Give Full Play to National Strategic S&T Force to Provide Vigorous Support for Carbon Peak and Carbon Neutrality Goals

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Abstract
Scientific and technological innovation plays key supporting and leading roles to achieve "carbon peaking and carbon neutrality" goals (referred to as "dual carbon"). It is necessary to make sustained efforts in the three aspects, namely energy structure adjustment, energy consumption, and carbon sequestration, and build a novel multi-energy-integrated energy production and utilization system based on hydrogen energy, energy storage, and methanol, in which the main lines are clean and efficient utilization of fossil energy, large-scale utilization and complementation of clean energy, low-carbon reconstruction of industrial processes, and intelligent multi-energy integration of building and transportation. In 2022, the Chinese Academy of Sciences has launched the scientific and technological action plan to support dual carbon goals. By implementing eight major actions including strategic research, cross-innovation of basic frontiers, breakthroughs in key technologies, comprehensive demonstration of new technologies and other scientific and technological innovation, deploying talent team building, international cooperation, improvement of innovation system capabilities, and popular science and dissemination actions, the action plan is to provide vigorous scientific and technological support for China's carbon peaking and carbon neutrality goals.

Keywords
carbon peaking carbon neutrality action plan technological innovation multi-energy integration

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**Give Full Play to National Strategic S&T Force to Provide Vigorous Support for Carbon Peak and Carbon Neutrality Goals**

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**Abstract:** Scientific and technological innovation plays key supporting and leading roles in achieving carbon peak and carbon neutrality (referred to as “dual carbon”) goals. It is necessary to make sustained efforts in three aspects, namely energy structure adjustment, energy consumption, and carbon sequestration, and build a novel multi-energy production and utilization system based on hydrogen energy, stored energy, and methanol, in which the main lines are clean and efficient utilization of fossil energy, large-scale utilization and complementation of clean energy, low-carbon reconstruction of industrial processes, and intelligent multi-energy integration of building and transportation. In 2022, the Chinese Academy of Sciences has launched the scientific and technological action plan to support “dual carbon” goals. By implementing eight major actions including strategic research, cross-innovation of basic frontiers, making breakthroughs in key technologies, comprehensive demonstration of new technologies and other scientific and technological innovation, deploying talent team building, international cooperation, improvement of innovation system capabilities, and popular science and dissemination actions, the action plan aims to provide vigorous scientific and technological support for China in achieving “dual carbon” goals.

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**Keywords:** carbon peak; carbon neutrality; action plan; technological innovation; multi-energy integration

1 Achieving carbon peak and carbon neutrality is an inevitable choice for China’s sustainable development

To achieve carbon peak by 2030 and carbon neutrality by 2060 (hereafter referred to as “dual carbon”) is a major strategic decision taken by the Central Committee of the Communist Party of China (CPC) with Comrade Xi Jinping at its core in light of both domestic and international imperatives. It is essential for applying the new development philosophy, fostering a new pattern of development, and promoting high-quality development. It also constitutes China’s solemn commitment to the world.

1.1 “Dual carbon” goals ensure China’s energy security and help building up its strength in energy

Currently, China’s dependence on imported oil and natural gas has exceeded 70% and 40%, respectively. In the complex international context, the security of oil and gas supply has become the top priority for China’s economic and national security. President Xi Jinping stresses that China must enhance self-reliance in energy. Therefore, we need to reduce the dependence on imported oil and gas. China enjoys abundant renewable energy resources. The most reliable way to ensure China’s energy security is to advance technologies in producing and utilizing non-fossil energy such as renewable energy resources (e.g., replacing crude oil and natural gas with renewable energy, hydrogen energy, and biomass oil). This is also a natural choice to achieve the “dual-carbon” goals, marking China’s progress in building up its strength in energy.

1.2 “Dual carbon” goals reflect the urgent need to build a Beautiful China

The Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy issued by the CPC Central Committee and State Council specifies to promote the comprehensive green transformation of economic and social development, accelerate the development of a clean, low-carbon, safe, and efficient energy system, improve the quality of low-carbon urban and rural construction, and consolidate carbon sink capacity. Achieving the “dual carbon” goals is a national strategy to address resource and environmental constraints, promote the upgrading of economic structure for sustainable development, boost the harmonious
coexistence between man and nature and the ecological civilization construction, and implement environmental governance and ecological restoration. It is the demand for building a beautiful China both currently and at a long run.

