Study of CCUS Strategies and Policies in China's Iron/Steel Sector

(Second Annual Report)

Summary Report

National Center for Climate Change Strategy and International Cooperation (NCSC)

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1. Developments in the Iron/Steel Sector: Overview

1.1 Development of the iron/steel sector

On the production side, iron/steel is vital to human social and economic activities and is applied to various sectors such as energy, building, transportation and infrastructure; the development of the iron/steel sector has also been driving human economic and social development. According to World Steel Association (WSA) statistics, in 2017, the global crude steel output in 2017 was 1.69 billion tons, to which China contributed 0.83 billion tons, accounting for roughly a half of the global output. In China, the iron/steel sector is an important pillar of the national economy, which has provided nation building with essential raw materials, propped up economic development in recent years, pushed forward the drive of industrialization and modernization and facilitated social development. Over the past 40 years of reform and opening-up, crude steel production shows a continuous growth trend, strongly supporting China's economic and social development. The crude steel output in 2018 was 29.2 times that in 1978, which was 31.78 million tons, making China the world's largest steel producer for 22 consecutive years. The Metallurgical Industry Planning and Research Institute (MPI) predicts that crude steel output in China will continue to increase in 2019 compared to 2018, (see Fig.1). As China's economy has shifted from high-speed growth to mid-to-high growth, along with the transformation of the development mode, economic restructuring and transition of growth drivers, crude steel consumption and production will present a generally declining trend in the medium and long term, while economic fundamentals remain solid. The iron/steel sector needs to achieve low-carbon development and high-quality supply transformation.

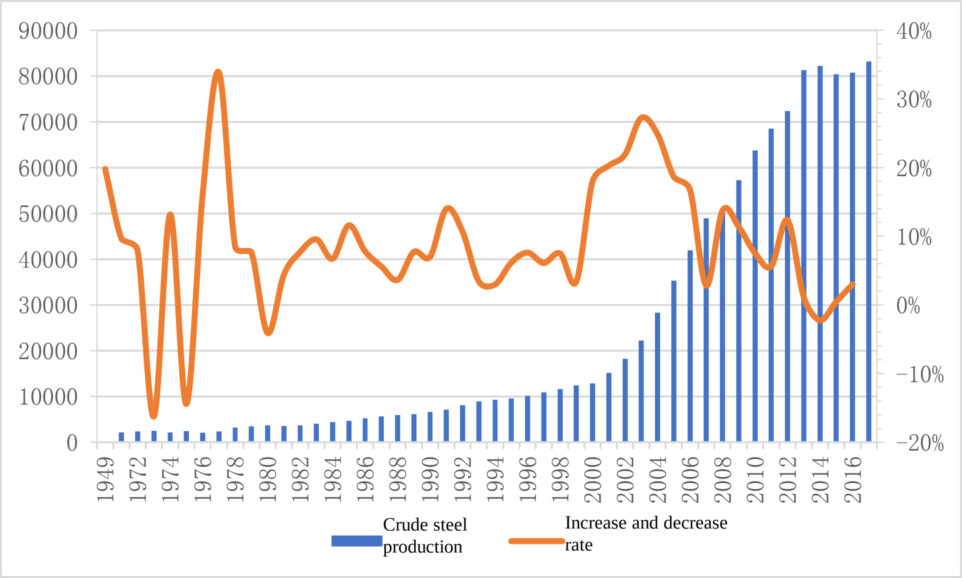

Fig. 1 Crude steel production, production growth rates and GDP growth rates during 1949-2017

Source: China Steel Statistics 2016 and World Steel Association's Steel Statistical Yearbook 2018

On the consumption side, global crude steel consumption data shows that iron/steel consumption presents a growing trend since 2008, except a decline in 2009 due to economic reasons. In terms of per capita consumption, China's per capita consumption in 2015 was 509kg/person, 55% less than Korea (1,155.7kg/person), which ranked No.1.

From the perspective of production capacity and utilization rate, China has unveiled a series of regulatory policies in recent years, intensified policies of eliminating backward production capacity, constantly raised standards for the elimination of backward production capacity and placed strict control over new production capacity. However, as economic growth drives demand, iron/steel production capacity continues to increase while the capacity utilization rate of crude steel shows a declining trend in general, which fell from 83% in 2005 to around 65% in 2015, indicating the overcapacity problem still exists.

1.2 Energy consumption of the iron/steel sector

From the perspective of energy consumption of per unit crude steel product, there is a certain gap between China and world level since 1990, especially when comparing with the EU, Germany, UK, the U.S., Brazil, Japan and Australia. As China stepped up its effort to promote energy conservation and consumption reduction in the iron/steel industry since 2000, energy consumption of per unit crude steel product has started to decline significantly and the comprehensive energy consumption per ton of crude steel in large and medium-sized key steel enterprises dropped from 906kgce/t in 2000 to 605kgce/t in 2010, representing a decrease of 49%. Nevertheless, with shrinking potential for further energy conservation and consumption reduction, the reduction of energy consumption of per unit crude steel product in China has slowed. In 2017, the average comprehensive energy consumption per ton of crude steel in China's key steel enterprises was 570.5kgce/t, decreased by 5.7% compared with 2010. In this regard, China is lagging some way behind developed countries such as the U.S. and UK.

From the perspective of total energy consumption, the iron/steel sector is a major energy consumer, which witnessed a roughly four times increase in the total energy consumption and an increase from 8% to 11% or so in its contribution to the national total energy consumption (calorific value calculation) from 2000 to 2017.

1.3 Carbon emissions of the iron/steel sector

The iron/steel sector is an important pillar of the national economy and also a resource- and energy-intensive industry. China ranks the first in the world by steel production for 14 consecutive years whilst consuming abundant fossil fuels and emitting a great amount of greenhouse gases (GHGs). According to 2018 MPI statistics, carbon emissions from China's iron/steel sector accounted for approximately 51% of the global total emission from iron/steel sector and 15% of the national total carbon emission, ranking second among all industries emission throughout China. According to *China Statistical Yearbook*, China's iron/steel output increased twelve times from 1995 to 2015, while the corresponding total carbon emissions increased only three times. In respect of carbon dioxide (CO_2) emissions per ton of steel, the figure in 2015 dropped by around 73% over 1995. This suggests that China's iron/steel sector has made great achievements in energy conservation and emission reduction, making a certain contribution to worldwide CO_2 emission reduction.

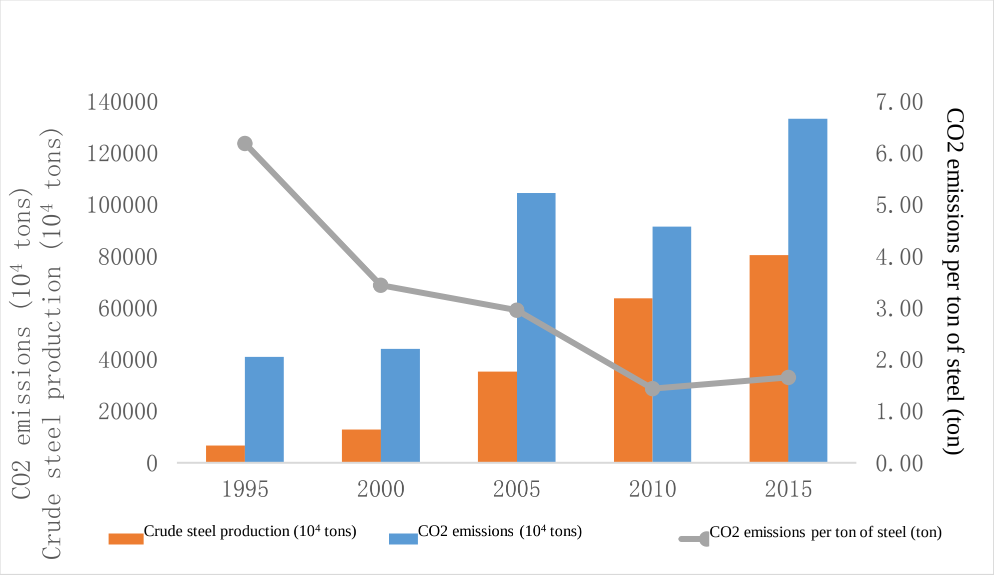

Fig. 2 CO_2 emissions in iron/steel sector during 1995-2015

Looking into the future, China's iron/steel sector still has huge potential for emission reduction. CO_2 emission per ton of steel is still higher than those of major steel producers all over the world, indicating some way to go before reaching the advanced level. On the one hand, China's electric arc furnace (EAF) steel ratio is approximately 50%-70% lower than the world average level, mainly due to rapid growth of the iron/steel sector and lack of usable scrap steel resources, which objectively results in high GHG emissions from China's iron/steel industry. On the other hand, given the primary energy mix in the iron/steel sector, coal takes up more than 80% of the total energy, also significantly higher than the proportions in advanced countries in the world.

