Strategies and Policies on Carbon Capture, Utilization and Storage in China's Industry Sector

（2017 Report --- Summary for Policymakers）

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1. Assessment of industrial development in China

1.1 Development status and trend of Chinese industrial sector

Industry has developed rapidly in China with accelerated construction and industrialization since the reform and opening up. It has supported the high-speed development of national economy and continued enhancement of national strength. In 2011, China became the world's largest industrial country, topping the output of over 220 of 500 major industrial products. As China economy has entered the “new-normal” status in recent years, the industrial sector as a whole remains huge despite growth slowdown of industrial added value. In terms of industrial structure, the secondary industry has secured a dominate position until overtaken by the tertiary industry in 2012. In the industrial sector, labor-intensive industries and heavy industries advance along with accelerated urbanization and industrialization. Particularly, heavy industries, represented by automobiles, petrochemicals and heavy-duty equipment, have received government support at national and local levels since the mid-1990s. The ratio of light and heavy industries in China maintains 3:7 beyond the 11th Five-Year Plan (FYP) period, significantly higher than the current level and even the peak level of developed countries.

1.2 Development status and trend of iron and steel sector

The iron and steel industry is an important pillar of the national economy. China has been the world's largest iron and steel producer with leapfrog growth in iron and steel production since 1996. The crude steel production surged from 1. 6 million tons in 1949 to 804 million tons in 2015, and increased at a high rate from 2000 onwards. Given the huge population base in the current stage of economic development, China's crude steel production per capita stays at a high level, though still lower than that of South Korea, Japan and other developed countries. In 2015, the crude steel production per capita reached 586 kg, 2.6 times the world's average. In contrast to crude steel production expansion, the capacity utilization rate fell from 88.7% in 2006 to 64.8% in 2015, implying serious overcapacity of the iron and steel sector. The product structure is dominated by low-end iron and steel products, such as building-used steel product, so the added value rate of China's iron and steel sector needs further improvement. Long-process production remain the mainstream in China's iron and steel production. The short process production accounts for only about 10% in China, but over 30% on average in the world. The proportion of electric arc furnaces (EAF) even exceeds 50% in the United States and other advanced countries.

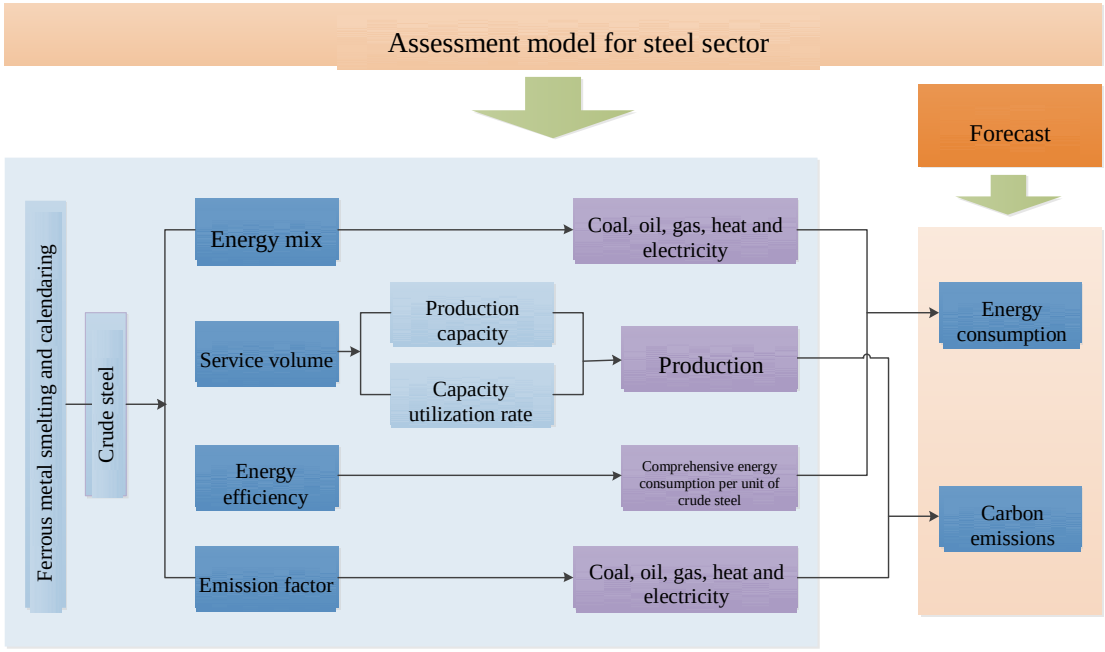
Under the impact of the above-mentioned factors, China's iron and steel sector continues to reduce energy consumption and carbon emissions per ton of crude steel. In 2010-2015, the comprehensive energy consumption per ton of crude steel decreased from 605 to 527 kilograms of coal equivalent (kgce) and reached the international forefront for leading iron and steel enterprises such as Bao Steel Group. Nevertheless, regarding energy consumption and carbon emissions per unit of steel production, China lags behind international leaders, due to the

disparity of steel enterprises and structure of steelmaking processes. There are still significant gaps among domestic steel enterprises which are widely divided by facility scale, energy-saving technology, and product structure.

1.3 Energy consumption and carbon emissions of iron and steel sector

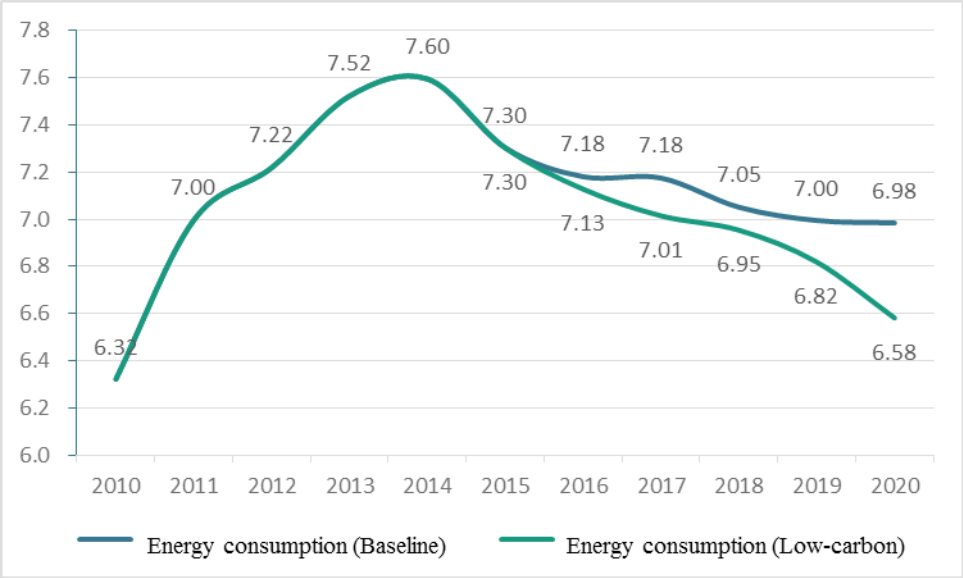
The National Center for Climate Change Strategy and International Cooperation (NCSC) has constructed a low carbon assessment model in order to calculate and forecast the energy consumption and carbon emissions of the iron and steel sector. Through analysis of different development scenarios, the model simulates the energy production and consumption and carbon dioxide (CO_2) emissions of the iron and steel sector in each year during 2016-2020 with 2010-2015 as the base years. The model framework is as shown below.