1.3 “Dual carbon” goals demonstrate China’s responsibility as a major country in building a community with a shared future for mankind

As the world’s largest energy producer and consumer, China has been actively tackling climate change and promoted the conclusion and entry into force of a series of treaties such as the United Nations Framework Convention on Climate Change, the Kyoto Protocol, and the Paris Agreement. China’s carbon neutrality will be of decisive significance to the global response to climate change. Achieving the “dual-carbon” goals means the highest carbon emission reduction realized by the country with the largest population in the world, demonstrating China’s role as a major country in actively responding to climate change and promoting the building of a community with a shared future for mankind.

2 Trends of science and technology in supporting the “dual carbon” goals

2.1 Challenges for science and technology in achieving “dual carbon” goals

The achievement of “dual carbon” goals is a grand but complex task, which represents a broad and profound social revolution concerning numerous mainstay sectors including energy production, industrial energy consumption, and transportation. Meanwhile, it is also confronted with a series of challenges such as heavy workload, limited time, and lack of qualified technologies.

Fossil energy dominates China’s energy mix. According to China’s energy consumption structure in 2020, coal, oil, natural gas, and renewable and nuclear energy accounted for 61%, 22%, 9%, and 8%, respectively. In terms of consumers, 65% of the energy was consumed by industries (including 56% for industrial production and 9% for raw materials production), 19% by buildings and 16% by transportation (Figure 1) [1]. For the same heat productivity, carbon dioxide (CO₂) emissions from the burning of coal, oil, and natural gas are about at a ratio of 10:8:6. Therefore, it can be estimated that the carbon emissions from the consumption of coal, oil, and natural gas in China are approximately at a ratio of 11:3:1.

Achieving carbon peak by 2030 requires China to establish a clean and low-carbon energy system that is safe and efficient in less than eight years. It also requires major progress in industrial restructuring and application of transformative low-carbon technologies in a large scale, with energy efficiency in key energy-consuming industries reaching international levels and a low-carbon development pattern in key areas taking shape. To reach carbon neutrality by 2060, China should raise the share of non-fossil energy consumption from 20% to 80%. Compared with developed countries, China only has 30 years to move from carbon peak to carbon neutralization, which means a huge challenge to the world’s largest energy consumer. As the key to solving these problems, technological innovation plays a supporting and leading role in achieving the “dual carbon” goals.
2.2 Efforts in three aspects to boost “dual carbon” technologies

Carbon neutrality refers to the situation when the amount of anthropogenic CO₂ emissions can be balanced by the sum of anthropogenic carbon sequestration and natural carbon sinks (Figure 2). The Chinese Academy of Sciences (CAS) launched a project of the Research on Framework and Roadmap of China’s Carbon Neutrality, putting forward the general idea of achieving carbon neutrality with efforts in the energy production, energy consumption, and carbon sequestration. For energy production, fossil energy consumption should be reduced by developing non-carbon energy for power generation and hydrogen production, thus forming a new energy supply system. For energy consumption, fossil energy should be replaced by non-carbon energy sources such as electricity, hydrogen energy, and solar energy. In terms of carbon sequestration, inevitable emissions of CO₂ can be removed via ecological construction, soil carbon sequestration, carbon storage and utilization, etc.

Figure 2 Diagram of carbon neutrality

2.3 Establishing a new energy production and utilization system featuring multi-energy integration

The CAS proposed the idea of building a new energy system featuring multi-energy integration in 2018[2]. The “dual carbon” goals require carbon reduction from the source, the main approach of which is to lower the total consumption of fossil energy. However, our efforts to reduce carbon emissions should not compromise social and economic development, or security of energy and industrial chains. Overall planning should be carried out according to the principle of establishing the new before abolishing the old [3]. When developing new energy such as renewable and nuclear energy, we should attach great importance to its close connection with the existing energy and industrial systems, establishing a new energy production and utilization system that integrates multiple energy sources. In addition, the achievement of “dual carbon” goals is accompanied by the replacement of high-carbon with low-/zero-carbon energy. Guided by the “dual carbon” goals, we should plan energy production and consumption in a systematic manner while ensuring the social and economic development. In view of China’s reality, we should build a novel multi-energy production and utilization system based on hydrogen energy, stored energy, and methanol, in which the main lines are clean and efficient utilization of fossil energy, large-scale utilization and complementation of clean energy, low-carbon reconstruction of industrial processes, and intelligent multi-energy integration of buildings and transportation (Figure 3). This will support the establishment of a new energy system that is clean, low-carbon, safe and efficient as well as an economic structure conducive to low-carbon circular development.