In 2009, China committed to reducing carbon emissions per unit of GDP (carbon intensity) by 40-45% in 2020. In the Outline of the 12th Five-Year Plan, China incorporated the carbon intensity index for the first time. In 2014, China further put forward targets such as achieving the peaking of carbon dioxide emissions around 2030 and making best efforts to peak early, reducing the carbon intensity by 60-65% rom the 2005 level and increasing the share of non-fossil energy to 20%. The *Work Plan for the Control of Greenhouse Gas Emissions during the 13th Five-Year Plan Period* states that by 2020, the carbon intensify will decrease by 18% over 2015 and total CO_2 emissions from key sectors such as iron/steel and building materials will be effectively controlled. In order to attain these targets, it is essential to effectively control carbon emissions from the iron/steel sector, which is of decisive significance for China to hit peak carbon emissions by 2030. The iron/steel sector has taken effective measures in the past decade to achieve energy saving and reduce carbon dioxide emissions per ton of steel, but the iron/steel sector will maintain high production, coal-dominating energy mix and long steel-making processes in the short run, hence carbon emissions from the iron/steel sector can hardly decline for some time to come.

2. Carbon Emission Reduction and CCUS Policies in the Iron/Steel Sector

2.1 Low-carbon policies for the iron/steel sector

This report sums up the low-carbon policies that have been introduced since the 11th Five-Year Plan (FYP) period in respect of structure optimizing, improvement of energy efficiency and optimization of the energy structure in the iron/steel sector.

Firstly, structure optimizing policies have been issued for the iron/steel sector to facilitate the elimination of backward production capacity in the industry. These policies mainly include four categories, namely elimination of backward production capacity, limitation of new production capacity, resolving the overcapacity and restructuring of iron/steel products, which lay a solid foundation for generally high-quality development of the industry. Among them, policies to eliminate backward production capacity, as the top priority of the **structure optimizing** of the iron/steel sector, clearly set out goals, deadlines and tasks in respect of the elimination of backward production capacity in the iron/steel sector; policies to limit new production capacity explicitly state the prohibition of new production capacity and of registration of iron/steel projects with new production capacity under any pretext and by any means; policies to resolve the overcapacity, from listing the iron/steel sector as an industry with excess capacity to promoting capacity replacement, provide solutions to reducing overcapacity in the iron/steel sector; policies to adjust the structure of iron/steel products define equipment, facilities and processes that should be eliminated or limited in the iron/steel sector in the catalogue for guiding industrial restructuring whilst encouraging comprehensive utilization of scrap steel and improvement of the quality of iron/steel products.

Secondly, policies for improvement of energy efficiency have been issued for the iron/steel sector to drive high-quality development of steel products. These policies are mainly focusing on reducing the comprehensive energy consumption and raising the standards for energy consumption in the iron/steel sector. Policies to reduce the comprehensive energy consumption in the iron/steel sector specify the overall energy efficiency for the iron/steel sector, which directly reflects the general performance and results of energy conservation and consumption reduction throughout the iron/steel sector. Policies have also been introduced to raise the standards for energy consumption in the iron/steel sector, including mandatory standards such as the *Norm of Energy Consumption per Unit Product of Major Individual Process of Crude Steel Manufacturing Process* (GB21256) and the *Norm of Energy Consumption per Unit Product of Coke* (GB21342) enacted in October 2014 and the *Norm of Energy Consumption per Unit Product of Steel Making Electric Arc Furnace* (GB 32050-2015) enacted in October 2016. By specifying three energy efficiency indicators, which include the limit value, the access value and the advanced value for different production links and processes in the iron/steel sector, these standards raise specific and targeted energy consumption control requirements for enterprises to save energy and reduce emissions.

Thirdly, policies for optimization of the energy structure have been issued for the iron/steel sector to facilitate the realization of the carbon emission control. These policies mainly include development planning for the iron/steel sector, policies that encourage the development of EAF steelmaking and those creating synergy effects. Development planning for the iron/steel sector sets forth clear low-carbon development targets, provides top-level design for low-carbon development of the industry and contains corresponding planning for future reduction of overcapacity, merging and reorganization, adjustment, transformation and upgrading in the iron/steel sector. Secondly, policies that encourage the development of EAF steelmaking serve the goal of gradually increasing the proportion of EAF steel and are oriented towards improving scrap steel processing capacity and reducing energy consumption in the iron/steel sector. Thirdly, policies creating synergy effects mainly include working together to prevent and control pollution, implementing the relevant provisions of the *Action Plan on Prevention and Control of Air Pollution* and putting into practice new emission standards.

Through the formulation and implementation of the above three types of low-carbon policies, the iron/steel sector phased out 122.72 million tons of backward iron production capacity and 72.24 million tons of backward steel production capacity during the 11th FYP period. At the same time, large-scale and modernization of the equipment has been promoted. During the 11th FYP period, the proportion of blast furnaces with a capacity of 1000 m^3 or more in key iron/steel enterprises increased from 48.3% to 60.9% and that of converters with a capacity of 100 tons or more from 44.9% to 56.7%. At the end of the 11th FYP period, there was an overall improvement in the main indicators of key iron/steel enterprises in terms of energy conservation and emission reduction. The comprehensive energy consumption per ton of crude steel fell to 605kgce, down by 12.8% compared with 2005. During the 12th FYP period, 90.89 million and 94.86 million tons of backward iron/steel production capacity respectively were phased out. Despite continuous execution of production capacity control policies during the 12th FYP period, overcapacity had not been addressed, with the capacity utilization rate of crude steel dropping from 79% in 2010 to 71% in 2015 and the debt rate of large and medium-sized key enterprises exceeding 70%. Overcapacity in the iron/steel sector already evolved from regional and structural excess into absolute excess. Meanwhile, in spite of a decline in the comprehensive energy consumption per ton of steel (from 605kgce to 572kgce among large and medium-sized key enterprises), this could not offset incremental energy consumption arising from the growth of iron/steel production. During the 13th FYP period, China has adopted a stronger policy to resolve iron/steel overcapacity and embarked on exploration into practical policies for carbon emission control, leading to continuous improvement of energy consumption in the iron/steel sector and a further increase in the utilization rates of resources and secondary energy sources. Large and medium-sized key enterprises have undergone a decrease in the comprehensive energy consumption per ton of crude steel from 572kgce to 570kgce and an increase in the capacity utilization rate from 71% in 2015 to currently 82%, implying that 80% of the targets by 2020 have been achieved ahead of schedule.

2.3 CCUS policies for the iron/steel sector

China is actively guiding the R&D and demonstration of CCUS technologies by publishing 26 CCUS-related policy documents at the national level (including rules, plans, notices and opinions released by the State Council and various ministries and commissions), which can be classified into five categories, namely technology promoting, demonstration support, target setting, environmental management and others. Based on evaluation of the 26 policy documents, it is clear that CCUS is a cutting-edge technology and a low-carbon technology to be promoted and that demonstration of CCUS projects is encouraged. In terms of special policy, there are only four policies directly related to CCUS so far. During the 12th FYP period, in 2013, the Ministry of Science and Technology (MOST) issued the *National Special Plan for the Development of Carbon Capture, Utilization and Storage Technologies during the 12th Five-Year Plan Period*, which sets out priorities and key tasks of CCUS development, makes clear the CCUS development path over the five years and promotes the R&D and demonstration of CCUS technologies in all respects. In 2013, the National Development and Reform Commission of China (NDRC) issued the *Circular on Promoting the Experiment and Demonstration of Carbon Capture, Utilization and Storage*, which strengthens the support and guidance for the experiment and demonstration of carbon capture, utilization and storage through six main tasks, including carrying out relevant experiment and demonstration projects in combination with actual conditions of CCUS, and practically promotes healthy and orderly development of CCUS. In 2013, the Ministry of Ecology and Environment (MEE) issued the *Circular on Strengthening Environmental Protection of the Environmental and Demonstration Projects for Carbon Capture, Utilization and Storage*, which strengthens environmental protection in CCUS experiment and demonstration projects in six aspects, including strengthening environmental impact assessment (EIA), and furthers technical studies on EIA, environmental monitoring, environmental risk prevention and control, environmental damages and so forth for experiment and demonstration projects. During the 13th FYP period, in 2016, the MEE issued the *Technical Guidelines on Environmental Impact Assessment for Carbon Dioxide Capture, Utilization and Storage (Tentative)*, which stipulates the procedures of EIA for CCUS projects based on current development and application of CCUS, from identifying main sources of environmental risks and risk bearers to determining the environmental background value and assessing environmental risks, thus managing environmental risks through preventive and emergency measures.

