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Development Strategy for China's Petrochemical Engineering Science and Technology to 2035

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Abstract: This article proposes a development strategy, strategic objectives, major tasks, and measures and suggestions for China's petrochemical engineering science and technology development with respect to 2025 and 2035. This is based on assessments of domestic and international trends in the petrochemical industry and in engineering science and technology development, analyses of China's economic and social development prospects until 2035, and predictions of China's major strategic demands.
Keywords: petrochemical industry; engineering science and technology; strategic research

1 Introduction

China's petrochemical industry system was established following more than 60 years of reform and development. Petrochemical products essentially satisfy domestic demand and significantly support relevant industries. With strong competitiveness, China has gained entry into a group of international petrochemical powers. In the upcoming 20 years, it is expected that the new scientific and technical revolution and industrial reform will continuously promote China's economic restructuring as well as industrial transformation and upgrading. This will require the development of engineering science and technology in the petrochemical industry.

The project titled "Development Strategy for China's Petrochemical Engineering Science and Technology to 2035" by the Chinese Academy of Engineering is guided by the principle of "innovation driven, informatization-industrialization integration, key point breakthrough, and green development." It analyzes major strategic requirements of China's economic and social development for petrochemical engineering science and technology for the next 20 years and proposes the tasks for its development by 2025 and 2035 after reviewing domestic and international trends in the petrochemical industry and in engineering science and technology development.

2 Outlook for global petrochemical engineering science and technology development for 2035

2.1 High-efficiency refining and petrochemical technologies

(1) It is expected that the technologies for producing cleaner liquid fuel from heavy and inferior crudes will be continuously developed. Between now and 2035, the number of global electric, hybrid, and other new energy vehicles will rapidly increase, while liquid fuel with higher quality will remain dominant in transportation. However, the feedstock for the liquid fuel tends to be heavier and more inferior. This requires constant progress in high-efficiency heavy and inferior crude processing technology and for broader developments and applications of slurry-bed residue hydrocracking technology.

(2) Competitive technologies that integrate refining and petrochemical will attract more attention. There will be more active R&D in technologies that aim to reduce production cost, decrease energy consumption, and increase economic benefits.

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These technologies include high-value olefin production technology (such as light alkane dehydrogenation and C3/C4 production by naphtha or heavy oil catalytic cracking); aromatics production technology (such as naphtha catalytic reforming, high efficient catalysts, and processes for aromatics conversion and separation); and technology for producing organic chemical raw materials with the byproducts of refining units.

(3) Refining of the technology platform at the molecular level will involve continuous improvements. An understanding of crudes is deepening from the compound level to the molecular level. Based on the study of refining reactions at the molecular level, more efficient catalysts and more advanced processes could be developed to achieve the selective conversion of hydrocarbon molecules and ensure that carbon and hydrogen atoms are completely used in hydrocarbons. Precise refining technology with high selectivity will be implemented to maximize the use of oil resources and drive forward refining technology progress in a green and low carbon way.

2.2 Green and low carbon production technologies and facilities

(1) With essentially green and low carbon process and facilities, future refining technology will realize the transition from end control to overall control for source reduction, process control, and end treatment including low energy consumption, high selective, and clean technologies for the refining reaction process and product separation and purification; technology optimizing refinery energy consumption; technology to efficiently treat and utilize the "three wastes"; innovative recycling economic mode and ecological connection between industry and society; and CO_2 capture and utilization technology.

(2) Newly developed catalytic materials with high efficiency will facilitate energy saving and environmental protection in refining and petrochemical reactions. The R&D and commercialization of advanced catalytic materials will be considerably faster due to the study of the fundamentals of quantum mechanics starting from the atom scale and considering final application requirements while being supported by high throughput computational modeling and reliable testing and calculation of data. This will lead to the important revolution of catalytic materials and improve energy saving and environmental protection in refining and petrochemical reactions.

(3) Petrochemical technology and technical process will be greener since they will benefit from the continuous development and application of innovative technology. The key factors for this include catalyst selectivity and activity improvement, optimization of feedstock distribution, reaction equipment innovation, reaction development, reaction products separation, and new refining coupling technology. Therefore, this could reduce the side reactions, simplify product separation and purification, and ensure the continuous employment of green integrated technologies for different petrochemical products.

