is recommended to increase to 20% from 2035. Furthermore, the solution of ERP as an intelligent technology should also be the focus of future development of cement industry.

Switching to garbage as alternative fuel is recommended to be promoted to 40% by 2050, as it is a vital measure which not only achieve energy saving of 5.36 Mtce in 2050 but also dispose garbage safely, harmlessly, and stably. Besides, using alternative raw materials (e.g., calcium carbide) to produce cement is suggested to reach 30% in 2050. It can effectively reduce 21.03 Mt of the process-related CO_2 emissions. Besides, new types of cement with lower carbon intensity, such as belite cement are encouraged to reach 30% by 2050. The development and application of emerging and innovative technologies can provide more emission reduction potentials. If 30% of the clinker production line is equipped with CCS technology, 191.96 million tons of CO_2 emission reduction can be achieved by 2050.

(To be continued: In the next part: Other Developments and Industry Response)

Minnovation™ Greening Cement Making: The Paths of Progress (Part-2)

Other Developments

Uses of MSWI Residues

Municipal Solid Wastes Incineration (MSWI) has been recognized as an effective treatment to reduce the volume of the MSW, while generating energy. MSWI residues (BA-MSW, BLA, and APC) are being collected from a local incinerator in Ontario, Canada. Pure calcium hydroxide and silica sand were used as additives for eco-cement clinkering. CAN/CSA-A3001 (Canadian Standards Association) Type GU Ordinary Portland Cement (OPC) is used as reference. Eco-cement clinkering at 800–1100 °C, which in the incinerator's operating heat range, opens the potential of converting an incinerator into a closed-loop green concrete production with no waste generated. Not only all the residues can be upcycled, locally available heat energy and the carbon dioxide collected from the stack can also be utilized.

Figure. Aggregatesizes used.

High-ferrite Cement

There is an effort to use a green cementitious material to reduce the clinkering temperature and CO_2 emissions by increasing the amount of ferrite as an intermediate mineral in the cement production process. The properties of the intermediate minerals, namely tricalcium aluminate (C3A) and tetracalciumferroaluminate (C4AF), in terms of liquid viscosity at high temperatures and the synergistic interactions between the mineral phases formed at different calcination temperatures during the hydration process were systematically studied. The results indicate that, by adjusting the composition, microstructure, and liquid viscosity of the intermediate minerals and the clinkering regime, a High-Ferrite Cement (HFC) with high activity can be prepared at a calcination temperature of 1375°C, which is about 50–100°C lower than that of ordinary Portland cement.

Working with Water-to-Cement Ratio

The effect of varying the water-to-cement (w/c) ratios and the soaking time of Glass Powder (GP) on the activation of the pozzolanic reactivity and the mechanical properties of green concrete are examined. Two w/c ratios (0.6 and 0.7), two glass contents (5% and 30%), and six GP soaking times are used. The New Mixing Method (NMM) uses the GP, partially dissolved in water and more Na^+ ions than Ca^{2+} are formed in solution since Na^+ ions have higher mobility than Ca^{2+} ions. The results indicate that greater normalized Compressive Strength (CS) is achieved under a w/c ratio of 0.7 for 5% and 30% GP content with soaking time of 6h. This increase is correlated with the formation of more nucleation sites due to the growth of calcium silicate hydrate rather than portlandite. The relative activation index calculation shows that the 30% GP mixes have higher values than 5% GP mixes.