In terms of technology roadmap, the *Technology Roadmap Study on Carbon Capture, Utilization and Storage in China* published jointly by the MOST and the Administrative Center for China's Agenda 21(ACCA21) in 2012 provides a technology roadmap for the development of CCUS. Positive achievements have been made since then: great progress has been achieved in various links of CCUS and conditions for large-scale demonstration have been met, laying a solid foundation for large-scale CCUS demonstration in the next step. In 2019, the *Technology Roadmap Study on Carbon Capture, Utilization and Storage in China* (2019 version) was published, providing a comprehensive, scientifically and objective evaluation and forecast on the current CCUS development status and trend in China based on the latest developments at home and abroad, and depicts the development roadmap of CCUS in China in 2025, 2030, 2035, 2040, 2045 and 2050, making technical reserves for near-zero carbon emissions in China in the long run. In 2016, NDRC published the *Action Plan for Innovations in the Energy Technology*

Revolution (2016-2030), to which the attachment identifies innovations in CCUS technology as a part of the roadmap of key innovations in the energy technology revolution and puts forward a roadmap for CCUS technology innovation for 2016 through 2050.

3. Analysis of Carbon Emission Scenarios and CCUS Potential in the Iron/steel Sector

3.1 Introduction to the carbon emission reduction model for the iron/steel sector

3.1.1 Model framework and analysis methods

The study figures out the technically feasible potential of major sectors for carbon emission reduction through the Strategy Analysis of Climate in China (SACC) model developed by NCSC, based on full consideration of future economic growth and changes in consumption demand, and in combination with the analysis of the evolution of technologies regarding carbon emissions. On this basis, the study focuses on the potential of the iron/steel sector for carbon emission reduction and the potential of CCUS for application in the iron/steel sector.

With 2015 as the base year, the SACC model covers multiple energy production and consumption sectors, such as electricity, industry, building and transportation. The construction of the model mainly follows the following idea: firstly, based on analysis of historical trends of economic and social development, and referring to relevant forecast and analysis data from leading research institutes at home and abroad, it puts forward macroeconomic and social parameters by 2050, including population, GDP and urbanization rate and identifies historical development trends of energy, building, transportation, industry and other major sectors as an important basis for setting parameters of future sectors. Secondly, based on expert reviews and literature research, it analyzes the trend of changes in the level of energy activities, energy structure, energy efficiency and technology innovation in such three end-user sectors as industry[1], building and transportation under the deep emission reduction path in a “bottom-up” manner, takes into special consideration the application of significant emission reduction technologies and the potential for carbon emission reduction in the medium and long term in major sectors, and then derives the final energy consumption demand in China. Thirdly, based on the electricity demand derived, it proposes installed capacity and generating capacity of non-fossil and thermal power respectively in the principle of giving priority to the development potential of non-fossil power. Fourthly, based on the study and analysis of the emission reduction potential, technologies and paths of energy production and consumption sectors, it puts forward policy recommendations on the path of deep low-carbon development in China. Model data comes mainly from the data published by China Electricity Council, China Energy Statistical Yearbooks and China Statistical Yearbooks.

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[1] This study incorporates the final energy consumption in agriculture and construction sectors into industry sectors.

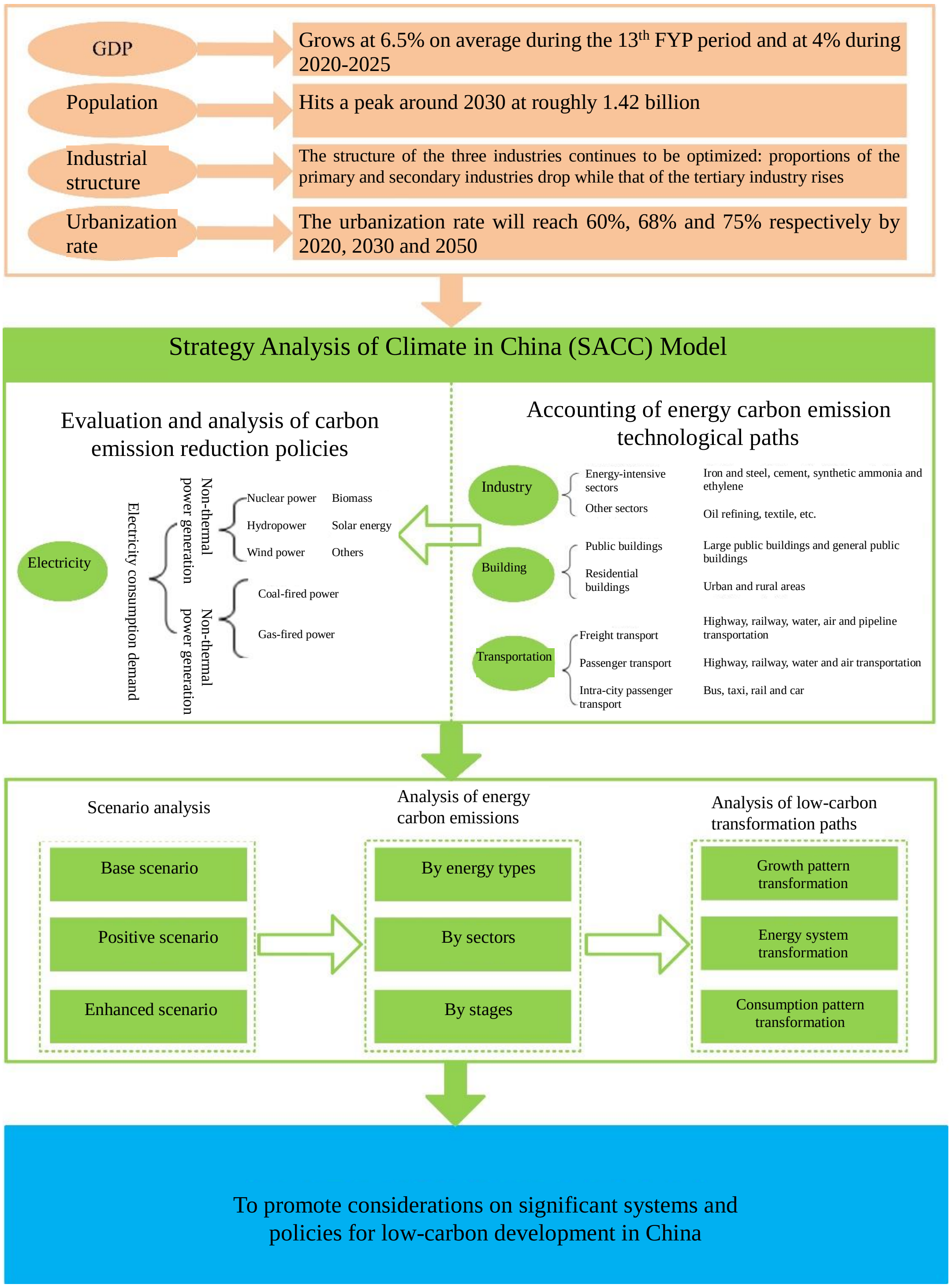

Fig.3 Framework of the SACC model

3.1.2 Construction of an assessment model for the iron/steel sector

The iron/steel sector carbon emission reduction module has been constructed within the framework of the SACC model, with 2015 as the base year, to simulate the energy production and consumption and CO2 emissions during 2016-2050, as is shown below.

