Financing the Low-Carbon Transition in Heavy Industry

Report / March 2024

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The contents of this report do not represent the views of the above experts and institutions.

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Introduction

Low-carbon transition in heavy industry is essential for reaching the temperature goal set in the Paris Agreement. Achieving this target of limiting the temperature rise to 1.5°C or 2°C above the preindustrial level requires net-zero CO_2 emissions without relying on carbon offsets from land use in the long term. It will be critical for heavy industry to take carbon reduction initiatives over the next decade — not only reducing its own CO_2 emissions and achieving early emissions reduction but also laying the foundation for other sectors to reach net-zero emissions by mid-century.

At present, the steel, cement, and petrochemicals and chemicals industries emit about 18% of global CO_2 emissions and consume about 3,300 million tons of standard coal equivalent (Mtce) annually[i]—almost equal to the total annual national primary energy demand of the United States. The energy consumption of the three industries includes 2,700 Mtce of fossil fuels, constituting approximately 82% of the global total.[1] Clearly, the success of the net-zero transition of heavy industry depends on the transition away from fossil fuels.

- Longer asset lifespan raises the risk of stranding assets from rapid transition. Industrial assets generally have a life span of 30–40 years. Under the requirement for rapid transition, the early retirement of existing capacity will cause significant economic costs. Therefore, newer industrial capacity results in a lock-in effect unless there is further substantial investment for retrofitting facilities.
- Enabling deeper emissions reductions in heavy industry will require significant investment in innovative carbon-reducing technologies. Unlike buildings, transport, and industry in general, heavy industry has limited potential to reduce emissions through electrification and cleaner electricity, and requires more disruptive technologies to achieve deeper emission reductions. However, these disruptive carbon abatement technologies are unattractive for investment because they are at an early stage of development with unproven economics:

    - Significant investment in new energy technologies is the foundation for revolutionizing energy use in heavy industry. Many processes require high temperatures — up to 1,500°C — and largely rely on burning fossil fuels, as large-scale high-temperature electrification is costly to implement with current technology. In addition, the availability of biomass fuels limits their applications in heavy industry, while other emerging energy sources, such as green hydrogen, are still under further development.
    - Eliminating process emissions is challenging and requires investment in carbon sequestration technologies, such as carbon capture, and in new industrial processes and

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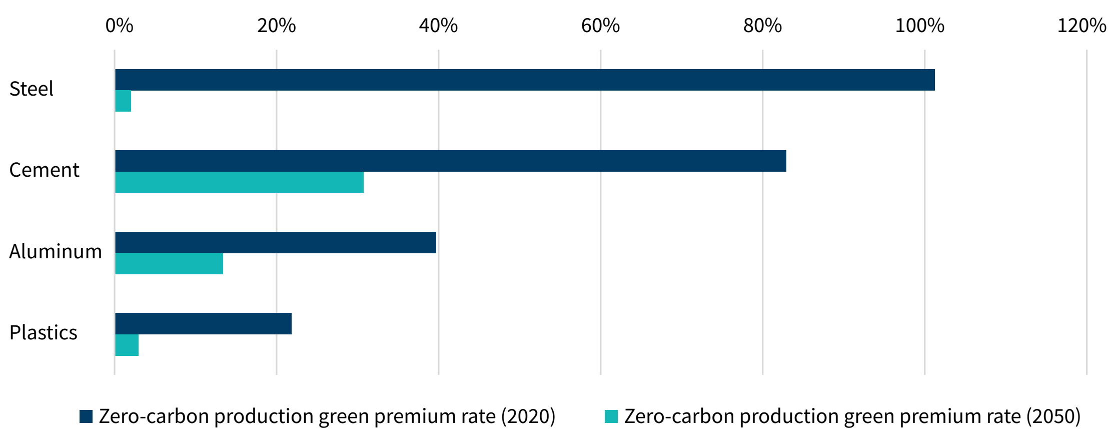
i According to the International Energy Agency (IEA), the total US energy consumption was 2,300 million tons of standard oil equivalent (Mtoe) in 2019 — roughly equal to 3,300 Mtce, using a conversion factor of 1 ton of standard coal equivalent to 0.7 tons of oil equivalent, https://www.iea.org/articles/the-challenge-of-reaching-zero-emissions-in-heavy-industry.

products. Some industries produce CO_2 emissions from chemical reactions. For example, the calcination of cement clinker produces large amounts of CO_2 and accounts for about two-thirds of the industry's direct emissions. This problem can be solved by manufacturing new products or applying new processes whose applicability and scalability have yet to be demonstrated. If it is difficult to change the current production path in certain industries, investment in carbon capture technologies will still be needed.

- The green premium for producing low-carbon industrial products remains high in the short to medium term. Compared with the traditional path, the current cost premium for producing zero-carbon industrial products is 20%–100% (see Exhibit 1), while most industrial products face intense competition with low profit margins. Downstream industries have limited ability to withstand high premiums. As China's carbon market system does not yet incorporate major heavy industries, producers face the challenge of switching to low-carbon, but more expensive, production without raising prices. Smaller margins also reduce the willingness of heavy industry enterprises and financial institutions to lead in low-carbon investment.

Exhibit 1 **Green Premium Rate for the Production of Key Zero-Carbon Industrial Raw Materials in China**



RMI Graphic. Source: RMI analysis

China's industrial sector accounts for about 66% of the country's total energy consumption.[ii] The sector accounts for nearly 40% of the country's total CO_2 emissions if only accounting for direct emissions and 64% if related electricity emissions are included.[2] Carbon emissions from four major heavy industries (steel, cement, petrochemicals and chemicals, and aluminum) amount to 52% of the national total, highlighting the importance of the low-carbon transition of heavy industry in meeting China's dual-carbon goals.

Since the launch of the 14th Five-Year Plan (2021–25), China's state ministries and commissions have issued a number of documents that create a "1+N" policy system for carbon peak and carbon

ii According to the National Bureau of Statistics, in 2020, China's total energy consumption was 4,980 Mtce. The industrial sector consumed about 3,300 Mtce or 66% of the total.

neutrality, stating that industry is a key area for promoting carbon peak and carbon neutrality. The government has subsequently issued the "Implementation Guidelines for Energy Saving, Carbon Reduction, Renovation and Upgrading in Key Areas of Energy-Intensive Industries (2022 Edition)" and the "Action Plan for Carbon Peaking in the Industrial Sector," which provide further guidance on the low-carbon development of the industrial sector.[3] At the same time, the decarbonization of China's heavy industry faces several major challenges:

- Large production capacity: China produces and consumes 50% of the world's total steel, cement, and aluminum, and is the largest producer and consumer of major chemical products. These industries have significant production capacity characterized by heavy assets and high energy consumption, making the transformation task formidable.
- High-carbon raw materials and fuel structure: The main raw materials for heavy industrial production in China are highly dependent on fossil raw materials, represented by coal. In addition, heavy industry mostly uses high-temperature, high-pressure processes in production,[4] where fossil fuel, mainly coal, is the main source of energy. The decarbonization of fuels faces significant technological, economic, and geographic barriers. For example, more than 90% of China's domestic steel production is based on the blast furnace–basic oxygen furnace (BF-BOF) process using coke as a reducing agent. Coal provides more than 95% of the heat in cement production, while it accounts for nearly 80% of the raw materials for the synthesis of ammonia and methanol in chemical production.
- Young assets: Most of China's heavy industry capacity was built in the past 30 years and most assets are still in early- to mid-life.[4] Industrial assets face the risk of accelerated decommissioning and asset stranding under the dual-carbon requirements, putting pressure on corporate finances and financial institutions' returns.

Large-scale financial support is urgently needed for the low-carbon transition in heavy industry. Heavy industry companies should achieve this by starting to upgrade their equipment now with proven transition technologies. However, in heavy industry, the upgrade of large-scale equipment and infrastructure requires massive capital investment. It also goes far beyond simply relying on existing mature technologies. Significant resources and funding are required for technology innovation and deployment, both for short-term breakthroughs and for long-term sustainability goals. If fossil energy is to be replaced by clean energy, the new technology pathways for heavy industry are very different from the existing ones, which are characterized by high R&D costs, large up-front investment requirements, high technological uncertainty, and long payback periods. The risk of stranded assets during the transition from old to new technological pathways should be a particular concern; to mitigate and share this risk requires substantial resources and financial instruments.

In the context of the energy crisis and the global economic downturn, heavy industry companies are generally facing significant financial pressures. With their working capital under pressure, their own funds can hardly meet the demand for low-carbon transition, and they urgently need external financial support. In the steel industry for example, in 2022, the coking coal purchase cost of benchmark steel companies increased by 24.9% year on year, and the injection coal purchase cost increased by 24.3%, according to the China Iron and Steel Industry Association. The operating revenue and profit of the benchmark steel companies decreased by 6.4% and 72.3%, respectively.[5]

In recent years, green finance in China has developed rapidly, boosting confidence in the transition of the entire market. By the end of June 2023, the green loan balance of 21 major banks reached RMB 25 trillion, making it the largest in the world and an important external source of financing for the low-carbon transition.[6] However, green finance investments have mostly focused on "pure green" projects with high technological maturity, such as clean energy, green transportation, and green building. For industries with high carbon emissions, such as heavy industry, or projects at relatively early stages of technology development, financial support remains insufficient, making it difficult to meet the transition needs of these sectors. Designing financing mechanisms to channel more funds into the low-carbon transition of heavy industry, especially for research, development, and promotion of innovative technologies, will be a key opportunity and challenge in achieving a net-zero future.

Low-Carbon Transition Pathways for Heavy Industry in China

Steel Industry

China is the world's largest steel producer and consumer. In 2020, China produced 1.065 billion tons of crude steel, accounting for 56.4% of the world total,[7] and consumed 995 million tons of steel, accounting for 56.2%. In the same year, China's steel industry emitted about 15% of the country's total carbon emissions, and over 60% of total global steel carbon emissions.[8] At present, domestic steel production in China is still dominated by the long process — with a carbon intensity three times greater than that of short processes. China's steel industry will shift to low-carbon metallurgy that reduces carbon emissions through energy-efficiency improvement, scrap-based short process, hydrogen-based metallurgy, and carbon capture (see Exhibit 2 and Exhibit 3).

Energy-efficiency improvements in steel production mainly involve waste-heat and pressure utilization, and distributed energy coupling. Over the past decade, China's steel industry has made rapid progress in energy-efficiency improvement, reducing key steel companies' energy consumption intensity from 600 kg of standard coal in 2010 to 545 kg in 2020. However, with respect to metallurgy processes' carbon emissions and energy consumption, there is still a gap between China and advanced countries. China has clear potential for energy-efficiency improvements.

One of the main trends in the transition to low-carbon steel is use of the scrap-based short process in which crude steel is produced from scrap feedstock with an electric furnace. In China, due to an insufficient supply of domestic scrap and electric furnace capacity, short-process steelmaking accounts for about 10% of national total crude steel. Social scrap and imported scrap resources will gradually increase, and recycling systems will become more efficient. The short process will be a key component in China's efforts to reduce the carbon intensity of steel production and its dependence on imported iron ore.