Industry Response

Holcim

Holcim are exploring a range of next-generation technologies to help decarbonize the built environment. Carbon capture, Utilization and Storage (CCUS) is one of the most important technologies in their portfolio. They are currently carrying over 30 CCUS projects ongoing, the techniques will lay the foundation to decarbonize the business beyond 2030. One of the most exciting CCUS techniques is called 'mineralization,' or locking CO_2 away into minerals. Holcim's partnering with Italian Energy company Eni to advance to advance their carbon capture portfolio, repurposing CO_2 from operations into green cement. Eni is putting its carbon capture and mineralization expertise to work to store CO_2 into olivine, a widely available mineral. Researchers at Holcim Innovation Center are exploring the use of this carbonated olivine as a new low-emission raw material for the formulation of green cement. This CCUS solution highly scalable. It would enable the permanent sequestration of CO_2 into building materials for greener construction, adding to a broad range of innovative low-emission raw materials. Holcim team is currently mapping the most relevant sites in Europe to conduct industrial-scale pilots. This partnership is in line with Holcim net-zero journey as well as Eni's commitment to decarbonize its sector.The CCUS portfolio covers over thirty projects across the US, Canada, and Europe, ranging from recycling CO_2 for crop growth in greenhouses, all the way to using it as a source of alternative fuel for aviation.

Heidelberg Cement

Heidelberg Cement is currently building the world's first full-scale installation for carbon capture at the Brevik cement plant in Norway, capturing 400,000 tons annually or 50% of the plant's emissions from 2024 onwards. "Based on the positive collaboration with the Norwegian government and other partners at our site in Brevik, we have now chosen to significantly ramp up our ambitions for a carbon capture installation in Sweden that is four times larger," said GivBrantenberg, General Manager of HeidelbergCement Northern Europe. The planning for the plant in Slite will benefit significantly from the experience gained at Brevik.

Heidelberg Cement intends to upgrade its facility in Slite on the Swedish island of Gotland to become the world's first carbon-neutral cement plant.

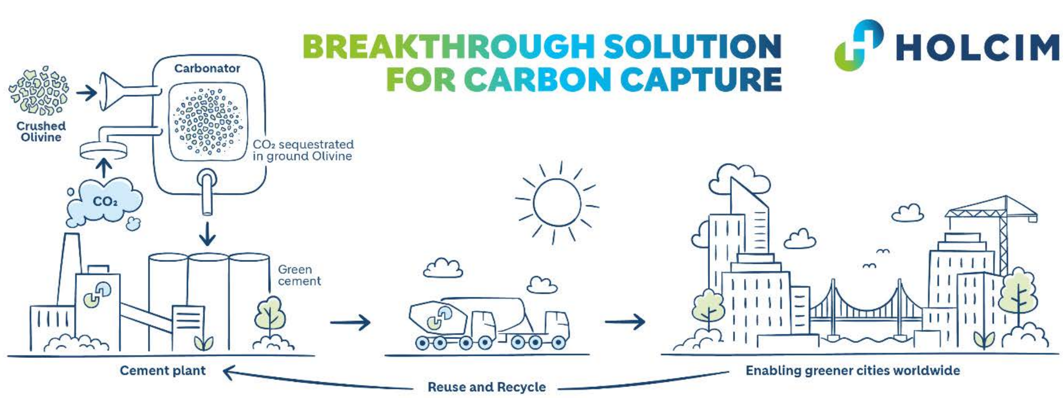
1. Up to 1.8 million tons of carbon dioxide are to be captured annually from 2030 onwards, which corresponds to the plant's total emissions.
2. The breakthrough project supports Sweden's ambitious carbon emission reduction goals as three quarters of the cement used for concrete production in the country are currently produced in Slite.
3. Heidelberg Cement will significantly benefit from the experience gained in its CCS project at the Brevik cement plant in Norway.

Anhui Conch Cement

The Chinese Ministry of Industry and Information Technology has named Anhui Conch Cement subsidiary Chongqing Conch's integrated cement plant in Chongqing State a National Green Factory for its "resource conservation, recycling, and harmonious development. "The company says that its efforts include "implementation of precision denitrification, wet flue gas desulfurisation, belt corridor noise reduction, electricity conversion bags, rainwater collection and other environmental protection technology reforms," as well as co-processing domestic waste from the city of Chongqing as fuel.

What Holds for the Future?