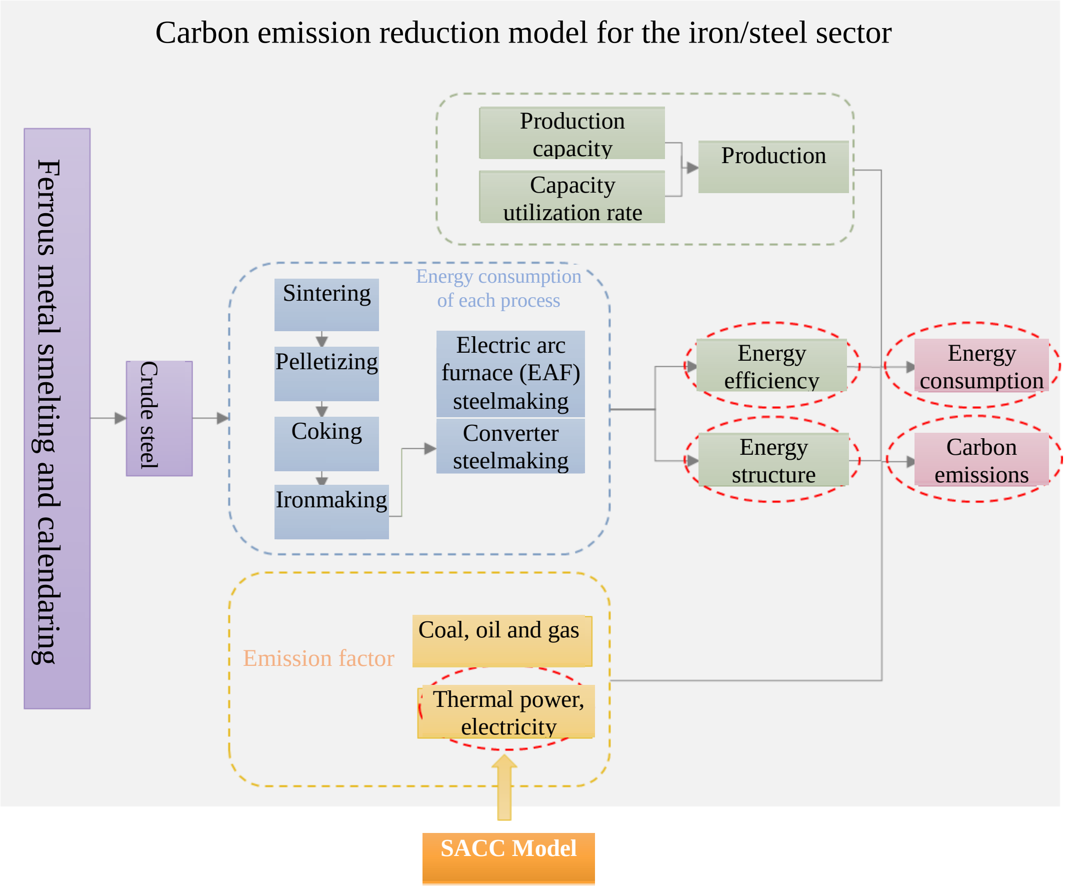

Fig.4 Framework of the carbon emission reduction model for the iron/steel sector

3.1.3 model construction and calculation methods

In the assessment of iron/steel production, energy efficiency and corresponding energy structure of each technical process in a bottom-up way under different scenarios and at different time nodes are figured out. In combination with the judgment of output, energy consumption of the iron/steel sector by energy types under different scenarios and at different time nodes is obtained. The forecast of main parameters is made based on factors such as national plans issued, the international advanced level and development trends of downstream sectors that consume steel. Later, carbon emissions from the iron/steel sector under different scenarios are figured out based on energy consumption by energy types and their emission factors. Among them, emission factors of thermal and electricity are derived from the data from the SACC model under corresponding scenarios. Specifically, the emission factor of electricity is calculated as below: adding up electricity consumption in end-user sectors such as industry, building and transportation under certain scenario and taking into account power transmission loss and other factors to obtain the total power generation in China, and then considering conditions such as historical power generation structures, electric power development planning and production technologies to work out the power mix that can meet power generation demand and calculate the corresponding emission factor of electricity. The emission factor of district heating is calculated in a similar approach.

The model also takes into account additional energy consumption from the application of CCUS in the iron/steel sector, which will partly affect emission factors of electricity and heat and carbon emissions from the iron/steel sector. Parameters affected by CCUS in the model are circled in red in the "Framework of the carbon emission reduction model for the iron/steel sector".

Some parameters in the model are calculated as follows:

$$\begin{aligned}&\text{Energy consumption of converter steelmaking}\\&\quad=\sum(\text{energy efficiency of large and medium sized processes}_i\\&\quad\times\text{the proportion of such processes}_i\\&\quad+\text{energy efficiency of small sized processes}_i\\&\quad\times\text{the proportion of such processes}_i)\end{aligned}$$

Where, i represents different processes, namely sintering, pelletizing, coking, ironmaking and converter steelmaking

$$\begin{aligned}&\text{Energy consumption of EAF steelmaking}\\&=\text{Energy efficiency of large and medium sized EAF steelmaking processes}\\&\times\text{the proportion of such processes}\\&+\text{energy efficiency of small sized EAF steelmaking processes}\\&\times\text{the proportion of such processes}\end{aligned}$$

$$\begin{aligned}&\text{Carbon emissions}\\&\quad=\sum\big(\text{energy consumption of converter steelmaking}_j\times\text{emission factor}_j\\&\quad+\text{energy consumption of EAF steelmaking}_j\times\text{emission factor}_j\big)\end{aligned}$$

Where, j represents different energy types, namely coal, oil, gas, heat and electricity. Emission factors of coal, oil and gas are calculated and estimated based on the People's Republic of China National Greenhouse Gas Inventory while those of heat and electricity are calculated from the SACC model.

3.2 Analysis of the cost of CCUS technologies for the iron/steel sector

3.2.1 Capture technologies

(1) Post-combustion capture

Of China's carbon capture technologies, post-combustion capture, dominated by chemical absorption, is the most mature technological direction which can be applied to most of the existing coal-fired power plants, cement plants and iron/steel plants. China is not far behind developed countries in terms of post-combustion capture. Because of simple principles of the technology system and good inheritance for existing power plants, post-combustion capture projects have all entered the stage of demonstration and China has launched demonstration projects for such technology with scale of 100,000 tons CO2 captured per year. Currently, commercial application of post-combustion capture is mainly restricted by high energy consumption and technology costs. Due to large volume flow rates of gases and small CO_2 pressure, the process of decarbonization is energy-intensive, with high equipment investment and operating cost. The post-combustion capture technology costs RMB 300~450 per ton of CO_2 captured. Besides, the technology is mostly applied in oil & gas and petrochemical industries.

(2) Pre-combustion capture

Pre-combustion capture is mainly used to capture CO_2 in Integrated Gasification Combined Cycle (IGCC) power generation systems and some chemical processes, as mixed CO_2 and H_2 is relatively easy to separate. A pilot plant with a capacity of 50,000 tons has run abroad, the experiment of a pilot system with a capacity of 60,000-100,000 tons has been launched in China. The IGCC power plants of 265 MW have been put into commercial operation and the capture facility with a capacity of 100,000 tons CO2 captured per year has been built. Compared with post-combustion capture, pre-combustion capture has great potential for reducing energy consumption and can also be used as IGCC and polygeneration systems. Despite high investment in early stages, the operating cost is low and the pre-combustion capture technology generally costs RMB 350~430 per ton of CO_2 captured. Meanwhile, the technology is faced with many obstacles, such as applicability to new power plants and relatively complex system, making it requires more auxiliary systems and key technologies, for example, gasifiers, which contain great risk of operational stability, are immature and costive.

(3) Oxy-fuel combustion

Oxy-fuel combustion technology is developing rapidly and can be utilized in new coal-fired power plants and some retrofitted coal-fired power plants. The development of main equipment for oxy-fuel combustion has been completed abroad, with industrial demonstration projects of 200,000 tons of CO2 captured per year built and those of 1 million tons CO2 under construction; China has completed a pilot system of 10,000 tons CO2 captured per year and is implementing the construction of an industrial demonstration project with a scale of 100,000 tons CO2. The oxy-fuel combustion technology exhibits good inheritance for existing power plants, great potential for reduction of equipment costs, guarantee of continuous power generation in case of a failure and low risks. At present, the technology costs RMB 300~400 per ton of CO_2. The key to addressing the bottlenecks restricting the development of oxy-fuel combustion is reducing the energy consumption of new scale oxygen production and system integration technologies and lowering the costs of the expensive low-temperature O_2 production and of air separation facilities. Meanwhile, most power plant materials do not meet the high temperature requirement of adiabatic combustion and the size of existing boilers for oxy-fuel combustion is relatively smaller compared to conventional ones.