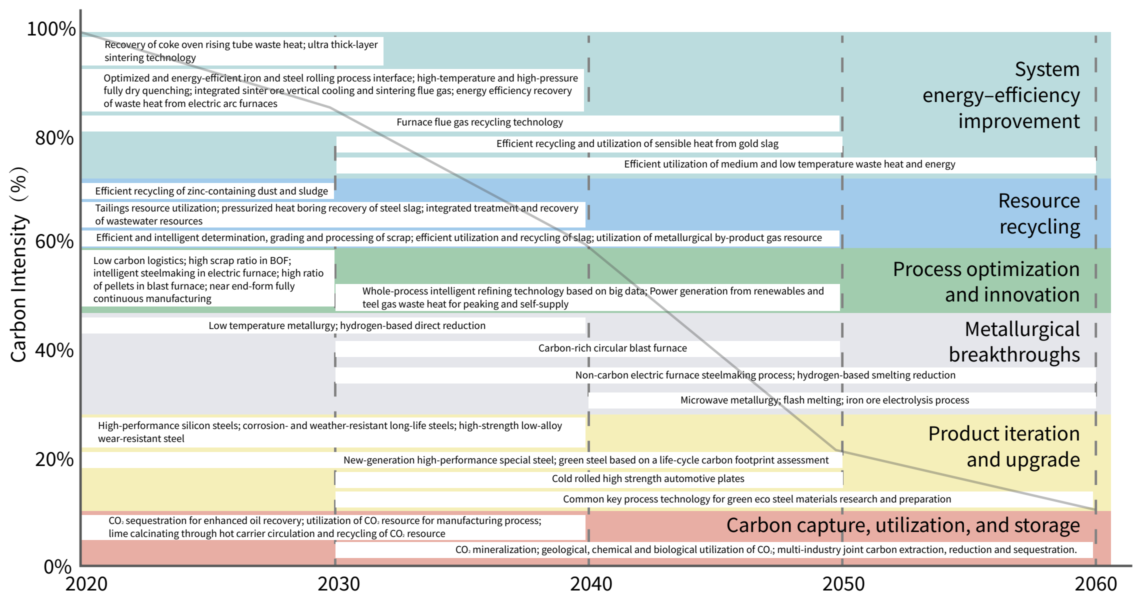
Hydrogen-based metallurgy mainly consists of injection of hydrogen into blast furnaces and hydrogen-based direct reduced iron (DRI). The first of these processes effectively utilizes existing blast furnace equipment, avoiding large-scale stranding of young assets. The hydrogen injection technique reduces carbon emissions by replacing partially pulverized coal and coke with hydrogen. DRI has a high potential for carbon reduction as hydrogen directly reduces pelletized ore to solid sponge iron. The emissions reduction potential can reach 95% when using green hydrogen. In the short term, injecting hydrogen into blast furnaces will be a focus of the industry. DRI is under pilot/demonstration and expected to be put into larger-scale production in the medium to long term.

The main use case for carbon capture in the steel industry is capturing CO_2 generated in the BF-BOF process. Speaking broadly, the steel industry has various emissions sources and low-carbon concentrations, so carbon capture is relatively difficult and costly. The CO_2 content of blast furnace gas is higher than that of other processes such as basic oxygen furnace. The blast furnace can be prioritized for capture, but carbon capture in the metallurgical industry is still a relatively expensive technology.

In addition, emerging technologies such as iron ore electrolysis may play an important role in the steel industry if these technologies mature and can be successfully implemented in large-scale pilots. Iron ore electrolysis reduces iron ore to iron at high or low temperatures by directly using electricity, but no pilot projects have thus far been launched in China.

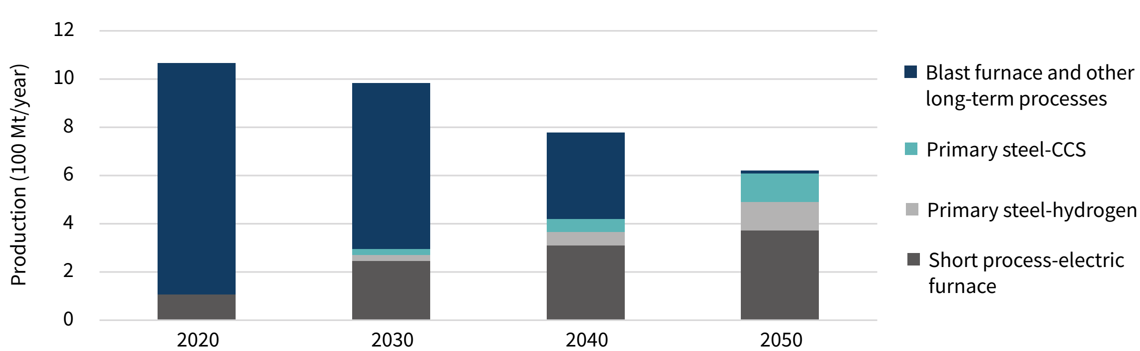
Given the technology maturity, cost-effectiveness, and other factors of each low-carbon production route, the short-, medium- and long-term pathways for the China steel industry are summarized as follows:

Exhibit 2 Roadmap to Carbon Reduction in the China's Steel Industry



RMI Graphic. Source: China Iron and Steel Association

Exhibit 3 Crude Steel Production Forecast for Different Production Routes (2020—50)



RMI Graphic. Source: RMI, https://rmi.org/insight/pursuing-zero-carbon-steel-in-china/

Near term (2020–30): The steel industry will rely mainly on energy-efficiency improvement and development of the scrap-based short process to reduce carbon emissions. National and industry-level policy requirements for ultra-low emissions transition, energy consumption intensity, and short-process development will further accelerate the deployment of low-carbon technology. In January 2022, China's Ministry of Industry and Information Technology (MIIT) issued "Guiding Opinions on Promoting the High-Quality Development of the Iron and Steel Industry," requiring that more than 80% of the nation's steel production capacity should complete the ultra-low emissions transition by 2025. The total energy consumption per ton of steel should be reduced by over 2% by 2025, to ensure carbon peaking by 2030. Guidance issued by MIIT and other ministries and commissions in July 2022 states that by 2025, the annual processing capacity of companies qualified to process scrap shall exceed 1.8 million tons, and short process will account for 15% of total steelmaking outputs.

Medium term (2030–40): Output reduction and the scrap-based short process will be prioritized to reduce carbon emissions. Hydrogen-based metallurgy and carbon capture will be commercialized gradually. Beyond 2030, China's steel production will plateau and then decline. Crude steel production is expected to drop to 780 million tons per year (Mt/year) in 2040. Production decline will require optimized development of existing capacities and the elimination of obsolete capacities in the steel industry. In 2040, the availability of scrap will further expand with increasingly higher recycling proportion and quality. The production capacity of short-process steelmaking is expected to reach 310 Mt/year. Hydrogen-based DRI and carbon capture will gradually become commercialized — driven by the falling cost of hydrogen, carbon pricing, and the scaling of equipment — each contributing steel production of about 108 Mt/year. In 2040, the total carbon emissions of the steel industry are projected to reach 850 Mt/year while the carbon emissions intensity will be reduced to 1.1 tons CO_2 per ton of crude steel.[9]

Long term (2040–50): Output reduction and the scrap-based short process will continue to play an important role, while hydrogen-based metallurgy and carbon capture will become more important to reach carbon neutrality. In 2050, crude steel production is expected to be 620 Mt/year, decreasing by 20% compared with 2040. Short-process capacity will contribute 60% of steel production, with scrap demand reaching 410 Mt/year. For hydrogen-based DRI and carbon capture, each production route will scale up to nearly 20% of total steel production, or about 240 Mt/year. In 2050, total carbon emissions from China's steel industry are expected to reach 190 Mt/year, while carbon intensity is reduced to 0.3 tCO_2/t of crude steel.

Cement Industry

As the world's largest cement producer and consumer, China produced 2.363 billion tons of cement in 2021, or 57% of the world's total, and consumed more than half of the world's cement.[10] China's cement industry emitted 1.37 billion tons of CO_2 in 2020, second only to its power and steel industries. Decarbonizing the cement industry faces two challenges: addressing process emissions and fuel substitution. Process emissions generated by carbonate decomposition during cement production account for about 60% of industry-wide emissions (Scope 1 and Scope 2). Currently, there is no massively available alternative process for producing cement or mass alternative of cement as a building material. Second, cement production is highly dependent on fossil fuels. More than 95% of the thermal energy used by the cement industry is derived from coal.

Comprehensive measures are needed to fully decarbonize the cement industry, including reducing cement consumption from the demand side, innovating low-carbon cement products, increasing the substitution rate of low-carbon fuels and electricity, and promoting CCUS technologies to offset difficult-to-eliminate process emissions (see Exhibit 4 and Exhibit 5).

The energy efficiency of cement production in China, although leading the world, still has potential for further improvement. The three commonly used cement energy-saving technologies at present are clinker sintering, grinding system, and digitalization. Based on the application of these technologies, the total energy consumption per unit of cement clinker products in China is 2.9–4.0 gigajoules per ton, which is about the same level as Europe and the United States. However, some enterprises with high energy consumption still fail to meet the national standard, and require immediate technological retrofitting. If cement production lines across China can improve their energy efficiency level from the current level 3 to level 1 according to the national standard, energy consumption and emissions will be reduced by about 14%.

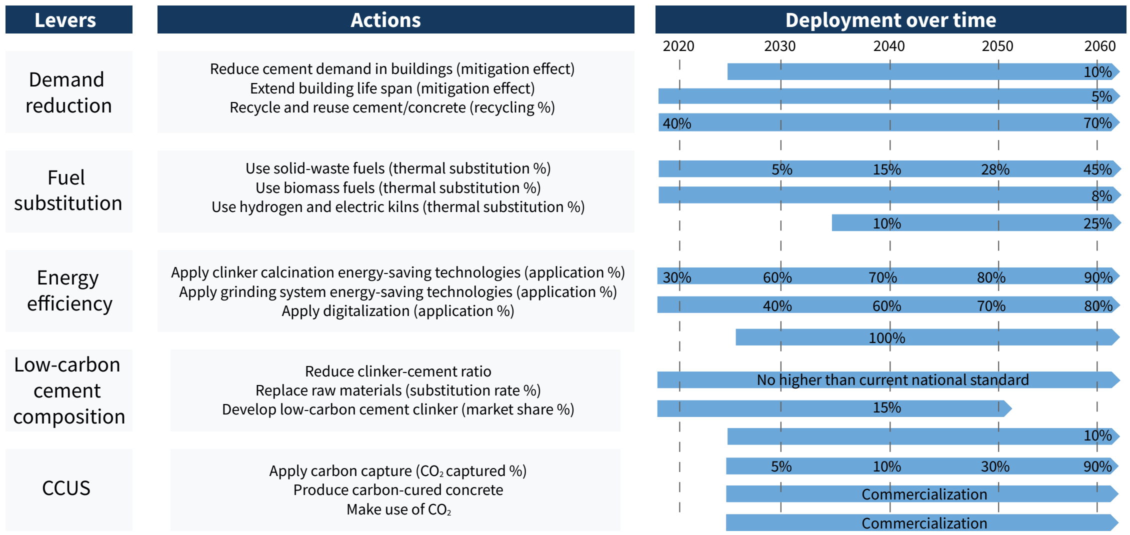
Fuel substitution in cement production is still in early development, with huge potential for improvement. Technology pathways for fuel substitution include solid-waste fuel and biomass fuel in the near term, and emerging heating sources such as hydrogen and electricity in the long term. Solid-waste fuel is a suitable fuel substitution for the cement industry. Although the development of alternative fuels in China's cement industry started to take off in recent years, the thermal substitution rate is still low, compared with more than 50% in some European countries.

CCUS technologies are essential for carbon-neutral cement. Among them, liquid chemical absorption, calcium loop, second-generation oxygen-rich combustion, and Low Emissions Intensity Lime and Cement (LEILAC) are worthy of implementation in the cement industry. However, the large-scale application of CCUS still faces challenges. For one, the geographical distribution of cement plants in China is not conducive to the centralized construction of CCUS infrastructure, increasing the cost of transporting CO_2. In addition, the concentration of CO_2 in the flue gas of the cement kiln is usually less than 30%, resulting in high energy consumption and capture costs. As the technology matures and economies of scale are achieved, CCUS may become one of the core technologies for carbon neutrality in the cement industry. CO_2 can also be combined with concrete, which is a downstream product from cement, to produce building materials, as well as used in geological storage, chemical synthesis, and other applications.

In addition, the use of clinker substitution, raw material substitution, and innovative low-carbon cement products also reduce emissions. With lower calcination temperatures — thus lower carbon emissions — new cement products are expected to gain higher market shares in the future, but due to uncertainty about their maturity and application potential, this report does note focus on them.