Figure 1. Assessment model for iron and steel sector



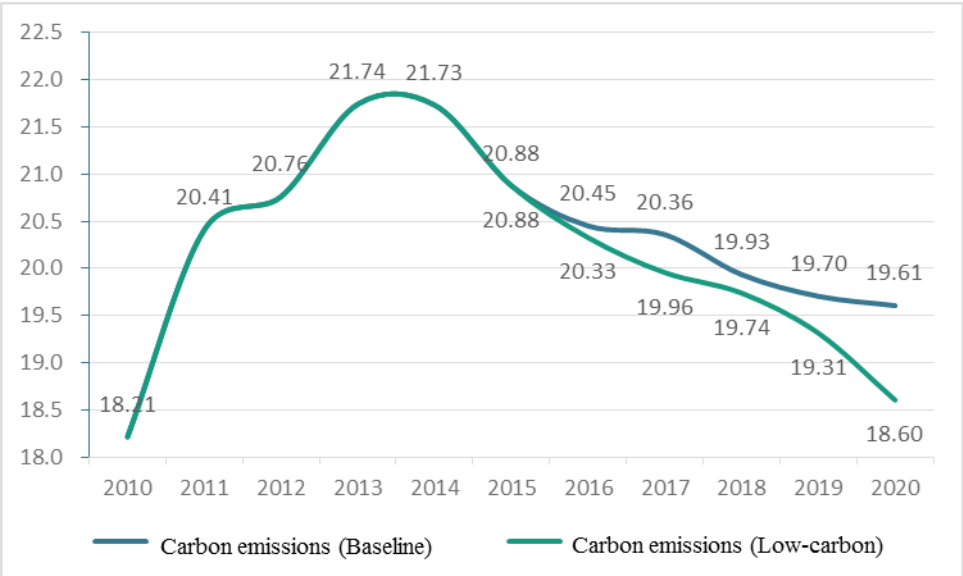
Based on the assumption that the intensity and quantity of national steel consumption will both decline in the 13th-Five-Year planning period, and taking into account the different change of such factors as the energy consumption per unit of crude steel, elimination of steel capacity and improvement of capacity utilization rate under the historical trend and national target requirement, two scenarios, i.e. the baseline scenario and planning scenario, are set in this analysis. The China's crude steel energy consumption in the two scenarios is given as follows.

Figure 2. Historical change and forecast of energy consumption (100 million tons)



According to the related analysis and calculation, the CO_2 emissions of China's iron and steel sector (including process emissions) peaked at 2.17 billion tons in 2013. If only the CO_2 emissions from energy consumption in iron and steel sector is counted, it reached the peak level of 18.1 million tons in 2014. The future CO_2 emissions of energy combustion in the iron and steel sector in two scenarios are shown as follows, considering such factors as steel production and capacity reduction, EAF utilization improvement, waste heat power generation alternative to coal-fired power generation, and expanded application of new low-carbon technologies.

Figure 3. Historical change and trend of carbon emissions (100 million tons)



2. Analysis of international and Chinese CCUS demonstration projects

2.1 International CCUS projects

According to the Global Carbon Capture and Storage Institute（GCCSI）, there were a total of 38 large-scale integrated projects (LSIPs)[1] at the end of December 2016. Among them, 15 projects in the operate stage have captured more than 29 million tons of CO2. The LSIPs are mainly based in the United States and China, but for those in operate and execute stages are mainly based in the United States and Canada. From an industrial perspective, most of the LSIPs in the operate stage involve natural gas and coal-fired power plants, with only one related to the iron and steel sector.

The existing international demonstration projects still have mitigation potential as the generated emission reductions are far from expected to control global temperature rise below two degrees. According to the International Energy Agency (IEA), there will be a 50% chance to control the global temperature rise below two degrees by 2050 when the CO_2 emissions are cut by 60% from the 2013 level and the emission reductions total 1,000 billion tons. By then, the CCUS-derived emission reductions will reach 6.1 billion tons, which implies an average annual increase of 50% from the current level of 2,9 million tons only. Besides, CCUS is currently used only mostly in natural gas and coal-fired power generation. As not yet deployed well in cement, steel and biotransformation industries, and the potential to reduce emissions in the industrial sector remains to be further tapped. In addition, the investment in CCUS applications, from both the government and the private sector, is extremely limited and falls far short of demand. The control of global temperature rise below two degrees by 2050 requires an input of 2.2 trillion US dollars in the power sector and 1.3 trillion US dollars in the fuel switch sector, while the global cumulative investment registered only 19,000 US dollars during 2004-2013.

2.2 Chinese CCUS projects

China has made remarkable technological progress in CCUS in recent years. It has deployed systematically the basic research, development and demonstration on CCUS in terms of mitigation potential, carbon capture technologies, biotransformation, EOR and geological storage. China has designed and implemented a variety of CCUS projects that cover different emission sources, technological directions, and conversion and utilization modes. At present, there are about 12 CCUS demonstration projects built or under construction in the country. In terms of emission sources, half of these projects are targeted at coal-fired power plants, with the rest mainly focused on coal chemical projects, and none of them captured CO_2 from the iron and steel sector yet. In terms of carbon transportation mode, tankers are supplemented by pipelines. In terms of treatment of carbon, most of them are EOR, the rest of them are industrial

[1] Large-scale integrated projects (LSIPs) are large-scale projects that integrate capture, transport and storage, which refer to projects with an annual capture capacity of 800,000 tons for coal-fired power plants and projects with an annual capture capacity of 400,000 tons for other emissions-intensive sources.

applications and saline aquifer storage.

Three findings can be given through the analysis. Firstly, there is a large demand and potential for CCUS demonstration project in China. According to the preliminary calculations and statistics, in the next 10 to 20 years, the annual carbon emission reductions due to CCUS is quite large and will exceed 10 million tons of CO_2 through conversion or utilization of CO_2 for the production of synthesis gas/ liquid fuel, synthesis of methanol and synthesis of carbon acid esters and polymer materials; and will reach about 500 million tons for EOR and synthesis of carbonate and inorganic materials. Secondly, the CCUS demonstration projects are still in the start-up phase in China and the related experiences are quite limited. As a whole, CCUS research, development and demonstration is in its infancy. The longest duration of carbon capture projects is only five years, and that for EOR and coal chemical projects only seven years. Most of CCUS demonstration projects were launched after 2008 and put into operation after 2010, of which the majority run for less than three years. Thirdly, the demonstration is not comprehensive, but rather concentrated in certain fields. After years of efforts, though China has laid a certain foundation for CCUS in all sectors, it's still lags behind from international leaders. Especially, the current demonstration projects mostly focus on carbon capture and EOR, and little cover geological storage, sequestration monitoring and early warning, and large-scale CO_2 transport and storage.