3.2.2 Transportation technologies

(1) Pipeline transportation

Pipeline transportation is a mature technology in the market and a common way of transporting carbon dioxide, which requires high one-time investment and shows the largest scale application advantage in large-volume transportation over a long distance. Currently, pipeline transportation is considered the most economical and reliable approach to large-scale and long-distance CO_2 transportation. It is suitable for transportation of CO_2 sources and sinks in large volume along relatively fixed directions. An IPCC report notes that the transportation cost of a 250km long pipeline is basically USD 1-8 per ton CO_2. Offshore pipeline transportation of CO_2 remains at the stage of concept research at home and abroad and there are not yet CO_2 transportation pipelines in commercial operation. At present, offshore pipeline transportation costs about RMB 4/ton·km if the construction cost is taken into account. In CO_2 pipeline transportation, onshore pipeline transportation of CO_2 has the greatest potential for application and cost-effectiveness. Foreign countries have practiced commercial CO_2 pipeline transportation for over 40 years. The assessment based on *China's CCUS Technology Roadmap* in 2019 states that China's overland CO_2 transportation costs about RMB 1.0/ton·km.

(2) Tanker transportation

Tanker transportation means transportation of CO_2 stored in liquid form in low-temperature and adiabatic tanks, mainly by rail or road, in which cases there is little difference in the techniques used, but some difference in the distance and scale of transportation. Road tankers are only suitable to short-distance and small-scale transportation, and are uneconomical when used on a large scale. Railway tankers are applicable to larger-volume and longer-distance transportation. In China, CO_2 transportation is dominated by onshore low-temperature tanker transportation, which, compared with that abroad, is inferior mainly in respect of pipe network planning and optimal design technologies for CO_2 source-sink matching, large-displacement compressors and other key equipment for pipeline transportation, and safety control and monitoring technologies. Small-volume transportation of liquid CO_2 for industrial and food uses by truck and rail has a history of more than 40 years. However, compared with CO_2 pipeline transportation, truck and railway transportation is limited by transportation scale and is relatively more expensive. At present, onshore CO_2 transportation by truck in China has been put into commercial use, which costs about RMB 1.1/ton·km and is mainly applied to transportation of 100,000 tons CO2/a. or below; therefore, aside from small CCUS opportunities and pilot projects, truck and railway transportation is unlikely to play an essential role in CCUS deployment.

(3) Ship transportation

Similar to tanker transportation, ship transportation is also achieved by storing liquid CO_2 in adiabatic tanks at far low temperature and pressure than ambient ones. It is relatively flexible in terms of transportation direction and is more applicable to large-volume and ultra-long-distance transportation. Although there is no large-scale ship transportation of CO_2, small CO_2 transportation ships do exist; moreover, in the petroleum industry, experience in large-scale ship transportation of liquefied petroleum gas (LPG) and liquefied natural gas (LNG) can be drawn to examine the feasibility of large-scale ship transportation of CO_2.

A contrastive analysis of different transportation technologies suggests that where onshore or offshore CO_2 storage is unavailable, ship transportation costs about the same as pipeline transportation and will exhibit greater competitiveness. In case of long-distance and small-scale or unstable transportation, ship transportation of CO_2 is more suitable than pipeline transportation and is a more flexible and economical transportation mode. China already has experience in small ship transportation on inland rivers and inland ship transportation of CO_2 has been put into commercial use in China, which is mainly applied to transportation of 100,000 ton/year or below and costs about RMB 0.3~0.5/ton·km. Tanker transportation costs higher than pipeline and ship transportation: the cost of railway transportation is 2-5 times that of water and pipeline transportation while the cost of road transportation is 3-4 times that of railway transportation.

Table 1 Latest developments and costs of transportation technologies

Capture technology	Development stage	Strength	Weakness	Application	Range of cost
Pipeline transportation	A mature market technology and also the most common approach to CO2 transportation	Stable transportation, little influence from external conditions, high reliability	Large investment, high operating cost	Suitable for large-volume, long-distance and steady-load transportation along fixed directions	Onshore pipelines: RMB 1.0/ton.km, marine pipelines: RMB 4.0/ton.km
Tanker transportation	In China, CO2 transportation is dominated by onshore low-temperature tanker transportation, which, compared with that abroad, is inferior mainly in respect of pipe network planning and optimal design technologies for CO2 source-sink matching, large-displacement	Road transportation: small scale, small investment, low risk, flexibility Railway transportation: large capacity, long distance and high reliability	Road transportation: small capacity and short distance Railway transportation: complex dispatching and management, restrictions from railway connection and construction of railway sidings and the	Road transportation is applicable to small-scale and short-distance transportation with scattered destinations Railway transportation is applicable to large-volume and long-distance transportation, where there is no	RMB 1.0-1.2/ton.km

	compressors and other key equipment for pipeline transportation, and safety control and monitoring technologies		requirement for supporting unloading and storage equipment	completed pipeline transportation system	
Ship transportation	Although there is no large-scale CO_2 ship transportation, small CO_2 transportation ships do exist; and in the petroleum industry, experience in large-scale ship transportation of LPG and LNG can be drawn to examine the feasibility of large-scale ship transportation of CO_2	Large-scale, ultra-long-distance or ocean line transportation, featuring large capacity and flexibility in destinations	Large investment, high operating cost, the requirement for supporting storage and unloading equipment, and great influence from climate conditions	Ship transportation is applicable to long-distance and large-scale CO_2 transportation, and is preferred if CO_2 emission sources and storage areas are connected with water routes	RMB 0.3-0.5/ton.km

There is no essential difference between CO_2 transportation in the iron/steel sector and that in the power sector or in the coal chemical industry, and what should be taken into account is merely source-sink matching and transportation distance. According to Li Xiaochun's research findings, in the analysis of CO_2 emission sources in the iron/steel sector, each source-sink combination is evaluated through spatial analysis of GIS software based on GIS data and source-sink spatial relations are presented in a map, without regard to matched combinations and their technological economy. The presentation of spatial relations means projecting CO_2 emission sources onto the CO_2-EWR storage site suitability map and observing the possibility of finding suitable storage sites for CO_2 sources within a 250km search radius from those CO_2 emission sources. In the finding of suitable storage sites for CO_2 sources within a 250km search radius, sites that can store CO_2 captured over a period of 20 years from these emission sources will be candidate sites. Source-sink matching results show that within a 250km search radius, 317 iron/steel plants have found suitable storage sites and formed source-sink combinations, with the total emissions accounting for 90% of the total in China’s iron/steel sector. Based on source-sink matching results and in combination with the above-mentioned analysis of the maturity of various transportation technologies, the study suggests the iron/steel sector should adopt pipeline transportation, with an average length of 116km.

3.2.3 Utilization and storage technologies

(1) Geological storage and utilization of CO_2

Geological storage of CO_2 is a process of long-term isolation of CO_2 from the atmosphere by storing the CO_2 captured in geological formations by engineering means. It mainly involves technologies such as, by geological mass for storage, storage in onshore saline aquifers, storage in marine saline aquifers and storage in depleted oil and gas fields. China has launched a demonstration project for storage in saline aquifers on an industrial scale and completed a nationwide assessment of theoretical potential for CO_2 storage. As indicated by studies by Li Xiaochun et al. and the Asian Development Bank (ADB), onshore saline aquifers in China has a theoretical storage capacity of a trillion tons of CO_2. Although storage in saline aquifers shows the greatest potential, it is after all a pure CO2 emission reduction technology which has no incidental economic benefits and costs high, so CO_2 storage is a path China must take in order for long-term deep emission reduction.

Geological utilization of CO_2 is the process of injecting CO_2 into the ground to produce or strengthen the exploitation of energy and resources by using geological conditions. CO_2 storage technologies that can also bring utilization benefits mainly include (1) CO_2-EOR technology: injecting CO_2 into oil fields at high pressure to mix CO_2 with crude oil, driving the crude oil into production wells and at the same time storing CO_2 underground. The increase rate of crude oil production depends on reservoir characteristics and the recovery rate in the stage of secondary oil recovery, and generally stays between 5%~15%; (2) CO_2-ECBM (enhanced coal bed methane recovery) technology: injecting CO_2 into deep unminable coal beds. The mechanism is competitive adsorption, under which coal beds adsorb more CO_2 than methane and whilst adsorbing CO_2, coal beds desorb CH_4, and the value of the desorbed CH_4 can offset some of the CO_2 injection costs.

(2) Chemical utilization of CO_2

Chemical utilization of CO_2 is characterized by chemical conversion, which is a process of converting CO_2 and co-reactants into target products, thereby realizing use of CO_2 as a resource. Chemical utilization can not only reduce CO_2 emission, but also create economic benefits. In recent years, chemical utilization of CO_2 has made great progress in synthesized energy, chemicals and organic functional materials, with numerous products involved, such as urea synthesized from CO_2 and ammonia, sodium carbonate generated from CO_2 and sodium chloride, and salicylic acid synthesized from CO_2, which have been put into commercial use. This plays an important role in low-carbon transformation and upgrading of traditional industries.