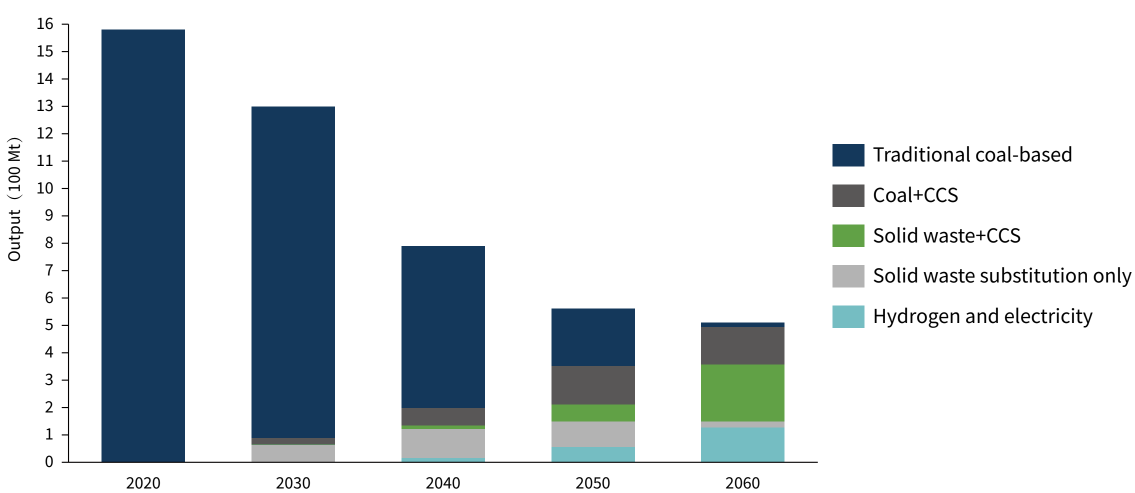
Looking ahead, under China's carbon neutrality target, the carbon reduction pathway for the cement industry is summarized as follows:

Exhibit 4 Roadmap of Priorities for Carbon Neutrality in China’s Cement Industry



RMI Graphic. Source: RMI and China Cement Association, https://rmi.org/insight/net-zero-decarbonization-in-chinas-cement-industry/

Exhibit 5 Projected Cement Clinker Output for Different Production Pathways (2020–60)



RMI Graphic. Source: RMI and China Cement Association, https://rmi.org/insight/net-zero-decarbonization-in-chinas-cement-industry/

Near term (2020–30): Carbon reduction in the cement industry is mainly based on reducing cement production and improving energy efficiency to peak carbon emissions early. In February 2022, the National Development and Reform Commission (NDRC) issued “Guidelines on the Implementation of Energy Conservation, Carbon Reduction, Renovation and Upgrading in the Cement Industry,” which requires that the clinker production capacity above the energy-efficiency benchmark level should reach 30% by 2025 while those below the level should be retired. In the future, the penetration rate of clinker sintering and intelligent energy-saving technologies will increase from the current 30%–40% to over 90%. The plan issued by MIIT and three other ministries and commissions in July 2022 states that by 2030, the building materials industry should significantly increase the level of fuel substitution and make breakthroughs in low-carbon technologies, including hydrogen calcination. Thus, the initial promotion of biomass and solid-waste fuels as alternative fuels is expected to be the next step to gradually reduce the industry's dependence on coal. By 2030, about 5% of the thermal energy used in cement production will be generated by solid-waste fuels, and hydrogen and electricity technologies will be developed. CCUS technology will enter the development and demonstration phase, and by 2030 it will be able to capture approximately 2% of cement production carbon emissions.

Medium term (2030–40): Demand reduction, alternative fuels, and CCUS will combine to promote emissions reduction in the cement industry. During this period, energy-saving technologies will play a minor role in decarbonization since the penetration of energy-saving technologies may almost cover all production lines, except that further promotion is still needed in some areas with unbalanced development. Thanks to the standardization and commercialization of waste collection, along with sorting and preprocessing, solid-waste fuels will be largely mass-produced by 2040, replacing about 15% of the thermal value of fuels. Hydrogen and electricity-to-cement technologies will be piloted and demonstrated, replacing about 2% of the thermal value of cement in some new kilns. CCUS technologies will mature and be able to capture about 10% of the carbon emissions from cement production.

Long term (2040–60): Alternative fuels and CCUS will play a larger role in reducing emissions in the cement industry. CCUS and alternative fuels will show strong economic improvement, and zero-carbon cement will demonstrate its cost advantage in combination with the carbon-pricing mechanism. By 2050, 40% of CO_2 emissions from the cement industry can be captured. Innovative technologies such as hydrogen calcination, electric kilns, and LEILAC will be more widely used after 2040. By 2050, solid waste and renewable pathways (using green hydrogen or green power) will replace about 28% and 10% of the thermal value, respectively. In the 2050–60 period, new alternative fuel technologies such as hydrogen and electricity will be mature and commercially available, and CCUS technology will be fully promoted. Solid waste and hydrogen green power will replace 45% and 25% of the thermal value, respectively, while 90% of the CO_2 emissions from the cement industry can be sequestered. Both the net CO_2 emissions of the cement industry and the carbon intensity of cement products will be close to zero.

Petrochemicals and Chemicals Industry

The petrochemicals and chemicals industry is a pillar of the national economy and a major heavy industry. With industrial expansion and improving living standards in recent years, the supply and demand of chemical products have grown rapidly in China. The petrochemicals and chemicals industry emits about 1.3 billion tons of CO_2 per year, accounting for 13% of the total national carbon emissions and 20% of the total industrial carbon emissions.[11] Since this industry offers a wide and complex variety of products, this report analyzes carbon emissions reduction pathways starting with three representative products: ammonia, methanol, and ethylene.

The main challenges to decarbonizing petrochemicals and chemicals lie in emissions reduction of feedstocks and fuels amid rising demand for the industry's products. The production of chemicals in China is highly dependent on fossil fuels. At the same time, as the domestic economy and quality of life improve, total demand for chemical products in China is expected to increase. Production capacity of high-end chemicals will expand to reduce dependence on imports. Therefore, decarbonization of the petrochemicals and chemicals industry will face greater headwinds than decarbonizing industries with declining production.

Decarbonization of the petrochemicals and chemicals industry could be implemented from the supply side and the consumption side. On the supply side, emissions are generated from the reaction process and energy consumption. Besides energy-efficiency improvement, raw material substitution, fuel substitution, and end-treatment technologies such as CCUS promise strong potential for emissions reduction. On the consumption side, the key for emissions reduction is to reduce reliance on energy-intensive products. Additionally, consumption reduction, product restructuring, and resource recycling could be promoted to enhance resource utilization. Looking ahead, energy-saving measures will contribute to a certain amount of emissions reduction, while energy structure adjustment, resource recycling, and end-of-pipe capture and storage will be essential to achieving zero-carbon emissions in this industry.

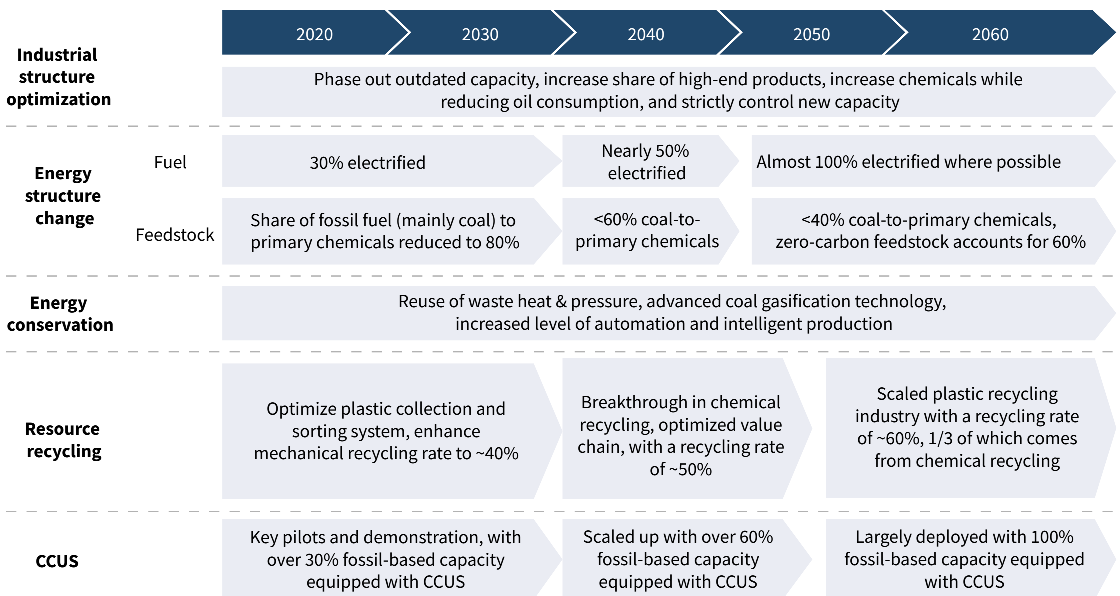
Among the key energy-saving technology options are waste heat and pressure recycling and reuse, distillation system energy-efficiency improvement, and circulating water system optimization. Chinese government directives require that producers of major energy-consuming products reduce their energy intensity. Taking ammonia as an example: energy consumed to produce ammonia has been reduced from 1,460 kg tce/ton in 2005 to 1,264 kg tce/ton in 2020 — a 15% decrease. The further improvement in energy conversion efficiency, waste-heat and pressure recycling and reuse, process heat integration, and other technologies will create greater potential for energy saving and carbon reduction in the petrochemicals and chemicals industry.

Green hydrogen production, storage, and transportation technology can play an important role in emissions reduction in the petrochemicals and chemicals industry. The petrochemicals and chemicals industry is the key downstream consumer of hydrogen. The production of ammonia and methanol, for example, consumes about 60% of the total hydrogen production.[12] Thus, developing green hydrogen offers great potential for emissions reduction in the petrochemicals and chemicals industry. In 2020 in China, hydrogen production based on coal, natural gas, and industrial by-products accounted for 62%, 19%, and 18% of the total, respectively, while green hydrogen made up just 1%.[13] The cost of green hydrogen is still not competitive with hydrogen produced by traditional means. With further reductions in the cost of electrolyzers, improved electrolysis efficiency, and lower electricity cost, green hydrogen will become more cost-competitive and gradually replace fossil-based hydrogen production.

Carbon capture technology can deliver significant advantages when applied in the petrochemicals and chemicals industry for the high concentration of CO_2 being emitted. About 77% of ammonia, for instance, was produced using a coal-based production pathway in 2020, with an emissions level of 4.2 tons CO_2/ton of ammonia.[14] The high concentration of CO_2 reduces the per-unit capture cost due to the lower CO_2 per-unit purification cost and economies of scale. As energy-intensive, high-emissions industries are constrained by carbon pricing, carbon capture technology will not only help limit environmental impacts by companies, it will also provide a source of carbon to replace coal for producing organic chemicals by separating the captured CO_2 from industrial sources for direct utilization.

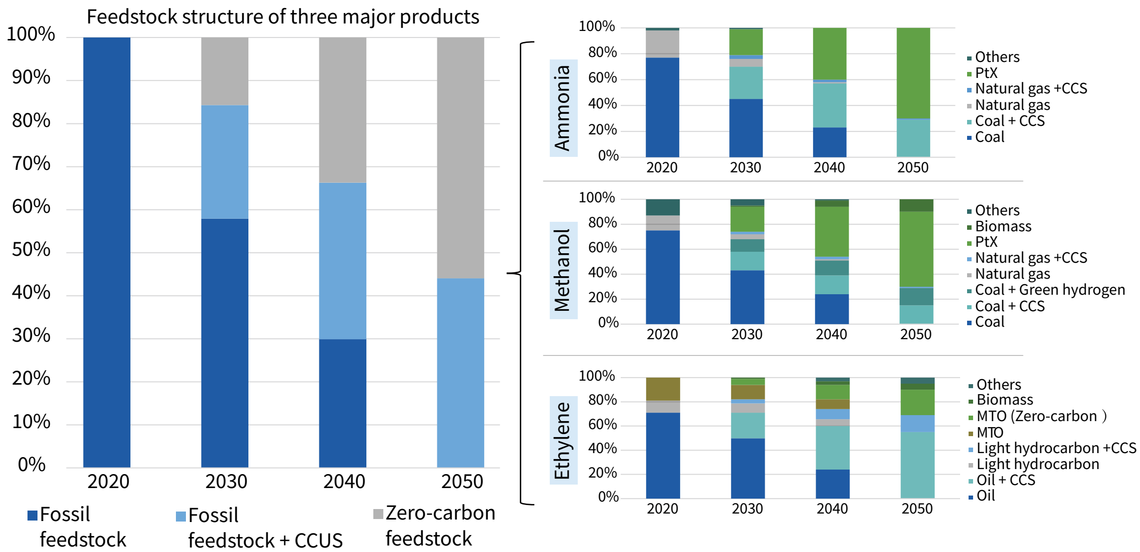
The carbon reduction roadmap for China's petrochemicals and chemicals industry is mapped out in Exhibit 6 and Exhibit 7, based on deployment and development priorities in the short, medium, and long term.