2.3 Technology with diversified feedstock

(1) Biofuel technology with lignocellulose and algae as feedstock has become more mature. The renewable biofuel production technology is the most promising technology among the technologies for producing liquid fuel from non-petroleum fuel feedstock. The technology preparing biofuel from available animal and vegetable oil by solvolysis and hydrotreating will continuously improve, and the technology for producing biofuel from lignocellulose and algae will involve significant upgrades and gradually mature. All these technologies are practically important with respect to the reduction of greenhouse gas (GHG) emission.

(2) Technologies for producing organic chemicals from diversified feedstocks are constantly emerging. The feedstock of organic petrochemicals tends to be diversified with petroleum, coal, natural gas, and biomass. Accordingly, processing technology based on the properties of feedstock will be developed to ensure the complete use of resources and decrease negative effects on the environment. A series of organic chemical production technologies will be gradually formed with the feedstock of petroleum, natural gas, coal, biomass, and the use of high polymer materials, among which petroleum is the dominant material.

(3) Green biodegradable lubricant will become biodegradable. Genetic plant modifications will improve vegetable oil properties, increase yields, and reduce costs. There is a large market for biodegradable lubricants from vegetable oil by chemical modification, and they could even replace mineral-based lubricants in a few areas.

2.4 High-end petrochemical technologies

The highlights of high-end petrochemical technology include high quality lubricant and grease, premium solvent oil, and functional paraffin production technology. High-end petrochemicals will be applied to develop and produce practical functional products based on the requirements of new electronics, transportation, medical care, food packing, agriculture, aviation, and other fields. Molecule design based on the study of the relationship between functions and molecular structures will be used to integrate monomer production, catalysts, reaction engineering, and processes as well as processing technology.

2.5 Intelligent production technologies

The broad application of Internet of Things, big data, cloud computing, intelligent robot, online monitoring and analysis instruments, and process simulation and online optimization technology allows petrochemical production to gradually step into a new intelligent era in which the flows of materials, energy, information, and capital are integrated and optimized; resources and capital are efficiently utilized; companies' abilities for

management, market-oriented adjustment, and competition are enhanced; and low emission and low pollution in the process are ensured. The decision-making platform based on supply, production, and sales plays a crucial role in the timely analysis of market needs and efficiency, and determining an optimal production solution based on the data related to shipment distance, capacity matching, and raw material supply among others. Therefore, the low inventory of raw materials, products, and sales is realized on this platform [1].

2.6 Safe production technologies

The technologies for equipment reliability online detecting, high sensitive detection of process dangerous factors, automatic alarm, intelligent emergency shut down, and automatic fixing will be characterized by rapid development based on risk management, and this will further guarantee essential safety in petrochemical production.

3 Analysis of the demand with respect to China's economic and social development for petrochemical engineering science and technology

3.1 Analysis of the development trends in China's petrochemical industry

3.1.1 Fundamental changes in China's energy consumption structure

The next 20 years correspond to a crucial period for the replacement of coal by oil and gas and fossil fuel by non-fossil fuel, and the optimization of the energy structure to mark a fundamental transformation. The proportion of fossil fuel will decrease while that of clean energy will significantly increase. Specifically, it is predicted that the proportion of coal will reduce from 65.1% in 2015 to 45.7% in 2035, petroleum will reduce from 17.3% to 16.3%, natural gas will increase from 6.0% to 14.5%, and non-fossil fuel will increase from 11.7% to 23.5% as shown in Fig. 1 [2].

3.1.2 Continuation of the trend of diversified petrochemical feedstock

(1) Ethylene from naphtha crackers will remain dominant although the percentage will decrease. As per predictions, China's feedstock for ethylene production by 2035 will be dominated by naphtha with the coexistence of diverse substances such as methanol, ethane, methane, and ethanol. The globally growing ethane yield from shale gas provides China with increased opportunities to import ethane for ethylene production. An increase in the cellulosic ethanol yield in China will also develop ethylene production from ethanol. High efficiency ethylene production technology with methane (which is being pilot plant tested) will have a revolutionary effect on the traditional ethylene production industry after its commercial application to verify reliability and economic efficiency. The economic efficiency of ethane to ethylene will be further enhanced after a breakthrough in the technology of the dehydrogenation of ethane to ethylene.