3. Low-carbon policy framework assessment

3.1 Foreign and China's low-carbon policies

3.1.1 Foreign low-carbon policies

Low-carbon development, as the future trend of global development, requires the joint action of the international community. Currently, countries around the world have acquired valuable experience in the practice of green low-carbon development, embodied in the following aspects:

(1) Highlight overarching design and develop low-carbon strategy. Although low-carbon development was not long proposed, the major countries and regions are gradually incorporating this concept into the national mainstream development strategies. A number of countries have developed macro-strategies and roadmaps that pave a solid foundation for accelerating low-carbon transformation and promoting medium and long-term low-carbon development. For example, Britain has integrated low-carbon development into the national overall strategy and taken a series of policy measures. Japan has considered low carbon in the strategic planning in energy, economic and social fields in early 21st century. The European Union has launched an energy and climate package, including the amendment to the EU emissions trading system (EU ETS), decision of supporting task assignment for EU member states, CCUS legal framework, renewable energy directive, legislation on automotive CO_2 emissions, and fuel quality directive, and drawn the roadmap to promote the development of low carbon technologies.

(2) Enhance implementation safeguard measures and improve laws and regulations. Legal or policy documents set out specific targets for low-carbon development, and on this basis, policies of investment, price and tax incentives are introduced to ensure the realization of these targets. The Comprehensive Climate and Energy Package, adopted by the European Union in 2009, made it clear to raise the share of renewable sources in EU energy consumption to 20% and the share in energy consumption of the transport sector to 10% by 2020 and cut the greenhouse gas (GHG) emissions by 20% from 1990 levels, and set out binding national targets for renewable energy, emissions trading system and CCUS application. The *Act on Promotion of Global Warming Countermeasures*, enacted by the Japanese Government in 1998, clearly stipulated that the control of carbon emissions target is the shared responsibility of governments, business operators and the general public.

(3) Introduce taxation policies and encourage innovative mechanisms. Many countries roll out policies and incentives in favor of low-carbon innovation in the whole society, which has injected new vitality to global low-carbon development, covering enterprise development model, energy supply and utilization, industrial upgrading, and financial investment. In 2001, Britain introduced the Climate Change Levy on energy use in industrial, commercial and public sectors. Germany widely uses such fiscal policies as subsidies, incentives, tax breaks, and through *Renewable Energy Sources Act*, guarantees the feed-in tariff for renewable energy sources over 20 years and provide financial support. Japan's taxation policies in favor of low-carbon development include tax system reform, preferential rate loans and subsidies, and incentives to environmental protection investment.

(4) Make flexible adjustments and use market mechanisms. Countries around the world have come to realize that government-led or technical means solely are difficult to achieve carbon reduction targets and market mechanisms are conducive to scientific and technological innovation and broad mitigation action. Lunched in January 2005, EU ETS is the largest international, multi-sectoral GHG emissions trading system. In addition to emission trading schemes, the market mechanisms to mitigate climate change include the Renewable Portfolios Standards as in Britain, Australia, Italy and the United States and the Energy Performance Contract as in the United States, Canada, Europe and India.

(5) Strengthen standards and push for scientific and technological progress. Policy instruments are highly valued in promoting the development of low-carbon technologies. The technological innovation system is combined with leading standards to stimulate scientific and technological innovation. In the United States, the carbon emissions standards for new power plants in the *Clean Power Plan* undeniably gave a strong impetus to mitigation in the power supply sector and pushed forward low-carbon technologies, though overturned by the incumbent President Trump's executive order. The British Government starts from institutional mechanisms to encourage innovation in low-carbon technologies. It continues to adjust the focus of policy support and increase the financial support year by year by channeling the Environmental Transformation Fund and other traditional funding sources in the field of environmental protection, which covers a series of new key low-carbon technologies, such as

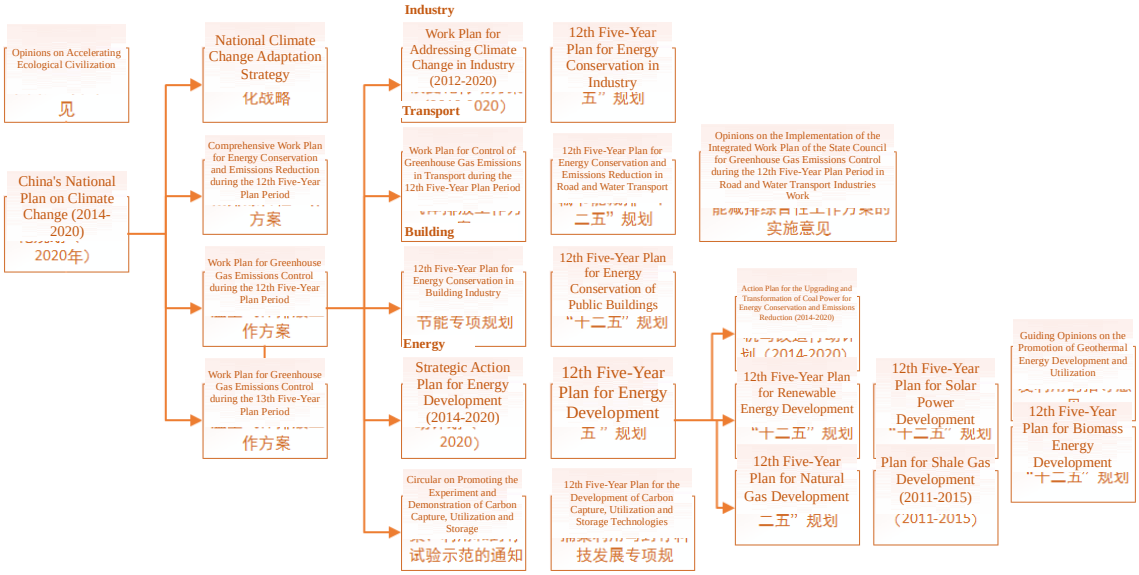
smart grid, renewable energy, CCUS, electric vehicles, energy-efficient buildings. Recognizing the importance of low-carbon technologies, the Japanese Government focuses research on nuclear power, renewable energy and clean fossil energy utilization and carries out research and development projects for renewable energy and energy efficiency, fuel cells, distributed energy network systems, and CCUS applications. The massive medium- and long-term plans for technological research, development and demonstration, involving huge financial investment, have yielded remarkable results.

3.1.2 China's low-carbon policies

China has made unremitting efforts to tackle climate change and promote low-carbon development. Low-carbon development has been identified as a major strategy for climate change adaptation and mitigation and economic and social transformation and considered as a major opportunity to accelerate the change of economic development patterns for economic restructuring and industrial transformation. The policies and targets for low-carbon development rely on the existing climate change policy system and environmental and energy management systems. They have gradually formed a full-fledged system that encompasses laws and regulations, administrative orders, economic incentives, market mechanisms and pilot projects. This system provides all-round, deep-level guidance and paves a solid foundation for low-carbon development.