Exhibit 6 Transition Roadmap for China's Petrochemicals and Chemicals Industry



RMI Graphic. Source: RMI, https://rmi.org/insight/transforming-chinas-chemicals-industry/

Exhibit 7 **Changes in Feedstock Structure of the Three Major Products in China's Petrochemicals and Chemicals Industry**



RMI Graphic. Source: RMI, https://rmi.org/insight/transforming-chinas-chemicals-industry/

Near term (2020–30): Carbon reduction in the petrochemicals and chemicals industry focuses on energy-efficiency improvement technologies, the elimination of outdated production capacity, and fostering the evolution and application of breakthrough technologies. The guidelines issued by NDRC in 2022 set advanced development goals for the ammonia, modern coal-chemicals, and ethylene industries. It requires that by 2025, the proportion of capacity above the benchmark level of energy efficiency in ammonia production and coal-to-methanol production should reach 15% and 30%, respectively, while those below the benchmark level should be phased out. The ethylene industry is required to raise the proportion of industry-benchmark capacity to 30% or more while scaling up and enabling lightweight and low-carbon development of raw material structure. The capacities below the benchmark level of energy efficiency should be transformed and upgraded in an orderly manner. Mature technology deployment shall be accelerated, including energy-saving equipment installation, waste-heat and pressure utilization, and energy system optimization. Meanwhile, breakthrough technologies will be fostered through applications and demonstrations, including renewable energy, coupled utilization of green hydrogen, and electrification. Green hydrogen will gradually replace fossil-based hydrogen as the feedstock for petrochemicals and chemicals production. For ammonia and methanol production, the use of green hydrogen as feedstock is expected to reach 20% in 2030. The application of carbon capture is relatively mature in petrochemicals and chemicals, with a penetration rate reaching 20%–30% in ammonia, methanol, and ethylene production by 2030.[15]

Medium term (2030–40): Green hydrogen and carbon capture technologies will become more mature and economical with broad adoption in the petrochemicals and chemicals industry. By 2040, the production pathway for petrochemicals and chemicals is expected to be further decarbonized. Ammonia and methanol produced from green hydrogen will be the optimal choice for new capacity, and is expected to reach a 40% penetration rate.[16] At the same time, ethylene produced from green methanol is expected to achieve small-scale application. The penetration rate of carbon capture technology in ammonia, methanol, and ethylene production will surpass 40%. Energy-efficiency improvement technologies as well as traditional means such as eliminating outdated production capacity will continue to unlock their carbon-reduction potential.

Long term (2040–50): Green hydrogen and carbon capture technologies will further help the petrochemicals and chemicals industry to reach near-zero emissions with an expected penetration rate of about 90%.[17] By 2050, with the retirement of legacy production capacity and the marketization of green hydrogen, the new production capacity in the industry will mainly adopt use of green hydrogen as a feedstock. Green hydrogen-based ammonia and methanol are expected to reach a penetration rate of 70% and 60%, respectively.[18] While some new and existing capacity is still based on fossil fuel, it will also meet carbon reduction targets through installed carbon capture devices. The naphtha- and light hydrocarbon-based pathways in the ethylene industry will also install carbon capture devices and achieve a penetration rate of 70%. Nearly 20% of ethylene production capacity will enable zero-carbon emissions through green methanol coproduction.[19] Process emissions from the petrochemicals and chemicals industry are expected to approach zero by 2050.

Financial Instruments to Support Low-Carbon Transition in Heavy Industry

Capital Demand for Heavy Industry Transition

Steel Industry:
To transition the steel industry, the key technologies that require investment are energy efficiency, low-carbon process routes, and carbon capture. Low-carbon processes mainly require investment in scrap-based electric furnaces, hydrogen-based DRI, and related supporting processes. We estimate the total fixed-asset investment required for the steel industry transition from now to 2050 to be at least RMB 1.6 trillion.[iii]

Energy efficiency is the largest investment area, with a total investment of approximately RMB 530 billion (33%). Energy-efficiency investment is high due to the obsolete capacity retirement and existing equipment upgrading requirements in the short to medium term. In addition, the need for significant short-process capacity increase will make electric furnaces the second-most important technology for low-carbon investment in the steel industry, with a total investment of around $360 billion (23%). Meanwhile, hydrogen-based DRI and carbon capture technologies also require more investment, at around $280 billion (18%) and $230 billion (14%), respectively. The capacity of these two new technology routes will increase steadily, and the relevant shaft furnace equipment and carbon capture equipment have higher per-unit investment cost. In addition, the investment of hydrogen-rich blast furnace and pellet manufacturing is relatively small, at about RMB 100 billion (7%) and RMB 70 billion (5%), respectively. (See Exhibit 8.)

In terms of the time line, steel production capacity variation and the maturity of each technology determine the investment window for the low-carbon transition. From now to 2050, the total demand for investment will first decrease and then increase:

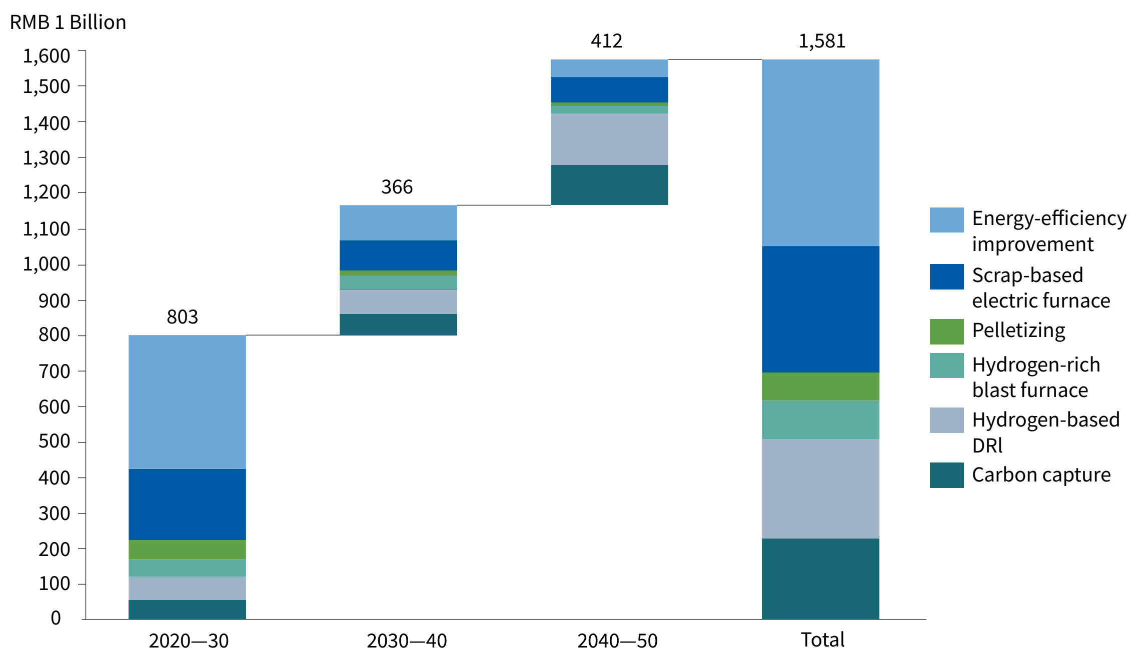
- Near term (2020–30): In this period, energy-efficiency improvements and scrap-based electric furnaces will be the two main investment areas. Energy-efficiency technologies such as waste-heat utilization will drive investment demand by about RMB 380 billion in the next 10 years. At the same time, with the gradual optimization of the scrap recycling system and a steady increase in the amount of scrap available, electric scrap furnace technology will become a main carbon reduction route. Electric furnaces will require an investment of about RMB 200 billion. The investment required for pelletizing and hydrogen-rich blast furnaces will

iii The transition investment estimated in this report includes fixed investments in the technologies needed for each industry to achieve zero carbon, but excludes technology research, operating costs, and investments in rebuilding traditional carbon-intensive production routes (e.g., BF-BOF for steel) after their retirements. The boundaries are aligned with the existing business boundaries of the industry. For example, investments in the steel industry do not include green electricity generation because most steel plants are not directly involved in electricity generation.

mostly beunder the purpose of existing long-process steelmaking's efficiency improvement and carbon reduction. Investment in hydrogen-based DRI and carbon capture at this stage are mainly for early R&D and demonstration.

- Medium term (2030–40): In this period, energy efficiency, scrap-based electric furnaces, hydrogen-based DRI, and carbon capture will be the main areas of investment. Energy-efficiency improvement and scrap-based electric furnaces will decrease in investment demand in the medium term, but still grow by RMB 95 billion and RMB 85 billion, respectively. The hydrogen-based DRI technology will have greatly matured during this period. Switching from gray and by-product hydrogen to green hydrogen will be spurred by carbon emissions reduction requirements. Hydrogen-based DRI is expected to require an investment of at least RMB 68 billion. As carbon capture technology evolves, it will be more readily applied in steel production. Carbon capture will require an investment of nearly RMB 60 billion. Based on current average blast furnace operation life of 12 years and the normal equipment lifetime of about 25 years,[20] China will see a wave of large-scale blast furnace capacity retirements during this period. Therefore, the investment demand for the capacity deployment period of new metallurgical routes will also grow significantly around 2030.
- Long term (2040–50): In this period, hydrogen-based DRI, carbon capture, and scrap-based electric furnace will be the three main investment areas. Hydrogen-based DRI will be mature and commercialized in the steel industry during this period, with an expected investment of RMB 150 billion. Carbon capture technology can be applied to existing young blast furnace assets with high energy-efficiency levels, requiring an investment of RMB 120 billion. The scrap-based short process will further penetrate over the next three decades and become the main production route in the long term. A larger investment of about RMB 70 billion will be required in the 2040–50 period.

Exhibit 8 **Projected Investment in Key Technologies for Carbon Neutrality in China's Steel Industry (Billion RMB)**



RMI Graphic. Source: RMI analysis

Cement Industry:
Key technologies that require large-scale investment for carbon neutrality in the cement industry are energy efficiency, fuel substitution, and CCUS. Considering these technologies only, we estimate that the total investment in fixed assets for carbon-neutral transition of the cement industry from 2020–60 will be at least RMB 800 billion.

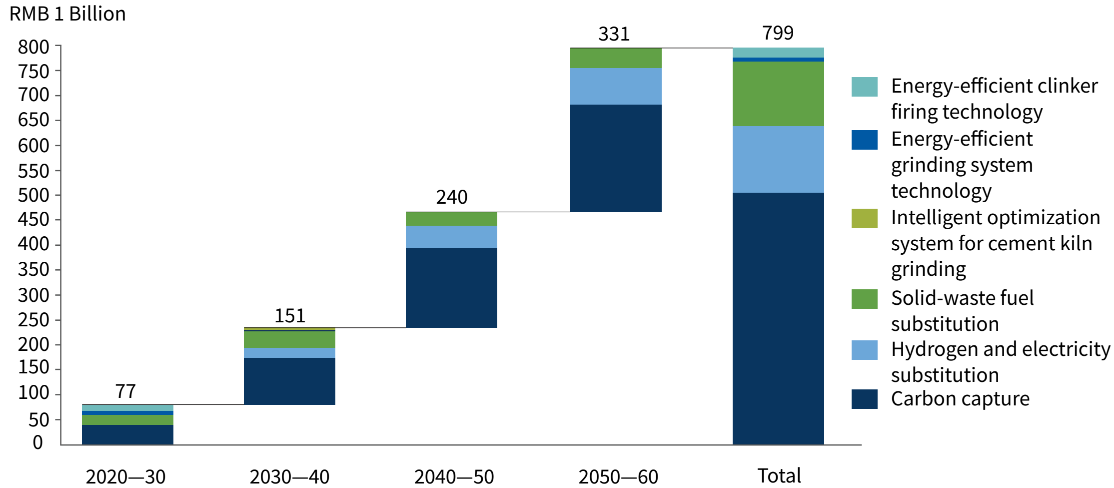
Among the technologies, CCUS requires the largest investment in the cement industry, with a total investment of about RMB 520 billion (64%). This is because carbon capture technology is relatively expensive and the extent of application of CCUS in cement industry is potentially large. Fuel-substitution technology comes second to CCUS, with hydrogen and electric cement kiln requiring an investment of about RMB 140 billion (17%), and solid-waste fuel substitution technology requiring RMB 130 billion (16%). Finally, energy-saving technology requires investment of about RMB 22 billion (~3%). (See Exhibit 9.)