(2) The capacity of untraditional propylene production technology will be competitive in the future. It is estimated that by 2035, the capacity of untraditional propylene production routes will continue to increase and constitute 47% of the total. Additionally, the capacity of traditional routes will decrease to 53%. In the future, the technology of the dehydrogenation of propane to propene will be limited by propane supply, and the technology for the dehydrogenation of coal (methanol) to hydrocarbon will be restricted by CO_2 emission reduction and the low price of oil and natural gas.

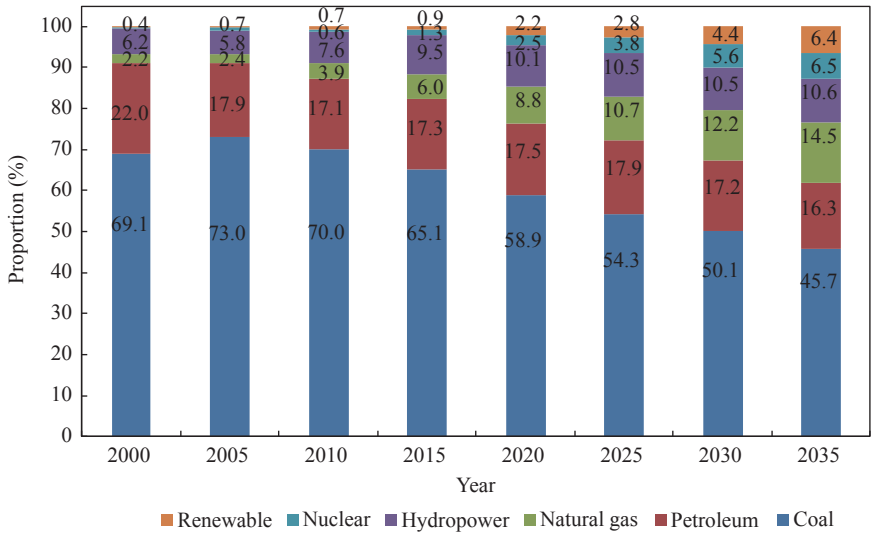

Fig. 1. Estimated structure of primary energy consumption in China.

3.1.3 A significant decrease in the demand for product oils and petrochemicals

(1) Demand for product oils. In the next 20 years, domestic demand for product oil will be lower due to the "new normal" of China's economic development, transformation and upgrading of industry structure, and the constraints of resources and environment. Simultaneously, with the rapid development of alternative fuels, China's product oil consumption will move at a mid or low speed and finally reach a plateau by approximately 2025 as shown in Fig. 2.

(2) Demands for major petrochemicals. In the next 20 years, domestic requirements for petrochemicals will continue to witness a few developments with high-speed urbanization and the realization of building a well-off society in an all-round manner. However, the consumption growth will considerably slow down as shown in Fig. 3.

3.1.4 Overcapacity remains serious

(1) The refining capacity will be in excess. During the period of the 13th Five-Year Plan, China's refining capacity will continue to grow. According to statistics from the China Petroleum and Chemical Industry Federation, the refining capacity of China will reach 9.6×10^8 t·a^{-1} by 2020. However, the consumption of oil products will continuously slow down. The refining overcapacity will constitute a more serious issue, while the utilization of refining capacity will decrease by 5% from that in 2015 to 64% in 2020.

(2) Overcapacity for most of petrochemicals. In the future, given the increasing number of petrochemical constructions that are put into operation gradually, it will be more difficult to relieve domestic overcapacity due to the economic slowdown and a reduction in export competitiveness. In approximately 2018, when the American ethylene project with a capacity of 1×10^7 t