(3) Biological utilization of CO_2

Biological utilization of CO_2 is characterized by biological conversion, which is a process of applying CO_2 to the synthesis of biomass through plant photosynthesis, so as to realize use of CO_2 as a resource. In recent years, biological utilization of CO_2 has become a promising technology in global CCUS. This technology will not only play a role in reducing CO_2 emission, but also bring huge economic benefits. Biological utilization mainly employs fixation of CO_2 with microalgae and CO_2 fertilizers to promote conversion into food and feed, bio-fertilizers, chemicals and biofuels. At present, the food and feed conversion technology has achieved large-scale commercialization, but other technologies are still in the stage of R&D or small-scale demonstration.

Table 2 The status and costs of CO2 storage and utilization technologies

Storage and utilization technology	Development stage	Strength	Weakness	Application	Range of cost
Geological storage and utilization of CO2	Widely used	CO2-EOR can enhance oil recovery while CO2-ECBM can enhance coal bed methane recovery	High cost and no economic benefits. EOR poses high requirements on oil reservoirs, but exhibits low storage capacity ECBM exhibits poor closeness; China's coal fields show generally low permeability, which is not conducive to injection and mining of coal bed gases; the technology is not yet mature	Storage in saline aquifers and storage in depleted oil and gas fields	RMB -177-510/ton
Chemical utilization of	Less widely used	Convert CO_2 and co-	Some technologies	Characterized by chemical	/

CO_2		reactants into target products	are still being explored and have not been put into commercial use	conversion	
Biological utilization of CO_2	Less widely used	Apply CO_2 to biomass synthesis through plant photosynthesis	Some technologies are still in the stage of R&D or small-scale demonstration	Characterized by biological conversion	/

Similar to the transportation link, the selection of utilization and storage technologies for the iron/steel sector is not different from that for other sectors, and what should be taken into account is only source-sink matching. By considering the source-sink matching set forth below and in combination with the above-mentioned analysis of the maturity of various transportation technologies and the demand for CO_2 emission reduction in the near, medium and long term, the study suggests that the iron/steel sector should adopt EOR as the near- and medium-term utilization and storage solution and storage in deep saline aquifers as the long-term storage solution.

3.3 Carbon emission scenarios setting in the iron/steel sector

The study has set three scenarios for low-carbon development of the iron/steel sector and CCUS development in the sector. Basic conditions of each scenario are listed below.

Base scenario: considering energy conservation and low carbon policies comprehensively that have been introduced for different sectors and ensuring that all targets regarding low-carbon development that have been proposed are attained. In the iron/steel sector, relevant planning targets during the 13th FYP period will be achieved, relevant policies will be continuously implemented beyond the 13th FYP period, energy efficiency will be improved steadily, no major technological breakthroughs will be made by 2050, the current mode of production will basically continue and key low-carbon technologies, including CCUS, can hardly be applied on a large scale.

Low-carbon scenario: adopting more aggressive policies to control carbon emissions than in the base scenario since the 13th FYP period, so as to force low-carbon economic and social transformation. In the iron/steel sector, energy efficiency will be further improved, unreasonable service demand of end-user sectors will be notably controlled, so that iron/steel production can be effectively controlled, and the application potential of CCUS technologies will be taken into full account.

Enhanced low-carbon scenario: remaining the same as the positive scenario in respect of economic development mode, energy supply and consumption and technological progress, and considering fully raising the level of electrification in each energy end-user sector and vigorously optimizing the power generation structure. In the iron/steel sector, owing to the development of EAF steelmaking, energy efficiency will increase significantly compared with that in base and low-carbon scenarios. Supporting systems that fully promote recycling of scrap steel from EAF steelmaking will be effectively improved, large-scale development of EAF steelmaking will be advanced and the application potential of CCUS will be taken into full account.

3.4 Analysis of carbon emission scenarios in the iron/steel sector

Under the base scenario, China's carbon intensity in 2020 and 2030 will decline by roughly 49% and 67% respectively over 2005, in both cases exceeding the targets set by the Chinese Government. Industrial carbon emissions will peak later than 2020 at approximately 6.3 billion tons of CO_2, which will decrease to 2.1 billion and 2 billion tons of CO_2 in 2035 and 2050 respectively. In the iron/steel sector, carbon emissions will decrease from 1.33 billion tons in 2015 to 1.2 billion, 0.78 billion and 0.46 billion tons of CO_2 respectively in 2020, 2035 and 2050. The iron/steel sector will have basically not applied CCUS technologies and failed to achieve carbon emission reduction through CCUS. By 2050, carbon emissions will be equivalent to a third of the 2015 level. In this scenario, crude steel output will stay at a high plateau during 2015~2025 and drop to 0.5 billion tons in 2050. Under the action of existing energy efficiency policies for the iron/steel sector, energy efficiency will reach the current world average level in 2020, with the target of lowering the comprehensive energy consumption per ton of steel during the 13th FYP period exceeded, the current German level in 2040 and the current EU level in 2050. EAF steelmaking will make progress slowly and the iron-steel ratio will reach the current world (excluding China) average level by 2045.

Under the low-carbon scenario, carbon intensity per unit of GDP in 2020 and 2030 will decline by roughly 51% and 71% respectively over 2005, in both cases substantially exceeding the targets set by the Chinese Government. Industrial carbon emissions will peak by 2020 at approximately 6.5 billion tons of CO_2, which will decrease to 2 billion and 1.7 billion tons of CO2 in 2035 and 2050 respectively. In the iron/steel sector, carbon emissions will decrease from 1.33 billion tons in 2015 to 1.1 billion, 0.72 billion and 0.08 billion tons of CO_2 respectively in 2020, 2035 and 2050, and 0.1 billion and 0.2 billion tons of carbon emissions will be reduced by CCUS in 2035 and 2050 respectively. Under this scenario, under the effect of a number of relatively enhanced production capacity control policies, crude steel output declined drastically in 2016 and will continue to decline year by year, fall to the 2010 level by 2030 and drop to 0.45 billion tons in 2050. Subject to energy conservation and low carbon policies for the iron/steel sector, energy efficiency will reach the current German level in 2035 and the current EU average level in 2040, and the comprehensive energy consumption per ton of steel in 2050 will be equivalent to about 55% of the 2015 level. The iron-steel ratio will reach the current world (excluding China) average level in 2035 and the proportion of EAF steelmaking will reach the current world (excluding China) average level during 2045-2050 and 20% and 50% respectively in 2035 and 2050.

Under the enhanced low-carbon scenario, the carbon intensity per unit of GDP in 2020 and 2030 will decline by roughly 53% and 76% respectively over 2005, in both cases substantially exceeding the targets set by the Chinese Government. Industrial carbon emissions will peak by 2020 at approximately 6.3 billion tons of CO_2, which will decrease to 1.7 billion and 1.3 billion tons of CO_2 in 2035 and 2050 respectively. In the iron/steel sector, carbon emissions will decrease from 1.33 billion tons in 2015 to 1 billion, 0.57 billion and 0.03 billion tons of CO_2 respectively in 2020, 2035 and 2050, and 50 million and 0.1 billion tons of carbon emissions will be reduced by CCUS in 2035 and 2050 respectively. In this scenario, carbon emissions reduced by CCUS are less than those in the low-carbon scenario, which are 0.2 billion tons, mainly because more powerful policies will be adopted in the enhanced low-carbon scenario to promote the development of EAF steelmaking and the power generation structure in the power sector will be more low-carbon, so that the total emissions from the iron/steel sector in 2050, if CCUS is not carried out, will be significantly lower than those in the low-carbon scenario. Moreover, reduction of emission sources will result in less CO_2 captured and smaller CCUS application potential. In this scenario, crude steel production capacity is further controlled compared with that in the low-carbon scenario and crude steel production will fall to the 2010 level in 2025 and gradually decline to 0.4 billion tons in 2050. Under the impact of a number of enhanced energy conservation and low carbon policies for the iron/steel sector, energy efficiency will reach the current EU average level in 2030 and the comprehensive energy consumption per ton of steel in 2050 will be equivalent to about 45% of the 2015 level. Under the impact of a number of policies supporting EAF steelmaking, including fully supporting the recycling of scrap steel from EAF steelmaking, EAF steelmaking will experience significant development and its proportion will reach the current world (excluding China) average level during 2035-2040 and 40% and 70% respectively in 2035 and 2050. The iron-steel ratio will reach the current world (excluding China) average level in 2025.