In terms of the time line, the investment window of key cement technologies changes with the maturity of technology and cement production capacity, and the total investment amount gradually increases:

- Near term (2020–30): During this period, energy-saving technology, solid-waste fuel substitution, and early CCUS technology will be the key investment areas. As China increases and implements initiatives to enable the cement industry to meet energy-efficiency standards, energy-saving technology will become a key investment target, requiring an investment of about RMB 20 billion. At the same time, as the cost of fuel from traditional sources rises along with pressure to make a green transition, cement companies will be motivated to replace coal with waste derivatives and biomass materials before 2030. In addition, facility retrofit for solid-waste fuel substitution can be based on the existing technology, with an expected investment of about RMB 20 billion. The current pilot and demonstration of CCUS technology will require an investment of about RMB 37 billion in the near future. Meanwhile, in the 2020–30 period, China's cement industry will launch an industry-wide campaign to eliminate substandard production capacity. About 26% of current cement production lines in China have a capacity below 2,500 tons per day, and these small producers will be phased out in this decade.
- Medium term (2030–40): Solid-waste fuel substitution, CCUS, and early hydrogen and electric kiln technology will be the main investment areas. The introduction of new cement production capacity will create demand for new cement production lines using renewable energy sources such as solid-waste fuels and hydrogen and electric kilns. The total investment in fuel substitution technology will be more than RMB 50 billion. At the same time, CCUS technologies will start to be commercialized, and the required investment will further increase to about RMB 95 billion. In addition, dry process cement kilns that were put into operation between 2005 and 2016 will be reaching the end of their 35-year lifespans and will be phased out starting from 2040. During this period, small and medium production lines with capacity of less than 4,000 tons per day will also be retired and the industry will become more concentrated. As a result, a window for new cement production capacity will emerge in the 2030–50 period due to the natural aging of cement equipment and the accelerated phaseout of substandard capacity.
- Long term (2040–60): During this period, investment demand for CCUS and hydrogen and electric furnace technologies will increase significantly. Investment in solid-waste fuel technology will increase steadily. Replacement of aging cement capacity will continue through

2050. With the widespread adoption of CCUS, investment in carbon capture will increase rapidly, with an expected long-term investment of more than RMB 380 billion. Breakthroughs in hydrogen and electric kiln technology will also be commercialized in the cement industry, with a long-term investment of about RMB 120 billion. At the same time, investment in solid-waste fuel substitution technology will continue to grow steadily. Between acquisition of new solid-waste fuel cement kilns and the renovation of some existing kilns, the investment in solid-waste technologies will exceed RMB 70 billion.

Exhibit 9 **Projected Investment in Key Technologies for Carbon Neutrality in China's Cement Industry (Billion RMB)**



RMI Graphic. Source: RMI analysis

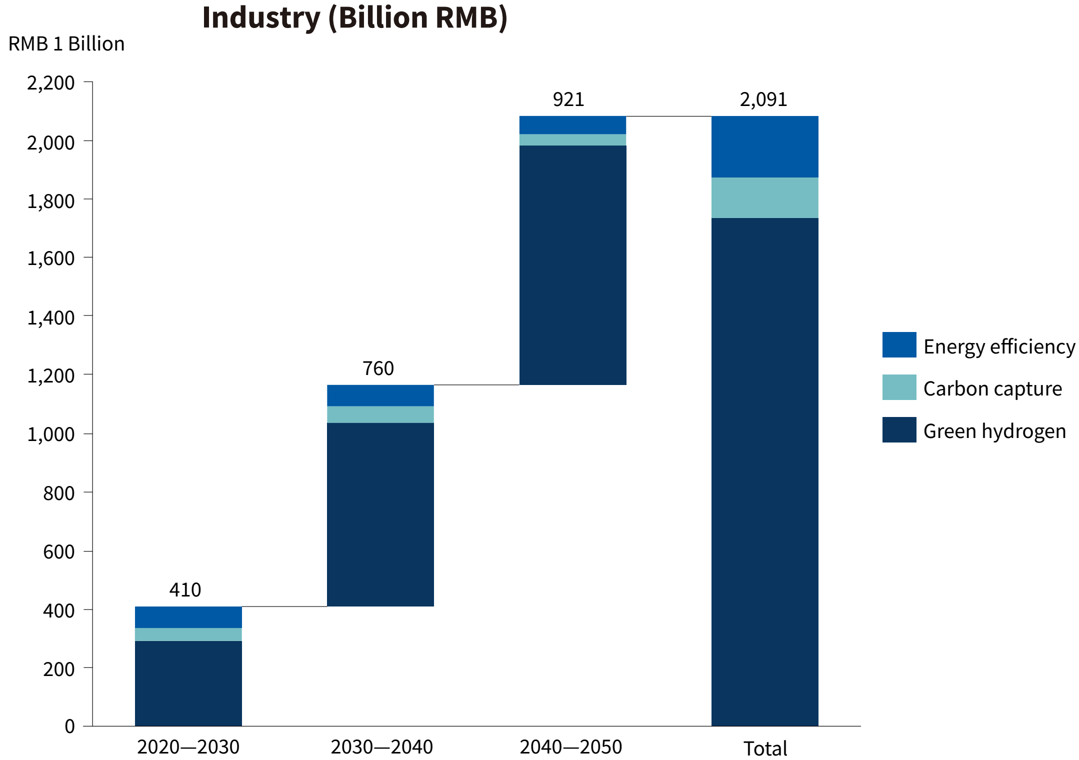
Petrochemicals and Chemicals Industry:
Carbon neutrality in this industry — focusing on ammonia, methanol, and ethylene — will require large-scale investment primarily in the areas of energy efficiency, green hydrogen, and carbon capture. Considering these key technologies only, the total fixed asset investment for the petrochemicals and chemicals industry transition to carbon neutrality from 2020 to 2050 will be at least RMB 2.1 trillion.

Green hydrogen production technology will require the largest fixed asset investment — about RMB 1.7 trillion, or about 83% of the total transition investment of the petrochemicals and chemicals industry. Energy-efficiency technology will require a total investment of about RMB 200 billion, or about 10% of the total transition investment amount. The total investment in carbon capture technology is relatively low for the petrochemicals and chemicals industry for two reasons. First, high concentrations of emitted CO_2 lower the capture cost. Second, emissions from the production processes will decline significantly due to wide adoption of green hydrogen. Therefore, total investment required for carbon capture technology is expected to be about RMB 140 billion, or 7% of the total. (See Exhibit 10.)

In terms of time line, investment in carbon neutral transition of the petrochemicals and chemicals industry in the near, medium, and long term mainly focuses on green hydrogen technology with rising amount of investment :

- Near term (2020–30): In this period, major investment will flow to green hydrogen technology R&D and upgrade, as well as to energy-efficiency improvement and carbon capture technology. Green hydrogen will require an investment of more than RMB 290 billion as it gradually matures and reduces costs in ammonia and methanol production. The investment needed for energy-efficiency and for carbon capture technology will exceed RMB 70 billion and RMB 40 billion, respectively. The former benefits from its compliance with national policies such as the guidelines for improved energy efficiency, while the latter will start commercialization with pilot projects.
- Medium term (2030–40): In this period, major investment will flow to support green hydrogen technology's broader application. During this period, green hydrogen technology will be ready for large-scale deployment in the industry with the improvement in technology and economics achieved in the previous period. Investment in green hydrogen for ammonia and methanol production is expected to be nearly RMB 630 billion, which doubles the amount to date. Additionally, chemicals producers will continue to deploy energy-efficiency technology. Carbon capture technology will start commercialization within the industry, driving investment past RMB 50 billion.
- Long term (2040–50): In this period, as green hydrogen is fully deployed, the projected investment required will rise by another 30%. Green hydrogen technology will have mature upstream and downstream supply chains, and the investment by the ammonia and methanol industries will reach RMB 820 billion. With the advancement of energy-saving devices and technologies, technological transformation can further unlock emissions reduction potential — with an anticipated long-term investment of more than RMB 60 billion yuan. The penetration of green hydrogen technology and the reduction of process emissions will reduce investment requirements for carbon capture devices to about RMB 40 billion.

Exhibit 10 **Projected Investment in Key Technologies for Carbon Neutrality in China's Petrochemical and Chemicals Industry (Billion RMB)**



RMI Graphic. Source: RMI analysis

Features of Capital Demand for Heavy Industry Transition

The low-carbon transition of heavy industry companies is driven by various internal and external pressures. Different transitional drivers influence corporate planning of transitional technology pathways, which in turn determine the corporate capital demand for transition. Although there are differences between transition pathways of companies in different heavy industries, their driving forces are similar and can be categorized into four main types: technology-driven, supply chain–driven, policy-driven, and reputation-driven.

- Technology-driven: Companies are motivated to choose low-carbon technology as the cost of these technologies declines, making traditional high-carbon emissions technology less economically attractive. Energy-efficiency technologies have become mature and economically viable, leading to a strong willingness among enterprises to adopt them voluntarily. Other emerging technologies, on the other hand, are mostly at the prototype and demonstration stages and have not yet achieved economic viability.
- Supply chain–driven: Companies are prompted to make a low-carbon transition due to changes in external supply and demand as a result of low-carbon transitions in upstream and downstream companies or changes in consumer preferences. For example, if an auto company seeks to reduce its Scope 3 emissions through supply chain management, and in doing so purchases large amounts of low-emissions green steel, the market for steel produced by traditional processes will shrink, prompting steel companies to adopt more energy-efficient processes.
- Policy-driven: The government issues policies to increase costs for traditional energy-intensive production while supporting new low-carbon emissions technologies, creating pressure for enterprises to transition to low-carbon production. National policies for companies include mandatory and incentive policies. Mandatory policies include enacting laws, setting standards, and enforcing phaseouts (for example, closure and phaseout of steel companies that fail to meet environmental or energy consumption standards). These policies are mainly designed to guide companies to adopt mature emissions reduction technologies, such as energy efficiency. Economic incentive policies — such as carbon emissions trading, loan preferences for transitional technologies, and subsidies for companies that demonstrate new technologies — help steer companies toward low-carbon production modes. These policies facilitate the adoption of a more diverse range of emissions reduction technologies by companies.
- Reputation-driven: Companies make low-carbon transitions to improve their reputations. Widely recognized as high polluters and high emitters, heavy industry companies can improve their social image and thus gain potential benefits by adopting emissions reduction technology.

While all companies are influenced by the four drivers, their impacts vary. In general, heavy industry companies are mainly driven by technology and policy at present, with the potential for supply chain and reputational factors to become more important in the future. Under the influence of technology-driven and mandatory policy-driven forces, there are significant differences in the funding requirements for various types of carbon reduction technologies in heavy industry.

In its effort to reduce carbon emissions, heavy industry priorities are: energy efficiency, recycling, electrification, green hydrogen, biomass, CCUS, carbon sinks, and new processes. Based on a comprehensive evaluation of the technical feasibility, cost-effectiveness, and resource availability of each of these priorities, Exhibit 11 illustrates their importance to carbon reduction in different heavy industries. This analysis reveals that for each of these priorities, it is necessary to identify the industries with the greatest potential for application, directing the flow of capital and policy support to the prioritized application scenarios. For each individual industry, it is necessary to identify the priorities with the greatest potential for carbon reduction — planning in advance and actively attracting investment.