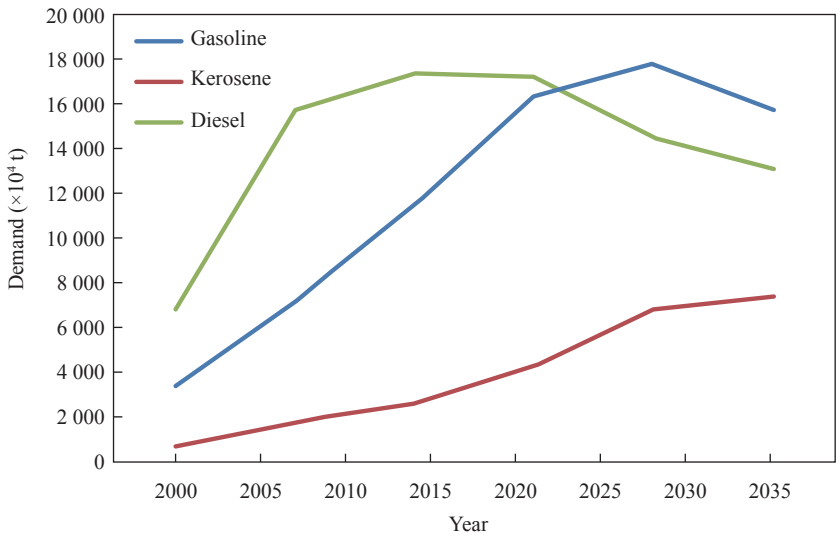

Fig. 2. Estimated demand for product oils in China.

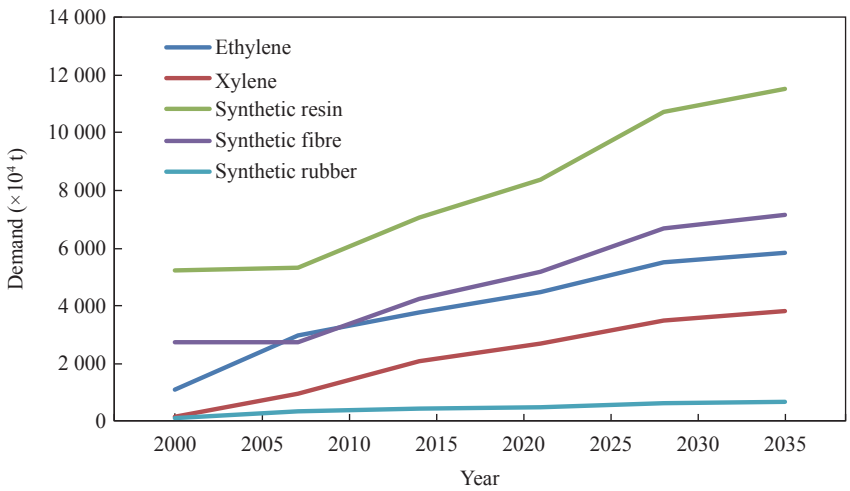

Fig. 3. Estimated demand for major petrochemicals in China.

comes into operation, a portion of the low-cost derivatives of ethylene and propylene will enter the Asian market to further increase the pressure on the domestic market.

3.1.5 The continuous upgrade of petrochemicals

China will accelerate product oil upgrades to reduce automobile exhausting gas pollution. The China VI fuel standard will be applied in Beijing in 2017 and promoted countrywide in 2019 as planned. Simultaneously, China requires higher quality petrochemicals with the acceleration of industrialization and urbanization. Functionalized materials with properties of energy conservation and environment protection and new types of fine chemicals will constitute important trends and growth points.

3.1.6 The development of alternative energy at a high speed

As per estimates, approximately 6.3×10^7 t traditional fuel will be substituted with biofuel, natural gas, and electricity by 2035. This number could be as high as 7.3×10^7 t considering the substitution of 1×10^7 t from coal liquefaction.

3.1.7 More severe environmental protection regulations

In order to protect the environment and reduce haze, the Chinese government has revised the *Environmental Protection Law of the People's Republic of China* by including various compulsory measures such as 10 chapters on atmosphere, 10 chapters on water, and 10 chapters on soil. This will further require petrochemical enterprises to reduce emissions of SO_2, NO_x, powder, chemical oxygen demand (COD), waste residue, volatile organic compounds (VOC), and CO_2, thereby increasing the pressure on their development.

3.2 Major strategic demand analysis of petrochemical engineering science and technology development

(1) To satisfy the domestic need for liquid fuels, it is necessary to develop technologies for converting heavy and inferior oil with high efficiency and for diversified refining feedstock.

(2) To meet the demand for organic chemical feedstock and to improve China's petrochemical industry competitiveness, it is necessary to develop technology for diversified chemical materials.

(3) To fit the development tendency of the future domestic market, it is necessary to develop advanced petrochemical technology.

(4) To satisfy the requirements for green and low carbon development in the domestic petrochemical industry, it is necessary to develop green technology for energy conservation and environment protection.

(5) To satisfy the requirements for intelligent petrochemical plants, it is necessary to develop technologies that deeply integrate informatization and industrialization.