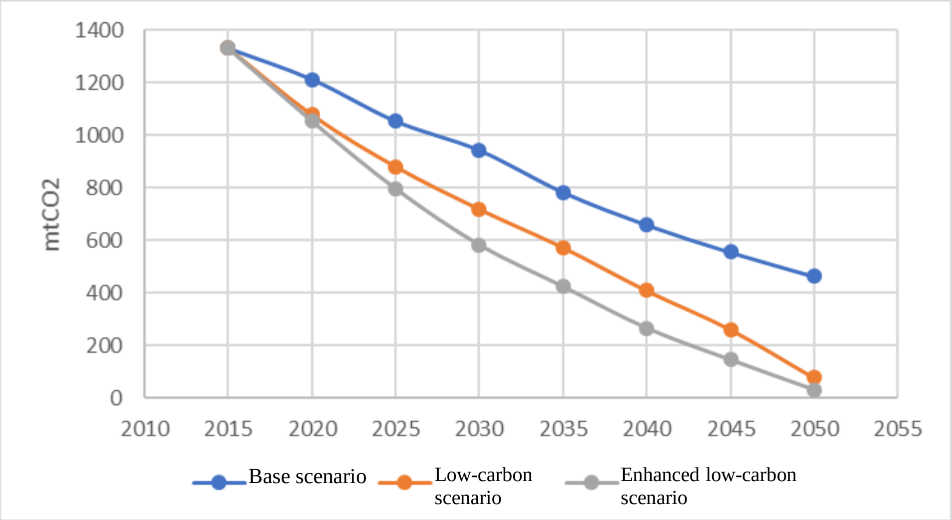

Fig.5 CO2 emissions from the iron/steel sector in different scenarios

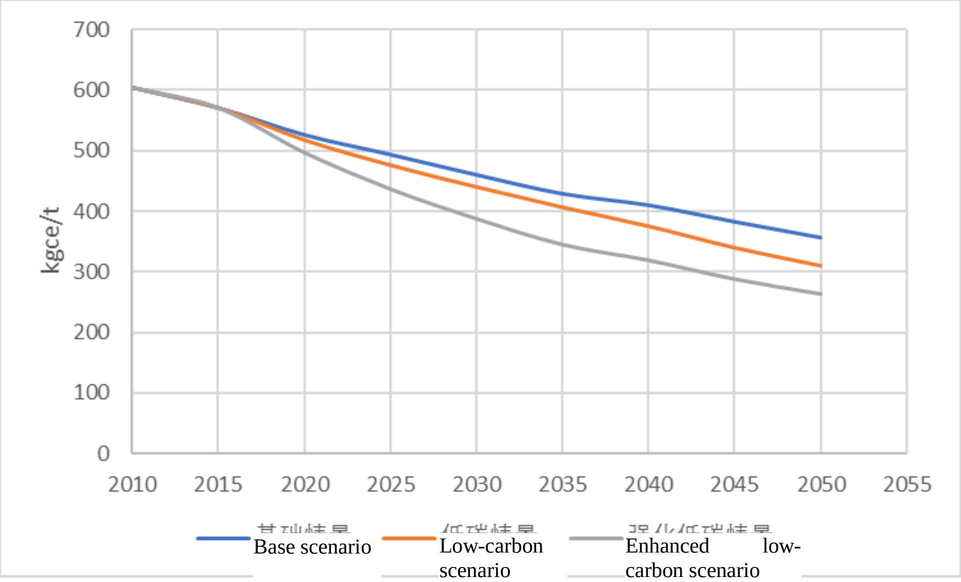

Fig.6 Energy consumption per ton of crude steel in different scenarios

3.5 Analysis of the emission reduction potential and costs of CCUS in the iron/steel sector

3.5.1 Analysis of the emission reduction potential of CCUS nationwide

To assess the aggregate economic demand for CCUS development in the near and medium term, it is necessary to judge the CO2 emissions reduced by CCUS in China in the near and medium term. The study figures out and sums up forecasts made by different research institutes of the emission reduction potential of CCUS in China and compares these forecasts, as is shown below.

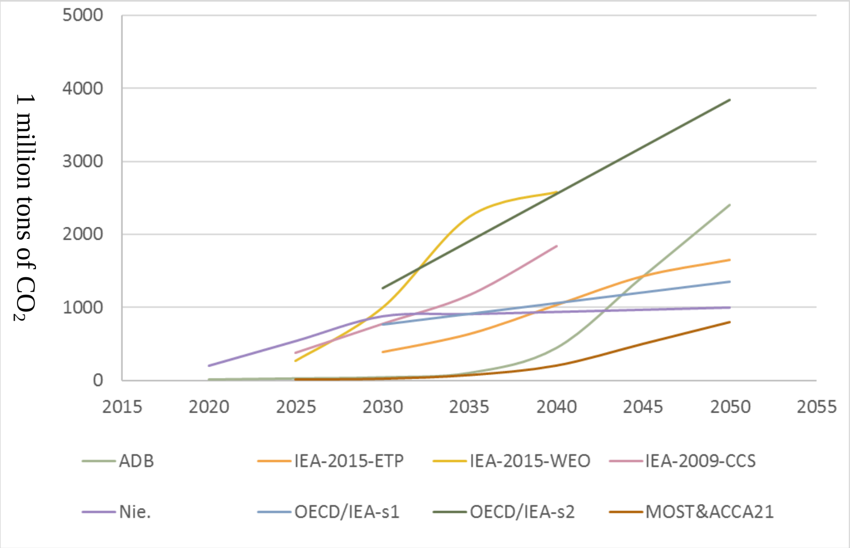

Fig.7 Forecasts made by different research institutes of carbon emissions reduced by CCUS in China (mtCO2)

Table 3 Forecasts made by different research institutes of carbon emissions reduced by CCUS in China

Scenario	Source of literature
ADB	ADB, Roadmap for Carbon Capture and Storage demonstration and deployment in the People's Republic of China, 2015
IEA-2015-ETP	IEA, Energy Technology Perspective 2015, 2015
IEA-2015-WEO	IEA, WEO 2015 Special Report on Energy and Climate Change, 2015
IEA-2009-CCS	IEA, Technology Roadmap Carbon Capture and Storage, 2009
Nie.	Nie Ligong et al., A Study of the Path to Global Commercialization of CCS Technology, 2016
OECD/IEA-s1	OECD/IEA, Energy Technology Analysis - Prospects for CO2 Capture and Storage, 2004: -+-++ scenario
OECD/IEA-s2	OECD/IEA, Energy Technology Analysis - Prospects for CO2 Capture and Storage, 2004: +++++ scenario
MOST&ACCA21	Department of Science and Technology for Social Development of MOST and the ACCA21, China's CCUS Technology Roadmap (2019), 2019

According to the forecasts made by different research institutes of the emission reduction potential of CCUS in different stages in China, the range of emission reductions in the near (2020), medium (2035) and long (2050) term is listed below. In 2020, China can reduce 10-200 million tons of CO_2 emissions through CCUS and 70-2,240 million tons of CO_2 emissions in 2035. To achieve a higher range of emission reductions, the deep emission reduction technology can be employed, which can reduce 800-3,840 million tons of CO_2 emissions in 2050. By 2050, CCUS can achieve commercial use on a large scale. Achieving near-zero carbon emissions worldwide shows a huge demand for CCUS technologies, so as to guarantee huge carbon emission reductions.

Table 4 Range of forecasts made by different research institutes of carbon emissions reduced by CCUS in China ($mtCO_2$)

Year	2020	2035	2050
Range of emission reductions	10-200	70-2240	800-3840

3.5.2 Analysis of the emission reduction potential in the iron/steel sector

Based on scenario analysis, both the low-carbon and enhanced low-carbon scenarios fully considered the application potential of CCUS in the iron/steel sector, with the emission reduction potential in different years shown in the table below. In the near term, as it takes some time to complete industrial transformation and CCUS technologies need to further develop to lower the costs, the iron/steel sector will not see any emission reduction effect of CCUS. The emission reduction potential of CCUS in the iron/steel sector can reach 10 $mtCO_2$ by 2030 and

15 $mtCO_2$ in 2035, accounting for 0.6%-21% of the national total, and register 50 $mtCO_2$ in 2040. During this period of time, CCUS technologies will not have scale effect in the iron/steel sector. By 2045, the emission reduction potential of CCUS in the sector can reach 75-100 $mtCO_2$ and in 2050 climb to 100-200 $mtCO_2$, accounting for 2.6%-25% of the national total.