(1) Improve legislation for top-level design. As a code of conduct to adjust power relations and social relations, laws not only provide legal protection but also establish the top-level design for low-carbon development. In China, there currently are about 30 laws and 90 regulations pertaining to low-carbon development and special laws and regulations under preparation and amendment to address climate change and low-carbon development. The National Leading Group for Climate Change Legislation was set up in 2011, comprised of the Environmental Protection and Resources Conservation Committee and the Law Committee of the National People's Congress (NPC), the Legislative Affairs Office of the State Council, and 17 ministries. In particular, the National Development and Reform Commission (NDRC) spearheads legislative research, survey and drafting, and expedites the legislative process of the *Climate Change Law* and the *Administrative Regulations on Carbon Emissions Trading*. Many cities have presented local legislation to address climate change and low-carbon development and explored legislation on climate change and emissions trading. *China's National Plan on Climate Change (2014-2020)* put forward targets for emissions control, low-carbon pilot and demonstration, climate change resilience, capacity building and international cooperation. In the sectors of energy, industry, building and transport, special plans have been formulated to address climate change, or provisions drawn from energy conservation and emissions reduction plans of other sectors. China's planning framework for climate change and low carbon is as shown in Figure 4. In addition, China presses ahead with low-carbon transition under the framework of national policy of ecological civilization construction. It takes low-carbon development as a basic way to accelerate the construction of ecological civilization.

Figure 4. Climate change planning by sectors



(2) Apply executive orders for low-carbon management. Herein administrative orders refer to mandatory orders for energy conservation and emissions reduction of government agencies, enterprises, individuals and the whole society. The policy instruments include mandatory standards and industry thresholds, with measures specific to backward production capacity elimination, transportation, construction and green government procurement. During the 12th FYP period, the 100 Energy Efficiency Standards Promotion Program was implemented for two consecutive phases, which witnessed the approval and release of totally 221 national standards for energy efficiency. In 2015, the Standardization Administration of China (SAC) approved and issued 11 national standards for GHG emissions in such key industries as power generation and steel production, and the Ministry of Transport, National Railway Administration, and State Forestry Administration promulgated respective standards for low-carbon development. NDRC provided the accounting methods and reporting guidelines for GHG emissions in 23 key industries and another industry in three batches. The National Technical Committee on Carbon Management, established with SAC's approval, is responsible for formulating and revising national standards for carbon management and building the system framework for national GHG management standards. In 2015, a unified low-carbon product certification system took shape with the introduction of *Administrative Measures for Certification of Low-carbon Energy-efficient Products*. Totally seven kinds of products have been listed in the *Low-carbon Product Certification Catalogue*.

(3) Strengthen economic incentives to provide financial support. Economic incentives mainly encompass price instruments and financial support funds. There are a wide range of financial support funds associated with low-carbon development. The funds are sourced from the central and local governments, including special fund for renewable energy development, incentive fund for energy management contracting, subsidies for building energy efficiency, and special fund for energy conservation and emissions reduction. Funds can be put in place before the implementation of projects, such as support funds for cleaner production, recycling

economy and energy conservation, or after the implementation of projects, such as provincial and municipal contributions to low-carbon pilot. In terms of form, there are subsidies for project investment, incentives instead of rewards based on results, public investment of government agencies in low-carbon management, clean development mechanism fund, and financial support for repayment.

(4) Encourage market mechanisms to increase market vitality. The Outline of the 12th Five-Year Plan first proposed "gradually establishing a carbon emissions trading market", in order to actively make use of market mechanisms and explore the control of GHG emissions at low cost. Later, NDRC decided to carry out the carbon emissions trading pilot in Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong and Shenzhen. At the end of 2015, the carbon market opened in the seven pilot areas. With the preparatory work from 2014 onwards, the national carbon market will start in 2017.

(5) Conduct pilot and demonstration, and sum up practical experience. China continues the low-carbon pilot and forms an all-round multi-level system for low-carbon pilot which encompasses provinces (cities), industrial parks, communities, districts (towns). A total of 86 low-carbon pilot areas have committed or intend to peak carbon emissions. The pilot work plays an active role in the national response to climate change and low-carbon development. All pilot provinces and cities have drawn the GHG emissions inventories. In addition, China actively carries out CCUS experiment and demonstration and low-carbon transport system construction. Issued by NDRC in 2013, the *Circular on Promotion of Experiment and Demonstration in Carbon Capture, Utilization and Storage* promotes and guides CCUS experiment and demonstration.

Table 1 China's low-carbon policy system

	Laws and regulations	**Administrative orders**	**Economic incentives**	**Market mechanisms**	**Pilot and demonstration**
Policy instruments	- Laws (approximately 30) - Regulations (about 90)	- Compulsive standards - Mandatory tasks - Industry access systems	- Price instruments - Financial support funds (investment subsidies, loan discounts, replacement subsidies with rewards)	- Carbon emissions trading Pilots - Certified emission reductions trading	- Low-carbon pilot in provinces and cities, parks, communities, towns, and other demonstration projects
Important content	- Energy conservation law - Renewable energy law - Climate change law	- Elimination of backward production capacity - Green procurement - Low carbon identification and certification - Energy conservation and low carbon action for 10,000 enterprises	- High energy consumption industry differential price - Low-carbon special funds - Energy - saving emission reduction fiscal policy comprehensive demonstration funds - Clean Development Mechanism	- Administrative measures for certified emission reductions trading - Emissions trading pilot in seven provinces and cities, pushing to establish a national carbon market	- 87 low-carbon pilot provinces and cities, 51 national low-carbon industrial parks, 8 national low-carbon districts (towns), and about prospective 1,000 low-carbon communities - Low-carbon transport and CCUS pilot and demonstration

3.2 China's low-carbon policies for industrial sector

3.2.1 Overview

Industry sector, a major energy consumer and carbon emitter in China, accounts for about 70% of the national energy consumption and carbon emissions. It is therefore urgent to change the model of industrial development towards low-carbon path. Industry-related low-carbon policies implemented during the 12th FYP period are summarized in this study, which include 10 plans, 9 programs, 13 opinions, 6 notices, and 8 decisions, measures and guidelines. They are divided into six categories: structural adjustment, standard development, regulatory instruments, economic incentives, market-based instruments and policy guidance, as shown in the table below.