2.3.1 Clean and efficient utilization of fossil energy

Coal accounts for more than 90% of China’s fossil fuel resources. China’s energy resource endowment is characterized by rich coal, poor oil, and inadequate gas, which determines its coal-dominated energy structure that is unlikely to change in the short run.

Coal is the most reliable and economical energy resource in China. Especially in the complex international context, it is necessary to replace imported energy with coal-to-liquids, -gas, and -chemicals, thus ensuring the national oil and gas security. Furthermore, coal is also the main fuel and raw material for basic industries such as metallurgy and building material production, while it has the drawbacks of low efficiency, heavy pollution, and high carbon emissions. Toward the “dual carbon” goals, we must strengthen efforts to develop energy conservation and emission reduction technologies to meet the emission standards of pollutants and carbon, thus ensuring the security of energy supply and industrial chain. It is a general trend that coal will shift from the dominant energy source to a basic one, then become a supplementary energy source. The introduction of fluctuating renewable energy poses new challenges to the stability of energy production and supply. Before the energy storage with long duration, high capacity and low cost is mature, we should develop efficient and flexible peak regulation power generation technology. As the stabilizer of the power system, coal-fired power generation should ensure the basic electricity supply.

2.3.2 Large-scale utilization and complementation of clean energy

China is currently working hard to develop renewable energy, nuclear power generation technology, energy storage technology, smart grid, and distributed energy. Large-scale application of renewable energy and nuclear energy can replace coal-based power. Green hydrogen can be gained on a large scale from electrolysis of water by renewable power. The coupling of green hydrogen with coal chemical industry, iron and steel, building materials and other industries can significantly reduce their CO₂ emissions. The reaction of green hydrogen with CO₂ for producing oil and chemical products is an important supplement to the petrochemical industry. In the long run, renewable energy is bound to become the main energy source in China. Therefore, it is
necessary to focus on developing new efficient solar cells, high-power offshore wind power, biomass energy, geothermal energy, and ocean energy.

Nuclear energy has high density, stable supply, and low carbon emissions. Accelerator-driven nuclear energy technology can convert spent fuel into usable fuel, increasing the utilization rate of nuclear materials manyfold and significantly reducing nuclear waste. Thorium molten salt reactor (TMSR) is a safe, flexible, and water-saving nuclear energy system, which is one of the important directions of nuclear energy development. Controlled nuclear fusion is the ultimate dream of human beings. China has made world-leading progress in this field, setting a number of world records, such as a plasma temperature of 120 million degrees celsius for 101 s and a long-pulse and high-parameter plasma lasting for 1 056 s. It is now moving towards building a compact nuclear fusion reactor ①.

2.3.3 Low-carbon reconstruction of industrial processes

China is now at the mid-to-late stage of industrialization, with high carbon emissions per unit of GDP. Energy consumption of China’s secondary industry accounts for about 70% of the total, with steel, cement, non-ferrous metals, chemicals and other energy-intensive industries as the main carbon emitters. In 2020, China produced 57% of the world’s crude steel, 58% of cement, and 57% of electrolytic aluminum, which led to China’s large total energy consumption and high energy intensity [6]. Since the manufacturing industry is at the middle and low end of the global value chain, China faces far more difficulties in the carbon reduction through industrial restructuring than developed countries.

(1) Reducing industrial energy consumption. There are mainly three ways to reduce industrial energy consumption. ① We should develop revolutionary low-carbon technologies and green hydrogen to reduce carbon emissions, such as hydrogen metallurgy and carbon-free electrolytic aluminum technology. ② To reduce industrial CO₂ emissions, we should improve the industrial electrification in combination with the clean electricity to replace fossil energy, such as electric furnace for metallurgy, electric boiler, and electric furnace. ③ The mix of raw materials and product should be adjusted to promote low-carbon reconstruction of industrial processes and industrial upgrading, such as crude oil-to-chemicals (COTC) technology and new technologies in cement production.

(2) Strengthening the coupling between systems of energy and industry. CO₂, carbon monoxide, and hydrogen from industrial processes can be used for the energy and chemical industries. For example, the exhaust gas from steel mills which is rich in carbon monoxide can be combined with green hydrogen to produce methanol, ethanol, olefin, aromatics and other chemicals or fuels through syngas conversion technologies. Residual heat from industrial processes can be used for heating houses and offices in urban areas, which can bring down the overall carbon emissions. The

coupling of energy with materials between different sectors and industries is expected to achieve an overall energy conservation and emissions reduction. For example, in many buildings, heat pumps are installed to provide energy. Water-source heat pumps extract heat from low-temperature groundwater or wastewater (from water plant, sewage plant, factory cooling water, etc.), which can greatly improve its efficiency and reduce the overall energy consumption.