Table 5 The emission reduction potential of CCUS in the iron/steel sector in different stages

	2030	**2035**	**2040**	**2045**	**2050**
Emission reduction potential ($mtCO_2$)	10	15	50	75-100	100-200

3.5.3 Analysis of CCUS costs in the iron/steel sector

(1) Analysis of the technological costs of CO2 capture in the iron/steel sector

With respect to CO2 capture, the corresponding costs of the capture technology selected in 3.2.1 are listed in the table below. As indicated by the analysis of the costs of CO_2 capture technologies in 3.2.1 and the selection of capture technologies, the post-combustion capture technology is applicable in the irons/steel sector, including chemical absorption, pressure swing adsorption (PSA), membrane absorption and membrane separation + low temperature separation + nitrogen recycling, which target blast furnace gas, hot-blast stove exhaust and lime kiln exhaust, and the construction, variable and fixed costs vary from size to size. A North China Electric Power University (NCEPU) study shows that, the scale being equal, the cost of chemical absorption is similar to that of membrane absorption, which are RMB 819-1,000 and RMB 822-1,031 respectively, and chemical absorption costs less. PAS costs RMB 910-1,280 and membrane separation + low temperature separation + nitrogen recycling costs RMB 1,078-1,331, which are higher.

According to the analysis of development stages and costs of CCUS, with the scale of 500,000 tons CO2/a designated to the year of 2020, the scale of 1 million tons CO2/a to the year of 2035 and the scale of 2 million tons CO2/a to the year of 2050, then the costs of capture technologies in the iron/steel sector in different stages are listed in the table below.

Table 6 CO_2 capture costs in the iron/steel sector in different stages

	Cost	Scale of CO_2 capture
2020	819-1331 RMB	500,000 tons
2035	726-1096 RMB	500,000 tons
2050	591-701 RMB	500,000 tons

(2) Analysis of the technological costs of CO_2 transportation in the iron/steel sector

With respect to CO_2 transportation, in combination with the source-sink matching and the judgment of transportation modes in 3.2.2, given the fact that CO_2 transportation pipelines for the iron/steel sector have an average length of 116.63km and in view of the analysis of the technological economy of different CO_2 transportation modes in China in the medium and long term, the costs of transportation technologies in the iron/steel sector in different stages are listed in the table below.

Table 7 CO2 transportation costs in the iron/steel sector in different stages

	Technology option	**Transportation cost per unit of distance**	**Transportation cost per unit of emission reduction**
2020	Tanker/train	RMB 1.0/t·km	RMB 116.63/ton
2035	Tanker/train	RMB 1.0/t·km	RMB 116.63/ton
2050	Pipeline	RMB 0.20/t·km	RMB 23.326/ton

(3) Analysis of the technological costs of CO_2 utilization and storage in the iron/steel sector

With respect to CO_2 storage, in combination with the judgment of CO_2 storage and utilization methods in 3.2.3 and the analysis of the technological economy of different CO_2 utilization and storage methods in China in the medium and long term, the costs of utilization and storage technologies in the iron/steel sector in different stages are listed in the table below.

Table 8 CO_2 utilization and storage costs in the iron/steel sector in different stages

	Technology option	**Cost**
2020	EOR	RMB -630~510/ton
2035	EOR	RMB -630~510/ton
2050	Deep saline aquifers	RMB 8~135/ton

(4) Analysis of the total technological costs in the iron/steel sector

Based on a summary of the two tables above, the costs of emission reduction by CCUS in China's iron/steel sector in different stages are listed in the table below.

Table 9 Costs of CCUS per unit of CO_2 emission reduction in the iron/steel sector (RMB/tCO_2)

	Capture			Transportation	Storage			Total		
	Min	Max	Mean	Mean	Min	Max	Mean	Min	Max	Mean
2020	819	1331	1075	117	-630	510	-60	306	1958	1132
2035	726	1096	911	117	-630	510	-60	213	1723	968
2050	591	701	646	23	8	135	71.5	622	859	741

In combination with the results of the evaluation of CCUS costs in China’s iron/steel sector above and the results of the analysis of the emission reduction potential of the iron/steel sector brought by CCUS in different years in the table above, the total costs of CCUS in the iron/steel sector are listed in the table below.

Table 10 Analysis of the total costs of CCUS in the iron/steel sector in the near, medium and long term

		Near term	Medium term	Long term
Emission reduction potential (mtCO_2)		0	15	100-200
Total costs	Min (RMB 100 million)	0	32	622
	Max (RMB 100 million)	0	258	860
	Mean (RMB 100 million)	0	145	740

As indicated by the table, in the near term (2020), restricted by the development stage of CCUS in the iron/steel sector, carbon emissions reduced by CCUS in this sector are still very limited, so the corresponding costs are negligible. In the medium term (2035), carbon emissions reduced by CCUS in the iron/steel sector will be approximately 15 million tons and the corresponding range of costs will be RMB 3.2 billion to RMB 25.8 billion, averagely RMB 14.5 billion. In the long term (2050), carbon emissions reduced by CCUS in the iron/steel sector will be roughly 0.1-0.2 billion tons and the corresponding range of costs will be RMB 62.2 billion to RMB 86 billion, averagely RMB 74 billion.

4. Policy Recommendations for Promoting the Development of CCUS in the Iron/Steel Sector

An overall consideration of the development status and trend of CCUS in China implies that CCUS is still in the experiment and demonstration period for some time to come and the general idea for the development of CCUS remains gradually completing full-chain and large-scale demonstration of CCUS technologies by stages through multi-area technological demonstration. As there's absence of CCUS pilot and demonstration projects in the iron/steel sector, it's necessary to accumulate experience and facilitate the reduction of the costs of CCUS technologies and the improvement of CCUS technologies by implementing pilot projects in the sector, so as to prepare for the future commercial application of CCUS. Specifically, it is recommended to take actions by three stages, namely the 14th FYP period, 2025-2035 and 2035-2050:

During the 14th FYP period, the general idea for the development of CCUS in the iron/steel sector is carrying out relevant experiments, identifying superior key technologies and pushing forward CCUS-ready in iron/steel plants. It is recommended to carry out CCUS experiments for the iron/steel sector and carbon capture experiments for key technological processes in the sector (e.g., blast furnace, direct reduced iron (DRI), etc.). Efforts should be made to explore the CCUS development mode that meets China's national conditions, identify superior technologies that can be popularized on a large scale and gradually promote the reduction of CCUS costs and additional energy consumption. CCUS should be regarded as a key technology in the strategic emerging industry, a key and core technology in the energy conservation and environmental protection industry and a cutting-edge energy technology requiring intensified deployment of iron/steel enterprises. Efforts should be stepped up to conduct technological R&D, experiment and reserve. It should be requested that newly built iron/steel production facilities due to decremental displacement and production shift should be CCUS-ready (including research on investment options, site and logistic channels, storage options), so as to help iron/steel plants to conduct CCUS retrofitting at a lower cost in the future.

In 2025-2035, the general idea for the development of CCUS in the iron/steel sector is conducting extensive promotion and deployment, realizing large-scale and full-chain experiment and demonstration of CCUS in the iron/steel sector and basically completing relevant supporting infrastructure building. It is recommended to strengthen the promotion of large-scale and full-chain CCUS demonstration projects for the iron/steel sector, complete CCUS demonstration projects with a capacity of 1 million tons CO2 per year, establish a CCUS demonstration industry system for the iron/steel sector involving upstream and downstream industries, and drive the development of relevant infrastructure and the growth of supporting equipment manufacturing. Actions should be taken to strengthen technological innovation, promote breakthroughs in key technologies, significantly lower the costs it takes to apply CCUS technologies to the iron/steel sector and improve the ability of the iron/steel sector to implement full-chain CCUS design, construction and operation. Efforts should be made to promote the construction of pipelines that serve main emission sources of the iron/steel plants and build industrial clusters around these emission sources.

In 2035-2050, CCUS will be widely applied in the iron/steel sector to promote the realization of near-zero carbon emissions in the sector in the future. Breakthroughs should be made in technological innovation, energy consumption reduction and other aspects, corresponding infrastructure should be improved, several large-scale and full process projects, each with a capacity of 1 million tons CO2 per year, should be completed and put into commercial operation. Under the combined action of other low-carbon technologies for the iron/steel sector, near-zero carbon emissions should be basically accomplished in the iron/steel sector in the future.