Table 2 Categories and highlights of low-carbon policies for industry

	Structural adjustment	Standard development	Regulatory instruments	Economic incentives	Market-based instruments	Policy guidance
Policy instruments	Plans, programs, opinions, decisions and other documents released by the State Council, NDRC and MIIT	Two product promotion catalogues involving 13 batches of products and seven cleaner production evaluation indicators released by NDRC and MIIT	Administrative regulations and departmental rules promulgated by the State Council, NDRC and MOF	Administrative regulations and departmental rules promulgated by the State Council, NDRC and MOF	Administrative regulations, departmental rules and local rules promulgated by the State Council, MIIT, NDRC and local governments	Administrative regulations, departmental rules and local rules promulgated by the State Council, MIIT, NDRC, and local governments
Policy highlights	- Inhibition of the fast growth of energy-intensive and high-emission industries - Elimination of backward production capacity - Adjustment of energy consumption structure - Production capacity replacement - Increase of the proportion of services and strategic emerging industries - Industrial transformation and upgrading	- Energy consumption caps and energy efficiency standards for products - Promotion of energy-saving low-carbon technologies - Development of cleaner production indicator system for key industrial sectors	- Decline in total industrial energy consumption - Energy efficiency and low carbon action for 10,000 enterprises, energy conservation and emissions reduction targets and tasks - Elimination of backward production capacity - Control of energy-intensive projects - Implementation of caps on energy consumption per unit of product - Special funds for energy conservation and emissions reduction	- Differential prices and punitive prices - Preferential policies concerning special funds, income tax, tariff and value added tax (enhance technological research and development, promotion and application, as well as introduction for renewable energy utilization, energy conservation and emissions reduction in the industrial sector implement energy management contracts)	- Carbon emissions trading market construction - Electric power system reform and market construction	- Measures for technology promotion and management - Transformation and upgrading projects guidebook - Special actions and demonstration projects - National pilot low-carbon industrial parks to guide and promote low-carbon development

3.2.2 Evaluation

The industrial development policy during the 12th FYP period aims at transformation and upgrading towards a resource-saving and environment-friendly industry and rests on energy conservation and emissions reduction to change development mode and adjust industrial structure. Vigorous efforts have been made to advance technological transformation and promote new energy-efficient and eco-friendly technologies, facilities and products. With the establishment of a sound work system for energy conservation and emissions reduction, remarkable results have been achieved in low-carbon development. First, the industrial structure continued to optimize as the proportion of energy-intensive industries declined and that of high-tech industries increased. In 2015, energy-intensive industries accounted for 27.8% of the added value of enterprises above the designated scale, down by 2.5% from the 2010 level. High-tech industries grew rapidly and took up a larger proportion. The average annual increase of added value hit 11.4% since the 18th CPC National Congress, 3.4 percentage points higher than that of enterprises above the designated scale. The percentage in the added value of enterprises above the designated scale reached 11.8% in 2015, up by 2.9 percentage points from the 2010 level. Second, a large amount of backward production capacity has been removed during the 12th FYP period, including 90.89 million tons of iron, 94.86 million tons of steel, 2.05 million tons of electrolytic aluminum, 657 million tons of cement (clinker and grinding), and 169 million weight cases of flat glass. Third, industrial energy efficiency was significantly improved. The energy consumption per unit of added value of enterprises above the designated scale dropped by 28%, representing 690 million tons of coal equivalent energy savings, while backward production capacity was eliminated more than tasked during the 12th FYP period. Particularly, the six major industries (steel, nonferrous metals, petrochemicals, chemicals, building materials and paper) narrowed the gap with the international advanced level by drastically cutting energy consumption per unit of product.

3.3 China's low-carbon policies for iron and steel sector

3.3.1 Overview

China's iron and steel sector started the work in energy conservation and emissions reduction in the early 1980s. It placed focus on leakage control, publicity and education, and institution and team formation, and carried out energy conservation of individual facilitates and processes in that period. During the 7th FYP period, attention was shifted to the overall energy efficiency while modern energy management was highlighted. The energy management system became independent of the enterprise management system. During the 9th FYP period, the iron and steel sector continued to emphasize on the transformation for energy conservation and development and application of energy-saving technologies and equipment, and introduced economic value into energy management. In the next five years, a number of policies were unveiled concerning energy efficiency and emission control of the iron and steel sector, which require controlling total iron and steel output, curbing blind capacity growth, removing backward production capacity, and expediting structural adjustment. During the 11th FYP period, China for the first time included energy intensity in the five-year plan for national economic and social

development. It put forward binding targets for energy conservation and energy efficiency and took proactive measures to adjust economic structure, change economic development mode, inhibit energy-intensive industries, and promote low-carbon energy. In the 12th FYP period, carbon intensity was integrated into the five-year plan for national economic and social development, and emissions control became an important consideration of industry, including the iron and steel sector.

A total of 36 key policies were rolled out for the iron and steel sector since 2006, including 12 during the 11th FYP period, 17 during the 12th FYP period and 7 during the 13th FYP period. They are classified into five categories: structural adjustment, industry standards, economic incentives, mandatory tasks, and guiding tasks, with highlights described in the table below. According to preliminary statistics, **structural adjustment** is addressed in many administrative regulations and departmental rules promulgated by the State Council, NDRC, and Ministry of Industry and Information Technology (MIIT). The policies focus on the control of production capacity by cutting excessive capacity, eliminating backward capacity, controlling new capacity and replacing capacity of the same or reduced amount, and on industrial concentration improvement through merger and reorganization, as well as demand structure improvement. **Industry standards** are embodied in the standards and specifications released by SAC, MIIT, NDRC and SAC, including integrated energy consumption standards and process energy consumption standards for existing, new and expansion enterprises, higher access thresholds and strict access requirements. **Incentive mechanisms** are put in place through administrative regulations and departmental rules promulgated by the State Council, NDRC and Ministry of Finance (MOF). They include tax incentives, subsidies to replace rewards, differential prices, punitive prices, and ladder prices, as well as carbon emissions trading scheme. **Mandatory tasks** are assigned through administrative regulations, departmental rules and local rules formulated by the State Council, MIIT, NDRC and local governments. Among them are the reduction of industrial energy consumption, control of industrial production, energy conservation and emissions reduction assigned to enterprises by central and local governments, as well as compulsory coal-to-gas and coal-to-electricity transformation in some areas. Assigned in the same way as mandatory tasks, **guiding tasks** aim to encourage industries and enterprises to carry out technological research, development and promotion, develop circular economy, conduct energy saving transformation and upgrading, and take measures for energy conservation and emissions reduction (including energy management system, supporting facilities, energy efficiency assessment and review). Industry policies of different highlights that mention such tasks also fall into this category.