Cement industry is one of the leading contributors of greenhouse gases after power plant industries. Approximately 4.1 billion metric tons of cement are currently produced globally every year, accounting for about 8 to 10 percent of global anthropogenic CO_2 emissions,



and is expected to continually increase in the future adding more CO_2 into the atmosphere. The cement industry should reduce the cement clinker to 60% and then take special measures in capturing and storing CO_2 to control the impact of cement industry on environment by 2050. The following paths are now being looked into:

Techniques for CO2 reduction in cement industries

The cement and concrete industry searches for ways to meet increasing demand while reducing the carbon footprint of the concrete produced. Techniques such as Carbon Capture and Storage (CCS), material substitution, alternative fuels and energy efficient technologies have been identified as some of the approaches to produce more sustainable cement. The roadmap, produced by the World Business Council for Sustainable Development (WBCSD), the International Energy Agency (IEA) and the Cement Sustainability Initiative (CSI), identified four levers (improving energy efficiency, switching to alternative fuels, reducing the clinker to cement ratio, and using emerging and innovative technologies) to improve the carbon footprint of cement and concrete production.

Carbon Capture and Storage (CCS)

CCS technologies, including absorption, membrane-based processes, mineral carbonation, and the use of oxyfuel, has been studied as one of the prominent solutions to minimize CO_2 emissions in the atmosphere. Modified cement products such as CO_2 concrete and several other new technologies, including Solidia technology, Carbicrete, and Carbon cure, are being examined to minimize the CO_2 emissions from cement production thereby making cement a sustainable construction material.

However, most of the studies are either limited to the application like precast industries or utilizes the raw materials that are available on a regional basis thus restricting their abundant use. Additionally, the widespread concerns relating to long-term reliability and high capital cost suggest that CCS alone may not be technically and commercially viable option.

Supplementary Cementing Materials (SCMs)

Other commonly used approach is the material substitution. SCMs such as fly ash, slag, GGBFS (Ground-Granulated Blast-Furnace Slag), limestone powder, silica fume, RHA (Rice Husk Ash), calcined clay, metakaolin, and pumice has been used to partially replace the OPC (Ordinary Portland Cement). These materials help in improving the performance of concrete either by pozzolanic or by cementitious reactions. However, all these SCMs come with their own limitations.

Fly ash is one of the widely used SCM that helps in improving the durability factor of concrete, especially the alkali-silica reaction; the future availability of fly ash however has already been a concern. Limestone dust is another widely used SCM especially in European countries; the reduced later age strength however limits the substitution levels above 15%. Also, the availability of natural pozzolans such as RHA, Pumice, and calcined clay are not distributed equally over the world thus has concerns about long term availability.

Nanotechnology

As a recent development, nanotechnology has been introduced in the field to compensate for the limitations of SCMs replacement in cement. Nanotechnology is the use of materials less than 100 nano meters (10 thousand times smaller than a cement particle) such as nano SiO_2, nano TiO_2, nano $CaCO_3$, nano Fe_2O_3, nano Zr_2O_3, nano Al_2O_3 and nano graphene (CNTs and CNFs). Nano materials change the structure of hydrated paste at a nano level thereby improving both compressive and flexural strength, performance, and durability dramatically. Most nano materials, however, comes with high price potentially increasing the cost of construction, and may not be a viable option for construction industries. Further, the effectiveness of using nano materials largely depends on proper dispersion of nano particles, and techniques used for dispersion such as sonication are cost intensive for construction industries to adopt. Thus, the economic and technical limitations of using nano materials have been a bottleneck for cement industries to adopt at commercial scale.

References

1. Development of cement composite with high-temperature detection performance using green earth, Case Studies in Construction Materials 22 February 2022.Jong-Han Lee, EunsooChoiJoo-Won Kang
2. Green transition pathways for cement industry in China
3. Resources, Conservation and Recycling24 December 2020. Cheng-Yao ZhangBiyingYuYi-Ming Wei
4. Green concrete made from MSWI residues derived eco-cement and bottom ash aggregates

5. Construction and Building Materials8 June 2021.Shipeng ZhangZaidGhoulehYixin Shao
6. Development of high-ferrite cement: Toward green cement production,Journal of Cleaner Production28 October 2021. Kechang ZhangPeiliangShenFazhou Wang