4 Development ideas and strategic objectives for petrochemical engineering science and technology in China

4.1 Development ideas

Given the direction of "innovation driven, informatization-industrialization integration, key breakthroughs, and green development," it is necessary to emphasize petrochemical engineering science and technology innovation, concentrate on key point breakthroughs and leap-forward development in crucial areas, push forward clean production, build a resource conserving and environmental friendly petrochemical industry, accelerate in-depth integration of informatization and industrialization, realize green and low carbon development, further strengthen the overall competitiveness of petrochemical industry, and finally make China a petrochemical power.

4.2 Strategic objectives

4.2.1 Objectives for 2025

The objectives include building a world-class innovation system for petrochemical engineering science and technology that is appropriate for the Chinese environment, ensuring breakthroughs in several core technologies and specialized technologies at a leading level in the world (petrochemical technology is generally expected to reach an advanced world standard by this point); and completing the pilot test of a smart factory for all round promotion.

4.2.2 Objectives for 2035

The objectives include building a petrochemical innovation system featuring "innovation led, smart and efficient, and green and low carbon" to support China's petrochemical development. It is important to significantly promote self-dependent innovation in core technologies, including refinery packaged technology, high efficient conversion technology for inferior residue, and green and low carbon technology. Additionally, these core technologies are expected to reach the highest level in the world to support and lead the role of technology and innovation to its maximum potential.

5 Major tasks for petrochemical engineering science and technology for 2035

5.1 Core technologies that require breakthroughs

(1) Technologies for inferior crude oil, residue, and heavy oil processing, including crude oil blending, inferior crude processing, high-efficiency residue hydrotreating, and hydrogen generation from fossil energy.

(2) Technologies for clean oil products, including high-efficiency coking and catalytic diesel upgrading, jet fuel boosting, and the production of high-quality gasoline and diesel blending components.

(3) Technologies integrating the refining and petrochemical industries, including chemical materials production by refining, aromatics packaged technology with broadening feedstock, and utilization of refinery dry gas and liquefied gas for high value products.

(4) Technologies for the production of high value-added products, such as high-performance lubricating oil/grease and functionalized wax including technology for the production of advanced lubricating base stocks and special lubricants, formulations and additives of lubricating oil/grease, and special lubricants.

(5) Technologies for light olefin production, including technology coupling adsorptive separation and cryogenic separation, ethylene production from methane, ethylene production with oxidation, and dehydrogenation of ethane.

(6) Technologies to increase aromatics yield, including catalytic reforming technology to increase aromatics production, light hydrocarbon high selective aromatization technology, and selective methylation of benzene/toluene with methanol for the production of xylenes.

(7) Technologies for polyolefin controllable polymerization and advanced processing, including key production technology of single active center catalysts, olefin copolymerization, and graft polymerization with a precisely controllable structure, and synthetic resin oriented processing technology.

(8) Technologies for biological base engineering plastics production, including those for producing high performance biological base engineering plastics such as polyamide 10T and 9T with bio-based features.

(9) Technologies for green rubber production, including technology for solution polymerized styrene-butadiene rubber and high cis-polybutadiene rubber, and recovery and reuse of fine powder from used tires.

(10) Technologies for producing high-performance and functionalized fibers, including high strength and high modulus carbon fibers, low cost carbon fibers, antibacterial fibers, antistatic fibers, and photochromic fibers.

(11) Technologies for producing functionalized high polymer materials with high performance, including antibacterial material and new building insulation materials that are extremely waterproof, non-inflammable, and non-toxic.

(12) Petrochemical engineering technology including the engineering technology adapted to large scale equipment, highly efficient reaction engineering and process intensification technology, and precise separation engineering technology with highly efficiency.

(13) Technologies for energy-saving and discharge reduction including new energy-saving refining technologies, fluid catalytic cracking (FCC) emission reduction technologies, new "three wastes" treatment technologies, and low-energy CO_2 capture, storage, and reuse technologies.

5.2 Major technical areas that require in-depth fundamental research

It is necessary to focus on the significant innovation of the following technologies by exploring scientific questions and performing in-depth fundamental research: low-carbon and high-efficient refining technologies; new catalytic material technologies; process intensification technologies; oil products technology for new internal combustion engines; non-hydrogen technologies that remove heteroatoms such as sulfur, nitrogen, and oxygen from oil; technologies to produce photo-transformation polymeric membrane materials; technologies to produce biomimetic water-collecting materials; and biofuel production technologies.