Table 3 Categories and highlights of low-carbon policies for iron and steel sector

	Structural adjustment	Industry standards	Incentive mechanisms	Mandatory tasks	Guiding tasks
Policy instruments	Administrative regulations and departmental rules promulgated by the State Council, NDRC and MIIT	Standards and specifications released by SAC, MIIT and NDRC	Administrative regulations and departmental rules promulgated by the State Council, NDRC and MOF	Administrative regulations, departmental rules and local rules promulgated by the State Council, MIIT, NDRC, and local governments	Administrative regulations, departmental rules and local rules promulgated by the State Council, MIIT, NDRC, and local governments
Policy highlights	- Concentration enhancement through merger and reorganization - Production capacity control (including excessive capacity reduction, backward capacity elimination, and new capacity control) - Production capacity replacement (including equal and reduced replacement) - Demand structure improvement	- Higher access thresholds and strict access requirements - Integrated energy consumption standards and process energy consumption standards for existing enterprises - Integrated energy consumption standards and process energy consumption standards for new and expansion enterprises - National GHG management standards	- Carbon emissions trading scheme - Differential prices, punitive prices, and ladder prices - Subsidies to replace rewards - Tax incentives	- Targets to reduce industrial energy consumption - Production control targets - Energy conservation and emissions reduction targets assigned to enterprises by central and local governments - Compulsory coal-to-gas and coal-to-electricity transformation in some areas	- Technological research, development and promotion - Development of circular economy - Energy saving transformation and upgrading - Implementation of energy conservation and emissions reduction measures (including energy management system, supporting facilities, energy efficiency assessment and review)

3.3.2 Evaluation

During the 11th FYP period, the low-carbon related policy for the iron and steel industry centered on structural adjustment. It intended to improve the overall technical level and energy efficiency through production capacity control with a view to industrial optimization and upgrading. The specific policy measures included merger and reorganization to improve industrial concentration, inhibition of blind production capacity expansion and elimination of backward production capacity to control total steel production capacity, and relevant financial and economic means. Under the combined policy impact, the iron and steel sector phased out 122.72 million tons of backward iron production capacity and 72.24 million tons of backward steel production capacity over the five years. At the same time, large-scale modern facilitates were put into use. Among the key steel enterprises, the proportion of blast furnaces with a

capacity of 1000 m^3 or more 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%. A more rational industrial structure was conducive to energy conservation and emissions reduction. At the end of 2010, there was an overall improvement in the main indicators of key steel enterprises. The energy consumption per ton of iron fell to 605 kilograms of coal equivalent, down by 12.8% compared with 2005.

During the 12th FYP period, the policy for the iron and steel sector has undergone some changes under the realistic conditions of tightening energy and environmental constraints and strengthening low-carbon efforts. With more focus put on energy conservation and emissions reduction, carbon reduction stood out as a constraint. In the five-year plan for the steel industry, "low carbon" was identified as the principle and objective, and the target of a 18% reduction in carbon emissions per unit of added value was defined. To this end, the thresholds for access to the sector were further raised and strict thresholds set for the phase-out of facilities. The completion of binding targets for energy consumption and environmental projects was made necessary to project approval. It is noteworthy that there was no policy specific to the control of carbon emissions in the iron and steel sector despite the binding target for carbon intensity. From 2011 to 2015, the iron and steel sector phased out 90.89 million and 94.86 million tons of backward iron and steel production capacity respectively. However, overcapacity still existed and evolved from regional and structural excess into absolute excess. The crude steel capacity utilization dropped from 79% to 70% or so over the five years, and the debt rate of key large and medium-sized enterprises exceeded 70%. Meanwhile, though the energy consumption per ton of steel declined, such as from 605 kg to 572 kg, but this could not offset incremental energy consumption with growth in iron and steel production.

During the 13th FYP period, China adopts a more robust policy to resolve steel overcapacity, and begins to explore the practical policy for CO_2 emissions control. In view of sluggish steel demand, serious excess capacity, and tight environment and energy constraints, the country elevates resolving the excess steel capacity into major decisions and arrangements of the CPC Central Committee and the State Council and into the major tasks for supply-side structural reforms. It aims to slash the crude steel production capacity by 100-150 million tons based on an elimination of more than 90 million tons of backward production capacity. The production capacity that fails to reach certain standards will be withdrawn by a combination of different policies and measures, including laws, regulations and policies concerning environmental protection, energy efficiency, quality, safety and technology. At the same time, better incentives will be offered to encourage enterprises to cut capacity through active reduction, mergers and acquisitions, transformation and conversion, relocation and renovation, and international cooperation. To provide support and strengthen policy guidance, national ministries and departments including MOF rolled out eight special policy documents, covering rewards and subsidies, fiscal and tax support, financial support, employee relocation, land use, environmental protection, quality and safety. In order to ensure the implementation of capacity reduction tasks, a 25-member inter-ministerial joint conference system for iron and steel and coal overcapacity resolution and poverty alleviation has been set up with approval of the State Council. The relevant provinces and cities have formulated the work programs and clarified work arrangements, targets and tasks in the five years period. A total of 28 provincial-level people's governments and Xinjiang Production and Construction Corps have also signed the

letter of responsibility for reducing excess capacity and eradicating poverty. In addition, the Chinese Government proposes low-carbon development as a basic approach of ecological civilization construction, and starts exploring policy specifically for carbon emissions control of the iron and steel sector. The national carbon emissions trading system to be launched in 2017 will cover such key industries as steel, electricity, chemicals, building materials, paper and non-ferrous metals, according to the 2015 China-US Joint Presidential Statement on Climate Change. Effectively control the carbon emissions of steel and other key industries is listed as a key task in the five-year plan for national economic and social development for the first time.

Among the low-carbon policies for the iron and steel industry, the structural adjustment policies that focus on production capacity control grasp the principal contradiction and the key issues of industrial development. The policy to cut production capacity provides a breakthrough to promote green low-carbon development. Also, it should be noted that the dedicated policy for carbon emissions control in the iron and steel sector remains absent and the supporting mechanisms are under preparation. Emission reductions are only a spin-off effect of industrial restructuring, energy conservation and energy efficiency improvement.

3.4 Policy recommendations on carbon reduction for China's iron and steel sector

Attach importance to top-level design for low-carbon development. Climate change adaptation and mitigation and low-carbon development become more and more important. Amid the growing demand for low-carbon transition, the traditional ideas and technologies of energy conservation and pollutant emissions reduction cannot completely represent and cover low-carbon development. At the national level, we should study and formulate a strategic plan that regulates and guides the low-carbon development of iron and steel industry by integrating binding targets for carbon reduction. Local governments should pay more attention to low-carbon development, reflect this priority indicator in the government performance evaluation, and establish an evaluation and examination system for low-carbon development. At the enterprise level, companies should change ideas and develop strategies oriented to low-carbon development. They are expected to refresh the traditional ideas in the pursuit of green development as social responsibility and obligation and compete for green low-carbon development not limited to cost efficiency.

Deepen industrial restructuring based on existing policies. First, the cost of steel product exports with low added value will be increased, while creating the conditions for research, development and production of high-end steel products. Second, the recovery and reuse of scrap steel will be strengthened. Support should be given to enterprises engaged in scrap steel recovery, processing and distribution based on advanced technologies. Given the current steel stock, the management of scrap steel recovery needs to be strengthened and in particular, the social steel recycling system should be improved. Changes needs to be made to promote technological upgrading for better scrap steel recovery and utilization, covering operating mechanism, equipment configuration, processing technology, product quality, and secondary pollution control.