Exhibit 11 **Seven Priorities for Carbon Reduction in Four Major Heavy industries**

	Energy efficiency	Recycling	Zero-carbon electrification	Green hydrogen	Biomass	CCUS	New processes*
Steel	• Waste heat and pressure utilization (coke oven rising tube waste heat, etc.) • Gas power generation, productization, and recycling technologies • Energy control refinement technology	Scrap recycling: • Recycled steel/electric furnace steel from scrap	Energy substitution: • Short-process electric furnace steel New processes: • Direct electrolytic ironmaking	As reducing agent and fuel: • Hydrogen-enriched smelting in blast furnace • Direct iron reduction • Hydrogen plasma smelting reduction	As reducing agent and fuel: • Limited resources, prioritized for use in areas where no other zero-carbon alternatives are available.	Treatment of carbon emissions from the existing blast furnace-converter pathway	Ironmaking by direct electrolysis
Cement	• Energy-efficient calcination technology • Energy-efficient grinding system technology • Digitalization technology	Cement and concrete recycling	Electric cement kiln technology	Hydrogen-based calcination	• Alternative biomass fuel • Alternative solid waste fuel	• Liquid chemisorption • Second-generation oxygen-enriched combustion • Integrated calcium cycle • LEILAC • CO_2-mineralized concrete technology	New cement products
Petrochemicals and Chemicals	• Waste-heat recycling • Construction of energy efficiency management system • Promotion of energy-efficient technology applications	• Recycling of waste plastics • Industrial waste-gas recycling as raw material	Electrical-heating steam cracking technology	• Provision of heat sources • Feedstock substitution	• Feedstock: Bio-based degradable materials and biofuels • Fuel: Heating	CO_2 recycling: • As raw material for chemicals • CCUS enhanced oil recovery	Methane-cracking hydrogen production technology
Electrolytic Aluminum	• System optimization: using computers to ensure a stable and continuous production process • Electrolyzer optimization • Wetted cathode: Reduce power consumption by decreasing the pole pitch and voltage	Recycled aluminum: Aluminum scrap as raw material for re-melting and refinement	Current technology uses electricity; indirect emissions from electricity use can be reduced if the share of green electricity is increased in the future	Electrolytic aluminum production mostly consumes electricity; no hydrogen substitution is found	Electrolytic aluminum production mostly consumes electricity; no biomass substitution is found	Treatment of emissions from electrolytic process using carbon anodes; very few CCUS projects for aluminum at present	Inert anode

NA | Low potential | Moderate potential | High potential

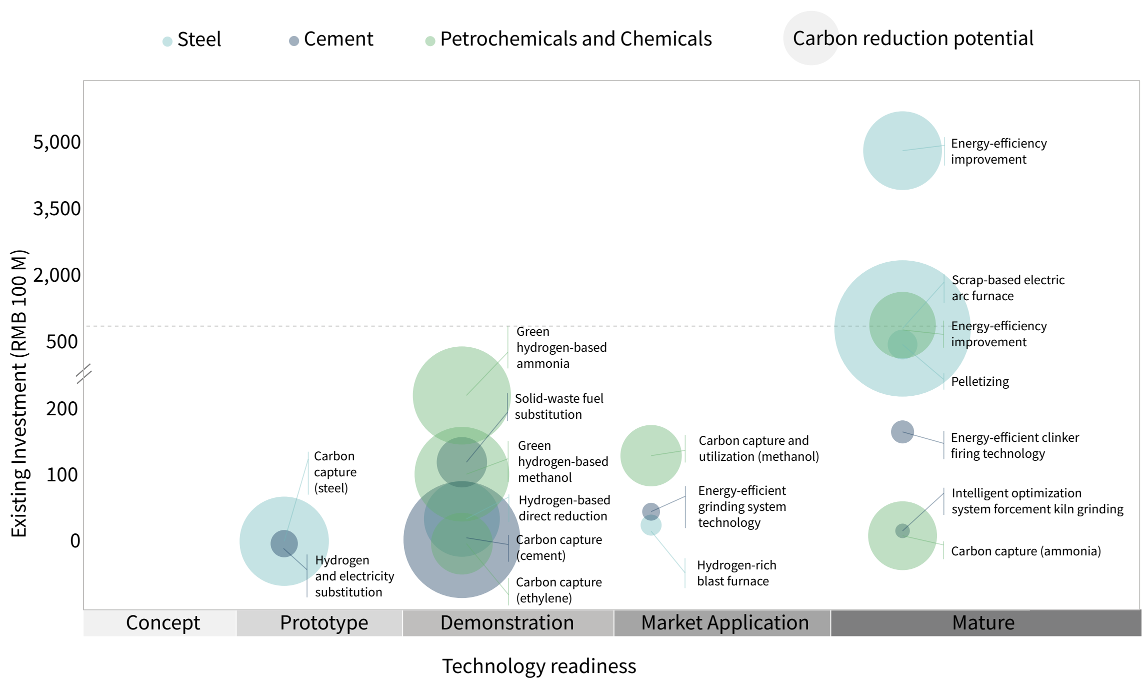
*Some emerging technologies are still in early stages and the potential is difficult to evaluate

RMI Graphic. Source: RMI analysis

At present, investment in carbon reduction technologies in heavy industry is strongly biased toward mature and economically viable technologies. However, most of the emissions reduction technologies in major heavy industries are at the prototyping and demonstration phase; few of them are mature and applied in the market. New technologies — including zero-carbon electrification, green hydrogen, biomass, CCUS, and new production processes — are generally immature, while mature technologies include energy-efficiency and recycling technologies. Exhibit 12 shows that mature technologies have received more investment, while early-stage technologies are still insufficiently funded — an indication of how financial institutions view the technology risk and return risk. Currently, more than 90% of low-carbon investments in heavy industry are brought to mature technologies. Investments of RMB 50 billion or more are all in technologies considered mature, while the largest investment for early-stage technology is only about RMB 20 billion.

It is worth noting that technology in the early stage that shows the potential for transformative carbon reduction in the future should receive more attention from investors. Through our analysis of the technological maturity, carbon reduction potential, and scale of existing investment of nearly 20 technology pathways in the three major heavy industries — steel, cement, and petrochemicals and chemicals — we found that technologies in the demonstration and earlier stage can deliver nearly 60% of the carbon reduction potential but have only received about 6% of the investment (see Exhibit 12). Mature technologies, by contrast, contribute less than 40% of the carbon reduction potential, but have received over 90% of the investment.

Exhibit 12 Carbon Reduction Potential, Technology Maturity, and Scale of Existing Investment of Industrial Decarbonization Technologies



RMI Graphic. Source: RMI analysis

Technologies with a higher degree of maturity, such as energy efficiency and recycling, have lower costs and better returns, so companies are highly motivated to invest in them — leading to a large demand for capital. As the cost and benefit of mature technologies are clear and the payback period is shorter, companies have lower debt risk, so they can accept funds with higher interest rates and shorter terms. In terms of the speed of funding, since the project is usually small with short preparation periods, companies prefer financing modes with lower thresholds and faster fund acquisition. Therefore, suitable funding sources for mature technologies include self-investment, bank loans, and contract energy management.

Technologies such as electrification, green hydrogen, biomass, and CCUS are not yet mature. As key technologies for mid- to long-term carbon reduction, these technologies still have high costs and long payback periods and are currently not subject to mandatory national policy requirements. Deploying them at scale is challenging from a cost-benefit perspective. However, considering their large emissions reduction potential and long-term strategic significance, companies are willing to deploy a small number of demonstration pilots at present to test their feasibility. Projects involving emerging technologies are typically large scale with significant funding requirements. In terms of debt risk, as emerging technologies involve more uncertainty, longer payback periods and higher debt-servicing risks, companies intend to choose financing tools with weak constraints, high flexibility, lower interest rates, and longer terms. Due to the longer project preparation period, companies may choose financing tools with higher investment thresholds and slower funding. So, proper corporate financing modes for new technologies include corporate bonds and equity financing. The details are summarized in Exhibit 13.

Exhibit 13 **Features of Capital Demand for Heavy Industry Transition**

Low-Carbon Transition Technology	Examples	Features	Financing Preference of Companies	Financing Approaches/ Modes
Mature technologies	Energy efficiency improvement, recycling…	Shorter payback period and lower debt risk enable companies to accept funds with higher interest rates and shorter terms	Companies prefer financing modes with lower thresholds and faster access to funds	Company self-investment, bank loan, contract-based energy management
Immature technologies	Electrification, green hydrogen, biomass, CCUS…	Higher potential for emissions reduction, new technology projects are large in scale with high up-front investment	Companies prefer weak constraints, high flexibility, lower interest rates, longer-term financing modes	Corporate bonds, equity financing

RMI Graphic. Source: RMI analysis

Currently, China’s green financial system has been basically established. Funding channels for the transition of heavy industrial enterprises have become more diverse, gradually expanding to include green loans, energy-efficiency loans, green bonds, and so on. However, the existing financing channels still have a relatively narrow coverage, with some carbon reduction technologies not included in the financing catalog. Additionally, while certain technologies are included in the catalog, they have not yet been deployed in the market (see Exhibit 14).

Exhibit 14 **Carbon Reduction Technology, Financing Channels, and Practical Cases of Heavy Industry Companies**

Carbon Reduction Technology	Financing Channels	Practical Cases
Energy efficiency	Rich financing channels, including energy-efficiency loans, green loans, green bonds, and contract-based energy management, with many relevant examples in the market.	Industrial Bank of China and the International Finance Corporation have collaborated on energy-efficiency financing projects to support retrofit projects that make a significant contribution to energy efficiency improvement and the reduction of greenhouse gases. Projects include waste-heat power generation of cement, waste-heat utilization of coke oven gas, waste-pressure power generation of blast furnace gas, energy-saving retrofit of industrial production lines, and comprehensive utilization of waste-heat recovery. At present, five credit financing solutions are available: direct loans for enterprise retrofits, energy management contracts, buyer credit for equipment suppliers, ramp-up for equipment suppliers, and financial leasing.
Recycling	Rich financing channels, including green loans and green bonds, with many relevant examples in the market	Hebei Iron and Steel Group issued three-year green medium-term notes for the procurement of scrap to recycle 573,200 tons of scrap steel, reduce 80,200 tons of CO_2 emissions, and save 153,000 tons of standard coal and 802,500 tons of water.
Electrification	Not included in the scope of green loans and green bonds. However, some provinces have removed electrification projects from the catalog of high energy consumption and high-emission projects.	Documents related to the "dual high" — high energy consumption and high emissions — issued by Jiangxi, Sichuan, and Henan provinces clarifies that short-process steelmaking in electric furnaces is no longer included in under the "dual highs."
Green hydrogen	Green credit and green bonds include "construction and operation of hydrogen energy utilization facilities," but projects are mainly concentrated in the transportation sector. No relevant financing cases have been found in the heavy industrial sectors yet.	NA
Biomass	Green credit and green bonds include "construction and operation of biomass energy utilization facilities," but no relevant financing cases have been found in the heavy industrial sectors.	NA
CCUS	Added to the *Green Bond Endorsed Projects Catalogue (2021 Edition)*, but no relevant financing cases have been found in the heavy industrial sectors.	NA
New processes	Excluded from the scope of green credit and green bond support.	NA

RMI Graphic. Source: RMI analysis

Existing Financial Guidance and Instruments

Enabling low-carbon transition in heavy industry companies requires large-scale financial support for investment and maintenance of infrastructure for low-carbon or zero-carbon production, decommissioning of legacy equipment, transforming business models, and ensuring a just transition. *The current Green Bond Endorsed Projects Catalogue* includes only a small portion of economic activities in high-carbon emitting industries, reflecting an insufficient focus on the targeted transition of heavy industry enterprises. However, emerging financial standards and tools provide new avenues for low-carbon transformation financing. Chinese regulators and market authorities have been actively exploring transition finance frameworks, standards, and market product mechanisms, and piloted the issuance of sustainability-linked bonds in 2021 and transitional bonds in 2022. Currently, the People's Bank of China is leading the development of China's transition finance framework, which is expected to provide further guidance for the transition in steel, power, construction, and agriculture.