5.3 Major petrochemical projects to be implemented

(1) Intelligent petrochemical plant project. It is expected that technologies including the Internet of Things, cloud computing, wireless industrial network, intelligence sensor, machine vision, and online optimization will be broadly applied in the petrochemical industry by 2035. They will be integrated with information technology such as business intelligence, digitalization, and intellectualization, and spread across petrochemical plants to cover the overall process from design, construction, operation and maintenance, and management to new product development.

(2) Methane to ethylene (MTE) project. It includes the industrial manufacturing of the MTE catalyst, development of a proprietary reactor, separation and refining process, and relevant scaling up technology development, and process integration and large scale industrial construction.

(3) High performance polymer project. It consists of the design of a polymer molecular structure based on performance requirement, the development of monomer production technologies, a polymerization catalyst and process, the reactor and production process, as well as the development of application technologies and equipment. These technologies will then be integrated to realize the commercial production of various types of high performance polymers.

(4) Polymer materials project for protected agriculture. This includes the production, development, and processing technologies for a polymer material with respect to long-life, anti-fogging, selective transparent film, and biodegradable film, and their promotion and broad application.

5.4 Major engineering science and technology projects to be developed

The following important science and technology projects should be developed:

(1) Biomass utilization technologies, including the development of production technology and proprietary equipment for large scale cellulosic ethanol production and biogas production from municipal organic waste, and technology development for bio-based chemicals or materials production and processing to realize the popularization and application of cellulosic ethanol, bio-based chemicals, and bio-based materials.

(2) New hydrogen production and storage technologies, including the development of low cost water-electrolytic hydrogen production, bio-catalytic hydrogen production, and photocatalytic hydrogen production technologies as well as porous material hydrogen storage, and aromatics chemical hydrogen storage technologies. The commercialization of the above technologies supports China's strategic objective of hydrogen fuel cell development.

(3) Petrochemical technologies by integrating informatization and industrialization including technology development for refining material and energy flow optimization, process simulation and online automation optimization, online testing and adjusting of feedstock and products properties, online monitoring and warning of equipment reliability, and insecurity warnings in production process and automatic emergency shut down. This supports the construction of petrochemical intelligent plant in an all-around manner.

(4) Waste polymer material recovery and utilization technologies including technology development for recovery and utilization of mechanochemical-based waste polymer materials, automatic detection, classification, and selectively catalytic cracking of waste polymer materials, and treatment of the pollutants generated in the process of waste polymer material recovery and utilization. These provide significant support for waste polymer material recovery and utilization in a high value-added manner.

6 Measures and suggestions

The following recommendations were obtained from the study:

(1) The continuous improvement of the scientific and technological innovation system based on petrochemical enterprises, establishment of the intellectual property protection system to reasonably share innovative achievements, reinforcement of the industry-university-research collaboration, and propagation of the construction of a new innovative alliance.

(2) The strengthening of the construction of the scientific and technological talents team in the petrochemical field, cultivation of multi-level talents, fostering a good environment to encourage innovation and failure tolerance, improvement of the performance evaluation system for scientific and technological personnel, building an encouraging distribution system with restraints, and fully motivating the enthusiasm of scientific and technological personnel.

(3) Increasing investments in science and technology, continuously improving research facilities and especially facilities related to process and application research on high performance functional polymer materials, and continuously pushing collaborative innovations in the industry-university-research-application.

(4) Supporting core petrochemical technology development at a national level, setting up major petrochemical projects for science and technology development, providing funding support to scientific and technological activities, and offering tax advantages for the implementation of major projects to ensure that the objectives for 2035 are successfully achieved.

(5) The development of a financial and taxation policy that supports petrochemical innovation and development and encouraging petrochemical enterprises investment in R&D.

(6) The strengthening of international cooperation and encouraging "bringing in" and "going out" of innovation. Additionally, talents can be introduced in a flexible manner as opposed to asking individuals to remain in a certain position, as long as they can contribute to build China's petrochemical industry as a crucial base of high-level science and technology collaboration. Relevant policies should be made to support state owned enterprises to set up research institutions abroad, and to acquire foreign patented technologies or small science and technology companies, so that a new international innovation platform for China petrochemical industry can be established.

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