Give full play to the regulation and guidance of standards for the iron and steel sector. First, the steel standards for downstream consumer industries will be raised through enhanced cooperation with building, automotive, machinery, vessels and home appliances industries, so as to adjust and upgrade product structure from the demand side. Second, industry standards should be improved, covering equipment, process energy consumption and steel performance and quality, and the implementation should be supervised more effectively. On this basis, product standards will be upgraded and refined, while sound industry standards are essential to industrial upgrading. Third, it is necessary to timely explore the carbon emissions standards for iron and steel industry based on the national GHG management standards and GHG emissions accounting methods and reporting guidelines, so that the standards can serve as both constraint and guidance.

Enhance capacity building to support the management of carbon emissions. First, enterprises are required to establish the support system and evaluation system for carbon emissions management, including carbon emission statistical monitoring system and emission database, and set up a special independent body to monitor pollutant emissions at any time. Second, the robust systems for the statistical monitoring, supervision, evaluation and examination of carbon reduction should be put in place. In addition, study, exchange and training should be maintained. Teaching materials should be prepared for carbon management in the iron and steel sector, and a variety of activities carried out for carbon reduction, including policy interpretation, experience extension, personnel training, exchange and cooperation at home and abroad. Experts will be organized to provide enterprises with advisory services in carbon management, carbon emission trading, and mitigation technology application.

4. CCUS policy framework assessment

4.1 International CCUS policies

At present, many developed countries have laid down CCUS policies and strategies according to respective conditions. They amend or add laws to regulate CCUS development and carry out active exploration in supporting policies and measures, in order to promote CCUS projects and technologies.

(1) The strategic layout indicates the direction for CCUS development. The strategic planning in the fields of low carbon, energy and climate change clarifies CCUS's importance in tackling climate change and makes arrangements for the CCUS deployment. The *Green Paper: A European Strategy for Sustainable, Competitive and Secure Energy*, published by the European Union in 2006, identifies CCUS as one of the three policy priorities to address the root challenges of energy security and climate change. Further, the *European Strategic Energy Technology Plan* (SET-Plan) unveiled in 2007 proposes the use of a dedicated policy to accelerate the development and application of low-carbon technologies. In the United Kingdom, the Stern Review released in 2006 has laid the basis for CCUS development and the *Meeting the Energy Challenge: A White Paper on Energy* in 2007 put forward process-wide CCUS demonstration in power plants across the country. Released in 2006, the *U.S. Climate Change Technology Program* (CCTP) suggests controlling GHG emissions through carbon capture and

storage.

(2) Advancing legislation provides a legal basis for CCUS development. The European Union has made significant breakthroughs in CCUS legislation. It has developed the world's first CCUS legislation *(Directive/2009/31 /EC of the European Parliament and of the Council on the Geological Storage of Carbon Dioxide* which stipulates the various aspects of geological storage, and adopted a series of detailed directives on all CCUS aspects. In the United Kingdom, the *Energy Act 2008* provides a framework for licensing, enforcement and registration of storage sites, and the world's first *Climate Change Act 2008* incorporates CCUS into the emission reduction plan for the power industry. The United States *Carbon Capture and Storage Early Deployment Act 2009* encourages the related industries to early deploy CCUS applications and the *American Clean Energy Leadership Act* released in July 2009 further clarifies the regulatory framework and financial assistance for CCUS development.

(3) The sound standard system regulates CCUS development and clarifies responsibilities and rights. Since CCUS is a complex technology involving multiple links and stakeholders, a standard system is needed to guide and regulate the CCUS development and define the responsibilities and rights of interested parties. There are safety standards for carbon capture in the *EU Directive 85/337/EEC* and environmental standards in the UK *Pollution Prevention and Control Act* and the *Control of Substances Hazardous to Health Regulations*. In regard to carbon transport, Norway and the United States specifically develop the appropriate standards and the European Union's existing pipeline standards can be applicable. The United States is the only country to introduce regulations on interstate and state transfer of pipeline responsibility. As to carbon storage, detailed provisions can be found in the *Directive on the Geological Storage of Carbon Dioxide* of the European Union (EU CCS Directive), the *Guidelines for Carbon Dioxide Capture, Transport, and Storage* of the United States, and the *Regulatory Guiding Principles for Carbon Dioxide Capture and Geological Storage* of Australia. In regard to monitoring and incident handling, the EU CCS Directive dedicates *Articles 13* and *Article 16* to leakage, and the *Recommended Practice: Design and Operation of CO_2 Pipelines* of Det Norske Veritas makes specific provisions for monitoring tools and content and incident response.

(4) Taxation means provide financial support for CCUS development. Internationally, the financial support for CCUS projects mainly include government subsidies, tax breaks, and investment from fund capital and private capital. In terms of fiscal policy, the EU's *Seventh Framework Programme for Research and Technological Development* (FP7) released in 2007 proposes funding projects related to carbon capture and sets aside 300 million EU ETS allowances to support 10-12 commercialized CCUS projects. In terms of tax policy, the *Climate Change Levy* stipulates that the UK electric power enterprises can enjoy an 80% tax relief as long as reaching certain targets for energy efficiency or emission reduction through CCUS applications. The *Section 45Q of the USA Internal Revenue Code* provides 20-dollar tax credit per ton of CO_2 captured and stored, and 10 dollars per ton of CO_2 captured and used for EOR.

Table 4 CCUS policies of major countries

Country	Policies and regulations	Highlights
European Union	Green Paper: A European Strategy for Sustainable, Competitive and Secure Energy (2006)	Identify CCUS as a preferred option to tackle climate change
	European Strategic Energy Technology Plan (SET-Plan) (2007)	Propose the adoption of specific policies to accelerate the development and application of low-carbon technologies
	Seventh Framework Programme for Research and Technological Development (FP7) (2007)	Fund CCUS projects and develop effective capture technologies
	Climate and Renewable Energy Package (2008)	Agree to finance CCUS projects and studies under the policy framework
	EU Emission Trading Scheme (2008)	Clarify CCUS' position in the scheme
	Directive 2008/1/EC (2008)	Rule the effects of carbon capture on the environment and human health
	CCUS Directive 2009/31 (2009)	Form the world's first detailed legislation on CCUS
United Kingdom	Meeting the Energy Challenge. A White Paper on Energy (2007)	Implement process-wide CCUS demonstration in power plants
	Energy Act (2008)	Set the legal framework for CCUS storage permits
	Climate Change Act (2008)	Identify CCUS as an important technical choice for the electric power industry
	Energy Act (2010)	Include provisions on agreeing and using CCUS technologies
United States	Climate Change Technology Program (CCTP) (2006)	Plan to control GHG emissions through capture and storage
	Bill for Regulation for Underground Storage of Carbon Dioxide (2008)	Update the *Safe Drinking Water Act* by including injection wells purely for carbon sequestration
	Guidelines for Carbon Dioxide Capture, Transport, and Storage (2008)	Stipulate that CCUS specifications should meet the requirements of *Clean Air Act* and *Clean Water Act*
	Carbon Capture and Storage Early Deployment Act (2009)	Stipulate that the related industries can collectively vote to set up CCUS research institutions
	American Clean Energy and Security Act (2009)	Dedicate a chapter to carbon capture and storage
	Regulations for Safe Actions on Carbon Storage Technologies (2010)	Regulate the specific implementation of CCUS projects
	House Bill to Include the Carbon Storage Act into the Legal System (HB259) (2010)	Provide the ownership of stored gas and responsibility transfer after CCUS projects are shut down
Australia	Regulatory Guiding Principles for Carbon Dioxide Capture and Geological Storage (2005)	Establish a unified CCUS framework within the jurisdiction of Australia
	Offshore Petroleum and Greenhouse Gas Storage Act (2006)	Provide the legality of offshore storage of CO_2