2.3.4 Intelligent multi-energy integration of buildings and transportation

Energy consumption of buildings and transportation is characterized by low per capita consumption, massive users, and wide distribution. The energy flow between electricity, transportation, and buildings through the intelligent multi-energy integration technology can improve the overall energy efficiency.

Electricity, gas, and heating are the dominant contributors to the energy consumption of buildings. On the one hand, we need to develop fuel-efficient technologies to improve the energy saving standards of buildings. On the other hand, building electrification can be adopted to reduce CO₂ emissions in the areas where conditions permit. At the same time, we can develop a distributed power system integrating photovoltaic power generation, energy storage, DC power distribution, and flexible power consumption in buildings relying on their on-site generation. With this method, the buildings will become the producer as well as the regulator of its energy, thus greatly reducing the energy consumption. In addition, we can develop technologies to achieve cross-season heat/cold storage and energy supply to distributed areas. Supply of hydrogen, electricity, heat, cold in a combined manner can significantly improve energy efficiency. The buildings capable of storing heat and cold can interact with the power grid and engage in the system peak load regulation on the generation side and the demand response on the demand side to improve the stability of power system. Electric vehicles (EVs) will become mainstream in the future. A fully charged electric vehicle can meet the electricity demand of a family of four in five days (calculated based on the per capita power consumption of Chinese households being 2.3 kWh/day in 2021 and the battery capacity of 50 kWh per EV). Intelligent vehicle-to-grid (V2G) technology makes it possible to regulate the electricity and power of buildings and power grid, significantly enhancing energy efficiency and reliability.

With the continuous and rapid development of China’s transportation industry, energy consumption will keep rising. The CO₂ emissions in transportation can be reduced by developing technologies to replace oil with electricity and hydrogen. The main trend of passenger cars is EVs. Hydrogen fuel cell has a promising prospect in heavy duty or special purpose vehicles. The biomass oil and gas can reduce the consumption of traditional oil and gas, promoting the low-carbon development of buildings and transportation. The development of green methanol/oil is also an important means to ensure national energy security.

Intelligent multi-energy integration can promote the development of new energy vehicles in China. In late 2021, China’s car parc exceeded 300 million, including 7.84 million new energy vehicles, which increased by 59% over that in 2020⁷. China’s New Energy Vehicle Industry Development Plan (2021–2035) released by the General Office of the State Council proposes to promote the integration of new energy vehicles and energy, and advance the efficient coordination between new energy vehicles and renewable energy. The ex-service batteries of new energy vehicles can be used as energy storage units for buildings and power grids.

2.4 Theories of carbon sinks and technologies for carbon sequestration and utilization

Carbon sinks play an important role in achieving carbon neutrality. The mechanism of carbon sink remains to be studied, and the available estimation methods still have many uncertainties. We should strengthen the basic research on the evaluation and increment of geological carbon sink, ecosystem carbon sink, the relationship between climate change and carbon sink, earth’s deep carbon cycle, stability of ecosystem carbon sink, feedback mechanism between climate change and carbon cycle, etc. It is necessary to develop new approaches to account carbon pools and evaluate carbon sink potential, thus providing theoretical guidance and scientific evidence for carbon neutrality.

1) Strengthening efforts in ecological construction and developing ecosystem carbon sink. We should step up management and conservation of forests, grasslands and other terrestrial ecosystems and coastal ecosystems, make breakthroughs in key technologies to boost carbon sequestration of ecosystems, develop technologies of carbon sequestration and emissions reduction for planting, animal husbandry, and fishery, and provide scientific and technological support for improving the carbon sequestration efficiency of major national ecological projects and the green development of agriculture. To boost carbon sequestration in ecosystems, the government should promote the construction of related demonstration areas, put forward suggestions and plans for the spatial layout at the national level. In this way, a three (stereo monitoring, technological demonstration, and decision-making)-in-one supporting system for research on ecosystem carbon sinks and climate change governance will take shape.

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(2) Strengthening basic research and making breakthroughs in core technologies concerning carbon capture, utilization and storage (CCUS). CCUS is an important means to cut carbon emissions of steel, cement and other industries facing difficulties in carbon reduction in the future, and is also the basic technology for China’s carbon neutrality. Therefore, we should pay more attention to the economy of CCUS.