Transition finance has gained global attention worldwide with an increasing number of countries and regions seeing their market regulatory agencies embark on the formulation of definitions, frameworks, classification schemes, assessment principles, disclosure requirements, and industry standards for transition finance. In November 2022, the International Platform on Sustainable Finance released a report on transition finance, stating that transition finance can encourage financing at different economic levels (including economic activities, entities, and portfolios). It provides insights for the development of the transition finance market.[21] The G20 Transition Finance Framework was introduced in the G20 Sustainable Finance Report in 2022,[22] setting principles such as quantifiability, verifiability, substantial contribution, avoidance of long-term GHG intensive lock-in, do no significant harm, and just transition. This framework aims to establish preliminary guidelines globally, guiding financial regulatory authorities in establishing policies for transition finance and promoting financial support for the low-carbon transition of high-carbon emissions industries worldwide.

International industry bodies such as the Climate Bonds Initiative (CBI) and the International Capital Market Association (ICMA) launched frameworks and basic principles for transition finance in 2020, driving financing for the low-carbon transition of high-carbon emitting industries to address climate change (see Exhibit 15). ICMA highlights that transition finance is applicable to business entities, and that companies that have set their emissions reduction pathways can be financed through instruments linked to key performance indicators (KPIs). The CBI's transition finance framework includes both project- and entity-level transitions with industry-specific transition standards. Notably, individual assets or projects can hardly influence company-wide low-carbon transition.[23] Market players thus need to develop short-, medium-, and long-term transition plans that focus on industry-specific transition pathways and technology features to minimize stranded assets and avoid carbon lock-in.

Exhibit 15 **Guidelines on Transition Finance**

	CBI	Science-Based Targets Initiative (SBTi)	Transition Pathway Initiative
Long-term target	Net-zero emissions by 2050	Net-zero emissions by 2050	Net-zero emissions by 2050
Medium-term target	2030 target and 3- to 5-year target	5- to 10-year target*	-
Pathway	1.5°C	1.5°C**	1.5°C, 2°C, and Paris Agreement commitments
GHG emissions scope	Scopes 1, 2, and 3 Scopes 1, 2, and 3 of the corresponding industry are specified in the industry-specific standards.	Scopes 1, 2, and 3 A company target should include Scope 3 emissions if they account for at least 40% of total emissions (i.e., Scope 1, 2, and 3 emissions). Near-term target must cover at least 67% of Scope 3 emissions. For upstream Scope 3 emissions from high-emitting industries, companies should review relevant industry guidelines to understand when it is appropriate to set absolute or intensity targets.	Scopes 1, 2, and 3 Scope 3 covers downstream emissions and does not cover supply chains.
Features	Pre-issuance, post-issuance, and ongoing certification of eligible debt instruments (project and entity level).	Provide guidance, standards, and recommendations to support companies in setting net-zero emissions targets aligned with climate science.	Assess and track the progress of the company's governance and management of GHG emissions as well as the risks and opportunities associated with the low-carbon transition.

*Refers to the near-term target in SBTi.

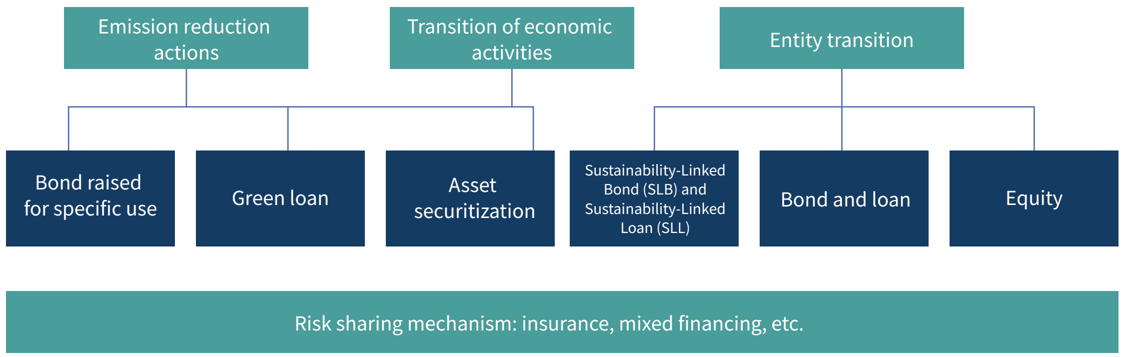
**Since July 15, 2022, SBTi will only validate Scope 1 and Scope 2 targets that are consistent with 1.5°C.[24]

RMI Graphic. Source: CBI

The evolution of financial standards and instruments offer access to multiple sources of financing for heavy industry companies. Different types of financing instruments can meet the needs of different transition levels in concept and scope. For example, investors can support project-level emissions reduction measures, including heat recovery, equipment optimization, monitoring and control-system optimization, and CCUS through instruments that restrict the use of funds. Investors can also support entity-level transitions in heavy industry through equity, and loans and bonds that do not restrict the use of funds (see Exhibits 16 and 17).

According to a 2022 study by the Organization for Economic Cooperation and Development, most respondents identified debt instruments as an important tool for transition finance. Half identified bonds, loans, blended finance, or public–private partnership mechanisms as the most used tools, followed by project finance (13%) and investment funds (10%). Only 13% of the responses were related to equity instruments, 8% indicated that private equity and venture capital would be deployed the most, and 5% mentioned listed equities, according to the report. The remaining 5% chose insurance products. Because many of China's heavy industry companies are highly leveraged, some experts believe that the transition finance market in China should develop equity products that are tailored to support the effective transition of such companies. In addition, the low-carbon transition of heavy industry companies requires changes in business models, including greater innovation and cooperation with startups, making their own venture capital investments, introducing equity investments in the long term or low-carbon business models by means of merger and acquisition (M&A).

Exhibit 16 Transition Finance Supports Low-Carbon Transition in Heavy Industry



RMI Graphic. Source: CBI

Exhibit 17 Financial Instruments to Support Financing for Low-Carbon Transition at Different Levels

Levels of transition activity	Scenarios for transition finance tools	Examples of transition finance tools or mechanisms
Industry level	Guidance on sectoral emissions reduction pathways	Sustainability-Linked Bond (SLB) and Sustainability-Linked Loan (SLL), equity
Economic activity level	Support the promotion of single or multiple emissions reduction actions	Fund raised for specific use
Entity level	Support corporate-level financing	Sustainability-Linked Bond (SLB) and Sustainability-Linked Loan (SLL), equity
Portfolio level	Support portfolio development toward net-zero financial markets	Transition fund
Action level	Support the transition of single or multiple emissions reduction actions	Fund raised for specific use

RMI Graphic. Source: CBI

Overview of Transition Finance Debt Instruments and Financing Cases for Heavy Industry Companies

The bond market is the most dynamic and sizable financial tool in today's evolving financial scene. And with the high level of transparency in information pertaining to bond issuers, supporting projects and associated financial products' transformation initiatives, emissions reduction goals, interest rates, maturity, and crucial performance indicators, this chapter concentrates on prevailing trends and factors linked to transformation within the bond issuance sphere. The objective is to offer insights for the design of products associated with transformation and the advancement of the transforming financial market.

Global landscape of transition-related debt instruments for heavy industry companies

According to the CBI database, as of June 30, 2023, 50 sustainability-linked bonds (SLBs) were issued by the global steel, cement, and petrochemicals and chemicals industries, totaling $16.5 billion. Of these bonds, 14 have been certified by Science-Based Targets Initiative for their GHG targets, and 31 bonds (62%) have chosen GHG emissions as KPIs, suggesting the interest of financial market players in GHG emissions reduction.

SLBs and transition bonds are the main transition-related labeled debt instruments currently available in the market. SLBs are the dominant financing mode at this stage, while the issuance of transition bonds, which restrict the use of the funds raised, is small in scale. This may be a result of the limited market guidance on the transition funds raised and the higher flexibility provided by sustainability-linked financing instruments for high-carbon emitting industries.

SLBs are forward-looking instruments that provide an excellent financing opportunity for heavy industry by not restricting the use of the funds. By allowing issuers to select KPIs that are aligned with their sustainability strategies, they enable issuers to finance sustainable business models and corporate transitions rather than specific projects such as solar power plants or green buildings. In addition, research shows that demand for high-quality SLBs is strong, and investors are willing to support a wide variety of issuers in achieving net-zero carbon targets. This means that issuing SLBs with GHG mitigation performance can help issuers access cheaper financing.[25]

In terms of low-carbon transition initiatives and financing, companies should set net-zero emissions targets and choose an emissions reduction pathway that is aligned with their industry. Based on the net-zero target, they should plan short-, medium-, and long-term initiatives, select KPIs, and finance these emissions reduction initiatives. Issuers typically use existing sustainability, transition, and environmental, social, and corporate governance (ESG) strategies and targets, such as sustainability performance targets (SPTs) and KPIs, to demonstrate to investors their commitment and dedication to the strategy. Investors can influence or increase the SPT selected by the issuer, and if the transition KPIs are not met, they can increase the amount of interest charged on the debt (e.g., from 10 bp to 25 bp).

Transition-related debt instruments for China's heavy industry companies

China's SLBs and transition bonds were piloted in 2021 and 2022, respectively. By the end of 2022, the total issuance of various types of labeled transition bonds in China's domestic market was RMB 117.22 billion, including RMB 87.2 billion in SLBs, RMB 22.39 billion in low-carbon transition-linked bonds, RMB 2.7 billion in low-carbon transition bonds, and RMB 4.93 billion in transition bonds.[26] China's steel, cement, and chemicals companies have issued SLBs and transition bonds. The steel industry has issued most among the heavy industries — $1.28 billion in SLBs and $250 million in transition bonds.

The KPIs for SLBs vary, and most of them are not yet linked to GHG-related indicators. One exception is Huaxin Cement, which has raised RMB 900 million ($133.1 million) through two bond offerings.[27] It is the first GHG-linked SLB in the domestic market, with a target of reducing carbon emissions per unit of clinker to 829.63 kgCO_2/t by the end of 2024. This bond will help boost the nascent SLB market in China and set a good example by selecting GHG emissions as a linked KPI. The remaining transition-related debt instruments from domestic sources have not yet done this. While SLBs can be linked to different KPIs to support movement toward corporate sustainability, GHG emissions–related indicators are useful for investors and regulators to compare the issuer's emissions reduction progress with its historic reduction effort and its peer companies, as well as to assess whether the company's transition is aligned with the 1.5°C target. Therefore, we suggest that issuers select GHG-related KPIs for transition financing.

Existing domestic transition-related bonds typically have a maturity of 3–5 years, while international bonds have a maturity of 5–10 years. Several international SLBs have a 10-year maturity. For example, the Swiss cement company Holcim issued an SLB in 2022 that will mature in 2032, with a sustainability performance target of reducing its Scope 1 emissions per ton of cement to 475 kg or less by December 2030.[28] The low-carbon transition is a long journey. Fixed-asset investment and transition projects require large amounts of capital and long construction cycles, and financial instruments with long maturities can provide favorable financing for low-carbon transition in heavy industry. We suggest that financial institutions design financial products that better meet the demands of heavy industry transition.

Cases of Transition Financing for Heavy Industry Companies

Case 1: Equity and Debt Instruments at H2 Green Steel in Sweden

H2 Green Steel, a company that produces steel based on green hydrogen and green electricity, has a production model that reduces CO_2 emissions by 95% compared with traditional coal-dependent steelmaking processes.[29] The company financed its hydrogen-powered green steel plant in northern Sweden through a combination of equity and debt financing.

By March 2023, H2 Green Steel has secured €3.5 billion in debt financing from major European financial institutions, backed by financial institutions through debt and credit guarantees.[30] H2 Green Steel presold 60% of the 2.5 Mt/year capacity in Phase I of the project to customers such as BMW and Miele.[31] As collateral for the bank, this order raised two-thirds of the project funding, with the rest coming from equity investment from prominent venture capital firms. Auto companies such as Scania and Mercedes-Benz also took a stake in H2 Green Steel in 2021.[32]

Case 2: SLBs of Huaxin Cement

Huaxin Cement issued two SLBs totaling RMB 900 million in July 2022, aiming to reduce carbon emissions per unit of clinker to 829.63 $kgCO_2/t$ by the end of 2024. It linked the coupon rate in the last interest-bearing year of the base term to the degree that it achieves its target.[33] If the target is not achieved, the coupon rate will be adjusted upward by 10 bp.