The above-mentioned developed countries have formulated policies to promote CCUS development at different dimensions, which largely recognizes the vital importance, regulates operating standards, and emphasizes the environmental impact. Nevertheless, there have not yet been perfect legal frameworks for CCUS development. In addition, the CCUS related policy and legal system is too vague to meet the requirements of government-expected large-scale commercial applications.

4.2 China's CCUS policies

China's CCUS-related policies are relatively vague and mostly provide macro guidance compared with those of developed countries and groups. China has published a total of 26 CCUS-related policy documents at the national level (including plans, programs, notice and opinions released by the State Council and ministries), including four CCUS specific documents. These policy documents can be classified into five categories: technology promoting (19, promoting and guiding the development and progress of CCUS technologies), demonstration support (12, encouraging to accelerate CCUS demonstration projects), target setting (3, setting stage-specific CCUS development targets), and environmental management (2, providing regulation on potential environmental risks and impacts of CCUS projects), and others (1). Among them, certain policy documents may fall into several categories. In general, China takes a positive attitude to CCUS development by indicating technology development directions supplemented by instructive targets, but the existing policies do not specify fiscal support.

As there are not yet dedicated laws and regulations in China for CCUS, CCUS projects are regulated by the existing legislation. Herein, the laws, regulations and rules that CCUS projects can follow or refer to are summarized, covering project approval, ownership recognition, project operation, environmental management, safety supervision, closure management (Table 5).

Table 5 China's existing legal and regulatory framework for CCUS projects

	Project approval	Ownership recognition	Project operation	Environmental management	Safety regulation	Closure management
Laws	- Construction Law - Tendering Law - Administrative Licensing Law"	- Property Law - Land Management Law - Contract Law	- Capture: Production Safety Law - Transport: Highway Law, Law on Protection of Oil and Gas Pipelines - Storage and utilization: Mineral Resources Law	- Environmental Impact Assessment Law - Regulations Concerning Environmental Protection in Offshore Oil Exploration and Exploitation - Law on Protection of the Marine Environment - Law on Air Pollution Prevention and Control	- Production Safety Law - Labor Law - Regulations on Work-related Injury Insurance - General Principles of the Civil Law - Tort Liability Law - Criminal Law	- Environmental Protection Law - Marine Environmental Protection Law
Regulations	- Administrative Regulations for Government Approval and Registration of Investment Projects - Catalogue of '', Government Approved Investment Projects (2014) - Decision of the State Council on Cancelling and Adjusting a Number of Items Subject to Administrative Examination and Approval	-	- Transport: Road Transport Regulations	-	- Projects: Regulations for Quality Management of Construction Projects, Regulations for Safety Production of Construction Projects, Regulations on Investigation for Administrative Accountability for Extraordinarily Serious Safety Accidents - Carbon: Regulations for the Management of Hazardous Chemicals	-
Rules	- Directory of Items Subject to Administrative Examination and Approval of the National Development and Reform Commission	-	- Pressure Pipeline Regulations for Chemical Enterprises	- Circular on Strengthening Environmental Protection of the Experimental and Demonstration Projects for Carbon Capture, Utilization and Storage - Catalogue of Construction Projects for Classified Management of Environmental Impact Assessment	- Regulation for Safety Management and Supervision of Pressure Pipelines - Directory of Hazardous Chemicals - Implementing Measures for Safety Permits of Construction Projects Involving Hazardous Chemicals	-

4.3 Policy demand for China's CCUS development

The CCUS legal system in China hasn't been established and regulations in key aspects needs to be formulated. As shown in the table above, there are specific CCUS laws and regulations at all levels. (1) China has a complete set of project approval procedures as reflected in the appropriate laws, regulations and rules, but the approval of CCUS projects is not specified. (2) China has confirmed the ownership of land and property in the legal form, but the legal provisions remain absent regarding ownership of underground space and sequestrated carbon and possible cross-border underground movement of carbon. (3) CCUS projects can follow the existing laws, regulations and rules in operation, covering such technical aspects as capture, transport, storage, and use, but the targeted CCUS standards are still needed. (4) China has established a full-fledged legal system and operational procedure for environmental impact assessment. CCUS projects shall carry out environmental impact assessment in accordance with the *Environmental Impact Assessment Law*, but the technical guidelines for CCUS projects were just released recently. (5) Since the legislation has classified compressed and liquid CO_2 into hazardous chemicals, the transport and storage of CO_2 shall follow the regulations for management of hazardous chemicals. However, whether carbon capture and compression is subject to such regulations needs to be clarified. (6) There are neither legal provisions on post-closure carbon storage projects, nor relevant laws, regulations and rules in any other industry on similar long-term responsibility. In the absence of legal basis for regulation on long-term responsibility and duty of care, the responsible bodies for CCUS projects remain unclear.

Comprehensive national strategy and systematic policy framework should be established. The CCUS development involves many competent authorities that have different concerns and attitudes, including NDRC, MOF, MIIT, Ministry of Science and Technology (MOST), Ministry of Environmental Protection (MEP), Ministry of Land and Resources, and State Oceanic Administration. For example, NDRC mainly considers the impact on energy supply security and carbon emissions reduction, while MOST focuses concentration on technological research and development. Authorities such as NDRC, MOST and MEP introduced a number of documents to promote CCUS development based on their competence and business focus. Nevertheless, a comprehensive national strategy or policy or regulatory system has not been formed, disabling coordinated resource deployment and unified management. In addition, only 4 of the 26 existing CCUS-related policy documents are dedicated to carbon capture and storage, but without specifying policy support, they serve as encouragement more than constraint. The supporting measures are not in place, except the detailed rules on environmental management released by MEF.

Funding and incentive policies that provide enough support and momentum for enterprises is needed. Lack of funds is a major obstacle to CCUS development in China. Currently, CCUS pilot projects are mainly financed by the national program of science and technology research and development. However, such access to financial resources is far from enough to cover project costs, and there is no special fund for CCUS pilot and demonstration projects. The important contribution of CCUS projects is mitigation of carbon emissions, but the mitigation efficiency of enterprises cannot be reflected if the mitigation cost is internalized.

CCUS experimental and demonstration projects are basically the spontaneous behavior of business investment, and many cannot start or sustain due to lack of funds.