3 CAS scientific and technological action plan for supporting the “dual carbon” goals

To fully implement the major decisions and plans of the CPC Central Committee and the State Council on the “dual carbon” goals, the CAS launched a strategic action plan to support scientific and technological efforts toward the country’s “dual carbon” goals (referred to as the “dual carbon” action plan), which strengthens top-level design and gives full play to multidisciplinary institutionalization. The “dual carbon” action plan can guide CAS’s research in this field in the future. As an open sci-tech plan that keeps pace with the times, it will be updated in light of the international situation and national strategies.

3.1 Goals of the “dual carbon” action plan

To meet the research demands of the “dual carbon” goals, CAS makes roadmaps for science and technology development, speed up the creation of cradles for original innovation, accelerate breakthroughs in key core technologies, and carry out comprehensive application and demonstration. Furthermore, it supports a low-carbon transition of the industry, strives to take up the sci-tech high ground, and cultivate a hub of innovative talents so as to increase China’s influence and voice on the world stage. The implementation of the “dual carbon” action plan will give full play to the role of CAS as the backbone of the national strategic science and technology force.

3.2 Main contents of “dual carbon” action plan

The “dual carbon” action plan includes eight major actions and 18 key tasks (Table 1).

4 Suggestions on the research for “dual carbon” goals

(1) Strengthening the strategic research on the “dual carbon” action. Considering China’s special resource endowment, development mode, and development speed, we can only follow a path that works well in China to achieve the “dual carbon” goals. We should strengthen strategic research, grasp the general trend of sci-tech development to forecast the development of key technologies, and make the corresponding roadmap. In addition, it is important to identify and discover potential emerging technologies as well as ground-breaking and revolutionary technologies. Moreover, efforts should be made to plan the development of a series of key technologies, estimate the comprehensive effect and influence of the technologies individually or in combination. We need to set out pragmatic roadmaps, a list of technologies, and timetables for the development of “dual-carbon” technologies as soon as possible to guide the technologies in achieving low-carbon transformation of the economy.

Table 1 Framework for scientific and technological action plan of the Chinese Academy of Sciences to support “dual carbon”

<table>
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<th>Eight actions</th>
<th>18 key tasks</th>
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<td>Strategic research</td>
<td>1. Setting out the roadmap for the sci-tech development of the “dual carbon” goals</td>
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<td>Cross-innovation of basic frontiers</td>
<td>3. Promoting cross-innovation of basic frontiers in energy</td>
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<td>Breakthroughs in key technologies</td>
<td>5. Developing technologies for efficient and clean utilization of fossil energy</td>
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<td>6. Developing technologies for renewable energy</td>
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<td>9. Developing technologies for carbon sequestration and carbon sink increment</td>
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<td>Comprehensive demonstration of new technologies</td>
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<td>Talent team building</td>
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<td>Improvement of innovation system capabilities</td>
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<td>17. Strengthening innovation infrastructure</td>
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<td>Popular science and dissemination actions</td>
<td>18. Popularizing and disseminating the “dual carbon” action</td>
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(2) Strengthening basic research for tackling the problems in the development of key technologies. The achievement of “dual carbon” goals is a huge systematic project and represents a profound social revolution, in which the dominant role of technology will be fully reflected. To support the technology innovation system, we need to strengthen the top-level design, give full play to the advantage of the national system, and make an overall plan throughout the country.

(3) Giving play to the guiding role of the government and the orientation role of the market. We should give full play to the role of institutionalized science and technology force. Considering the role of the market, efforts can be made to motivate the enterprises and emphasize their primary responsibility in emission reduction. Cooperation is required while competition encouraged at the same time and forged ahead in a stable manner. It is suggested that the relevant government departments provide special innovation funds for
the research and development of the technologies supporting the “dual carbon” goals and roll out policies to encourage and guide enterprises and industries to develop, demonstrate, and apply the related technologies, which can speed up the upgrading of technologies and industries. Moreover, attention should be paid to the industrial restructuring. The correlation between industries, as well as the interaction between regions should be enhanced.

(4) Giving play to the leading role of the national strategic science and technology forces. The main national strategic science and technology force, like CAS, has an institutionalized research team on the technologies for achieving “dual carbon” goals, who has gained great achievements over a long period of time. Under the guidance of the “dual carbon” action plan, CAS will set out a forward-looking layout, work with related national departments, and strengthen the cooperation with local governments and key enterprises. It will deploy and implement a number of major projects, and actively advise on and undertake major national tasks. Furthermore, it will issue relevant policies to provide comprehensive support in terms of talent cultivation, platform establishment, and international cooperation, in an effort to provide strong scientific and technological support for the achievement of China’s “dual carbon” goals.

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References


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