According to Huaxin Cement's 2021 ESG report, its direct GHG emissions intensity (Scope 1) was 0.8198 tCO_2e per ton of clinker, and its indirect GHG emissions intensity (Scope 2) was 0.026 tCO_2e per ton of clinker.[34] The company has been recognized by the market for innovative financing with issuance of the first SLBs linked to GHG emissions in China.

Next Steps

A zero-carbon transition in heavy industry requires not only technological upgrading and transformation at the project level, but also steering traditional investments in the industry toward transition and upgrading. The large capital requirements of the transition call for effective financial guarantees. It will be necessary to leverage the development of green finance and seize the opportunity of developing transition finance, effectively promoting the concept of Green+ Transition finance to provide the necessary financial support for heavy industry's low-carbon transition.

Further Unlocking the Potential of the Green Finance Market

After years of development, green finance has become an important driver to support low-carbon transition. However, so far green finance has provided limited support to heavy industry for two reasons. First, the mechanism itself is limited by the definition of green and is not inclusive of heavy industry. Second, many heavy industry companies, given their high emissions, also lack the incentive to explore green financing mechanisms. But it is not impossible for heavy industry to benefit from green finance. As long as appropriate strategies and actions are taken, heavy industry companies can also be supported by green financing to accelerate their low-carbon transition.

First, existing green credit and bond financing instruments should be extensively used for projects in the transition process. As green finance grows in China, green finance products in the banking industry are also expanding. Banks are providing support to green industries and green projects through credit and financial services. Green bonds also provide financing opportunities for some projects. Counting green bonds under CBI's definition, China became the world's largest green bond issuance market in 2022.[35] At the same time, green bonds have the advantages of low cost, long maturity, marketization, and internationalization.[36] As mentioned above, at the project level, pure green technologies such as solar photovoltaics, green hydrogen, and CCUS have already been added to some of the industry catalogs of green bonds and green credits. Heavy industry companies can rely on these supporting catalogs to tap the potential of green bonds or green credits to boost the low-carbon transition.

Second, improve the quality of information disclosure to attract more sustainable/ESG investments. Some sustainable investment and ESG strategies exclude high-carbon emitting industries. Others include relatively well-performing companies in these industries through ratings or strengthen cooperation with companies to promote the establishment of carbon-management mechanisms and decarbonization. In general, the rating system and investment decisions related to sustainability and ESG rely on high-quality information disclosure. Therefore, heavy industry companies should improve the quality of carbon disclosure by disclosing their Scope 1, 2, and 3 GHG emissions in their annual reports, ESG reports, or other public platforms such as official websites. They should also set short-, medium-, and long-term GHG emissions-reduction targets, and implement emissions-reduction measures to gain access to sustainability-related financial products.

In the context of the global carbon market, it is important to enhance the carbon-management capacity of companies and actively pursue carbon financial innovation. The carbon market and carbon tariffs will accelerate the low-carbon transition in heavy industry. The EU Carbon Border

Adjustment Mechanism will cover steel, cement, aluminum, fertilizers, electricity, and hydrogen during the transition period, and the relevant industries will be required to disclose their carbon emissions. After the transition period, imported goods will be subject to carbon tariffs based on the carbon market price in the importing country, which will increase the pressure on some of China's heavy industry companies in their low-carbon transition. In the context of the carbon market and carbon finance, heavy industry companies may strengthen their carbon-management capacity, explore financing opportunities arising from carbon management, and consider switching to low-carbon or zero-carbon production processes to reduce carbon costs.

While heavy industry companies must actively improve their financing capacity, the ability of green finance to support the low-carbon transition for these companies also relies on the efforts of policymakers and financial institutions. The transition in heavy industry requires targeted policy support that helps companies with high decarbonization performance and potential to obtain funding, rather than excluding certain companies due to their sectors. At the same time, emissions reduction and avoidance of carbon lock-in risks should be ensured while increasing the confidence of financial institutions in investing in low-carbon transition. Support mechanisms can include subsidies, green trade initiatives, energy transition mechanisms, and carbon pricing, as well as R&D, investment in key infrastructure, and green public procurement.

Seizing the Opportunity of the Transition Finance Market

Industrial production facilities typically have long lifespans and a slow turnover of capital stock. Therefore, heavy industry will still be locked into high-carbon emitting processes under the new investment cycle if low-carbon investment lags. Transition finance is thus required to capitalize on the transition window in heavy industry, motivating investors to fund low-carbon processes when new investment in production capacity is needed.

At present, the global transition finance market is still in its infancy, and transition financing is not yet widely practiced. At this stage, research on transition goals and paths in the industry is under way, but market consensus is needed. Currently, the targets, paths, and KPIs chosen by companies are varied, making it difficult for investors and regulators to assess the GHG emissions reduction performance. In terms of market guidance and framework development, existing market guidelines for transition finance, SLBs, and loans are not sufficiently detailed. This has heightened capital market concerns about greenwashing and transition-washing. However, in-depth and granular transition frameworks and guidance at the corporate level may be too complex and difficult to implement for some users of the current sustainable finance market.

To seize this window of opportunity of rapid growth in transition finance and ensure that it can support the effective decarbonization of heavy industry in the future, the following issues should be the focus:

First, addressing the mismatch between the capital demand of heavy industry for low-carbon transition and the requirements of financial institutions will require innovative design and adoption of customized financing modes. At present, many heavy industry companies are still unlisted, and their financing is dominated by bank credit. Many high-carbon emitting companies already have high debt ratios. Their bond financing mainly comes from short-term loans of less than one year. Low-carbon transition is a long journey that requires companies to obtain low-cost, long-maturity capital support, so they need to switch from short-term loans to long-term loans, optimize the maturity structure, and gain support for equity financing.[37] In addition, it is difficult to rely on debt instruments alone to support the low-carbon transition in heavy industry, and changing the business model of companies with high carbon emissions requires the support of financial products or industrial investment funds with higher risk tolerance.

Second, the selection of appropriate KPIs for SLBs is crucial to maintain the credibility of the transition finance market. The SLB has become a popular market instrument for financing the low-carbon transition of high-carbon emitters. Globally, the KPIs chosen by SLB issuers vary widely, so it is difficult for investors to assess and track the emissions reduction performance of issuers and bonds, and to assess the credibility of the transition. In addition, issuers often choose KPIs linked to ESG ratings, but due to differences in the methodologies of rating agencies, an improvement in ESG ratings does not effectively reflect GHG emissions reduction by companies. The European Central Bank no longer considers improved ESG ratings or scores as acceptable SPTs when assessing the eligibility of assets as collateral for its credit operations or asset purchase programs.[38] China's steel, cement, and chemicals companies have participated in the issuance of SLBs to finance their low-carbon transition, but only Huaxin Cement has selected indicators directly linked to reduction in GHG emissions. While market guidance on SLBs is still lacking, standardizing SLB-related standards and certifications will help raise investors' confidence and market transparency and further drive robust growth in SLBs.

Finally, the low-carbon transition in heavy industry requires multiparty support and collaboration among upstream, midstream, and downstream industries. The low-carbon transition in heavy industry requires large-scale investment, which is difficult for companies to accomplish on their own. Supporting policies can be applied to the upstream construction of low-carbon energy and infrastructure; the establishment of standards for low-carbon production processes and the rational implementation of carbon pricing in midstream enterprises; and the downstream promotion of market demand for low-carbon steel, cement, and chemical products.

To better support the low-carbon transition in heavy industry while maintaining market credibility and reducing the risk of greenwashing, this report provides the following outlook for the further development of the transition finance market:

- **Transition finance could evolve from the current green finance system and play a strong role in supporting the transition of heavy industry companies.** Because *The Green Bond Endorsed Project Catalogue* does not cover transition technologies, a separate catalog of projects supported by transition finance could be developed to focus investment in transition credits and bonds for heavy industry transition technologies.
- **Transition finance should focus on the dynamic process of gradual realization of carbon reduction targets.** In addition to the catalog of qualified projects, transition finance should also clarify the emissions reduction standards of qualified projects and the paths that companies need to follow. This means greater requirements for companies. They can leverage financial instruments such as sustainability-linked loans, SLBs, ordinary bonds, and equity to finance their company-wide low-carbon transition by setting reasonable transition targets and developing low-carbon transition strategies and plans.

- **Transition finance support for heavy industry transition should capitalize on asset and facility replacement, including incentivizing investment in low-carbon processes when investment is needed for new equipment or facilities.** Industrial production facilities typically have long lifespans, and there is only one window for a round of low-carbon transition investment before 2060. Effective policies should be used to accelerate capital investment in the low-carbon transition in heavy industry.
- **Financial institutions should continue to innovate transition finance products.** At present, transition finance is dominated by debt instruments. However, it is difficult to support the low-carbon transition in heavy industry by relying on debt instruments alone. Technologies such as electrification, green hydrogen, biomass, and CCUS need support from financial products with higher risk tolerance to strategically deepen the low-carbon transition of companies. In addition, development finance institutions can provide startup capital for the transition and bring in private capital. Transition equity investment funds and M&A funds can be set up to support companies' equity financing needs and strategically promote the transition.
- **Financial institutions and regulators should track the transition credibility of invested companies.** Transition finance is designed to help high-carbon emitting industries reach net-zero emissions rather than just guarantee short-term carbon-reduction performance. To facilitate the long-term stability of SLBs, transition bonds and other related market instruments, principles, standards, and categorization schemes that effectively regulate market practices should be introduced. Regulators can introduce voluntary best practice KPIs to help market participants assess the transition credibility of financial products.

Appendix

Sustainability-Linked Bonds and Transition Bonds Issued by Steel, Cement, and Chemicals Companies in China

SLBs							
Issuer	Sector	Volume	Issuance date	Expiry date	Mechanism	KPI type	KPI description
Hongshi Cement	Cement	RMB 300 million	10/05/2021	10/05/2024	Increase in face interest rate by 20 bp	Energy consumption per unit in cement production	80.1 kilogram of coal equivalent (kgce)/t by 2020 (baseline) 77 kgce/t by 2023 (target)
Huaxin Cement	Cement	RMB 450 million	19/07/2022	19/07/2027	Increase in face interest rate by 10 bp	Unit carbon emissions for clinker	829.63 $kgCO_2$/t by the end of 2024 (target)
Anshan Steel	Steel	RMB 2 billion	26/01/2022	26/01/2025	Increase in face interest rate by 10 bp	Energy consumption per ton of steel	584 kgce/t by 2020 (baseline) 565 kgce/t by the end of 2022 (target)
Baoshan Steel	Steel	RMB 5 billion	6/09/2021	6/09/2024	Increase in face interest rate by 10 bp	Nitrogen oxide (NOx) emissions per ton of steel	0.67 kg/ton in 2022 (baseline) 0.63 kg/ton by the end of 2023 (target)
Liuzhou Steel	Steel	RMB 200 million	7/05/2021	7/05/2024	Increase in face interest rate by 50 bp	NOx emissions per unit of product (crude steel)	1.123 kg/ton in 2020 (baseline) 0.935 kg/ton in 2022 (target)
Shandong Steel	Steel	RMB 1 billion	30/08/2021	30/08/2024	Triggering redemption mechanism	Enhancement of production efficiency	604.00 kgce/t in 2020 (baseline) 592.00 kgce/t in 2022 (target) The target has been met.

Transition Bonds					
Issuer	Sector	Volume	Issuance date	Expiry date	Use of proceeds
Wanhua Chemicals	Petro-chemicals and chemicals	RMB 200 million	2022/6/23	2024/6/23	Integrated polyurethane industry chain — ethylene project.
Baoshan Steel	Steel	RMB 500 million	2022/5/24	2025/5/24	Construction of the Baosteel Zhanjiang Iron & Steel Co., Zhanjiang Steel hydrogen-based vertical furnace system (one-step) project.
Panzhihua Steel	Steel	RMB 200 million	2022/7/4	2025/7/4	Project for utilizing waste heat and excess energy for power generation within the steel company, and industrial electrification transformation project.
Shandong Steel	Steel	RMB 1 billion	2022/6/23	Perpetual	Laizhou branch kinetic energy conversion system optimization and upgrade project.

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