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Strategic Paths and Countermeasures for Constructing a Great Power of Coal Resources

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Abstract: As the most abundant mineral resource in China, coal plays a dominant role in the country's energy structure. China is the largest producer and consumer of coal resources in the world. Therefore, it is imperative for China to build a competitive coal industry. In this paper, we first clarify the emerging concept and characteristics of a "great power of coal resources (GPCR)". Next, we assess the status and challenges of China's coal industry from the perspectives of green resources, engineering technology, human resources education, enterprise economy, and development of the Belt and Road initiative. Third, we propose strategic targets and paths to achieve the position of GPCR. Finally, this paper offers corresponding policy proposals for developing a GPCR. China's coal industry has advantages in resource supply and utilization capacities but is not competitive in technologies, industries, and markets associated with the exploration, development, and utilization of coal resources. To improve the international competitiveness of its coal industry, China needs to increase its reserves of green coal resources, promote the innovation capability of engineering technology, optimize enterprise development and the market environment, and provide strong personnel and institutional guarantees.
Keywords: coal resources; great power; sustainable development; energy strategy

1 Introduction

As one of the most important primary energy sources and industrial materials in China, coal has prominently contributed to the country's energy security, as well as its social and economic stability and growth, for a long time [1–3]. In fact, under the progress of more than seven decades since the establishment of the People's Republic of China, the Chinese coal industry has made great achievements; today, China produces and consumes the largest quantity of coal in the world [4]. China has considerably increased its proven reserves owing to the continuous progress in technologies and equipment for exploration and development. China maintains world-leading underground coal mining technologies; enjoys a higher industrial concentration and a quicker pace of "going global" in an optimized layout; employs more staff members with continually improving competency and remuneration; has made breakthroughs in market-oriented reforms with improved management systems and mechanisms; and functions as an important engine for the society and economy of China's middle and western

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regions. The country's improvements in engineering technologies have enabled worldwide engagement and competitive advantages [5].

China's coal geology is generally controlled by fourfold belts: two latitudinal belts spreading from the west to east (i.e., the Tianshan-Yinshan-Yanshan Mountains and the Kunlun-Qinling-Dabieshan Mountains) and two longitudinal belts spreading from the north to south (i.e., the Greater Khingan–Taihang–Xuefeng Mountains and the Helan–Liupan–Longmen Mountains). Separated by these belts, the coal-bearing basins and coal resources are in a hash shape [6]. Although coal is abundantly found in Shanxi, Shaanxi, West Inner Mongolia (i.e., the western part), and Ningxia; in East Inner Mongolia in central China; and in North Xinjiang in west China, wherein tremendous potential for exploration and development exists, it is depleting in the eastern part of China except for a few provinces and cities in the Yellow River, Huaihe River, and Haihe River basins [7]. As a result, developers have had to tap into deep resources having more complex geology and disaster risks in Eastern China, causing the western region—although arid and ecologically weaker—to become the country's major contributor to coal production. The rationality and urgency of this westward shift of China's coal development is, to a certain extent, justified by the hash-shaped layout along with the regional distribution of water resources, the geographical and environmental conditions, and the country's social and economic development [6,7]. Regarding utilization, more than half of the coal is used for coal-fired power generation, which is technically challenging for higher efficiency, near-zero pollutant discharge, and lower carbon emission. In the coal chemical industry, which is in a new era of upgrading, most projects in operation or in the pipeline are located in the arid western region where they are restricted by a shortage of water and by the ecology [8]. Meanwhile, there is a severe over capacity in China's coal production; however, in terms of global expansion, China's coal providers lack competitiveness and are poorly globalized. Coal enterprises are still supported by inadequate human resource (HR) systems and are not capable of manipulating global coal resources, the industry, or the market [5].

It is believed that the future of the Chinese coal industry is not in seeking higher capacity and consumption but in pursuing the competitive edge and strength to make coal resources sustainable [9]. The next couple of decades will present strategic opportunities for China to construct a "great power of coal resources" (GPCR). To this end, it is imperative for the Chinese coal industry to accelerate its innovations in engineering technology and to cultivate and develop HR for high-quality development of coal mines, enterprises, and the industry. Therefore, the necessity and importance of GPCR construction becomes ever-increasingly prominent.

2 Meaning and characteristics of GPCR

2.1 The concept of GPCR

GPCR refers to "a country that has strong capacity to guarantee coal supply; state-of-the-art exploration, development, and utilisation of coal that can not only drive associated industries and regional societies and economies but also support the nationwide energy security and sustainability; and global competitiveness in coal and relevant fields" [5]. In terms of coal resources, this means a guaranteed coal supply, advanced technology and equipment for coal development, competent workforce, and economically competitive enterprises that can manipulate global resources. In other words, a GPCR should have a strong base of coal resources, a massive market of coal production and consumption, globally competitive and large-scale groups of mining companies, advanced coal-engineering technology, clean and efficient coal development and utilization, superior innovation in technology and management, a stable and competent coal workforce, and a strong industrial radiation capability.

At the core of a GPCR is strong competitiveness, not only in terms of resources, technologies, products, and market but also within the nationwide energy system; the ability to promote regional economies and societies; and the global competitiveness to manipulate worldwide coal resources and market. Certainly, competitiveness of coal resources is related to the availability, security, and environmental friendliness of these resources, which ultimately reflects on the industry's economic attributes. The competitive advantages of resources in the market are closely related to many factors such as the capability of technologies for exploration and development, the cost of mining, and the quality and dressing cost of raw coal. The competitiveness of the coal industry also covers the ability to extend to and drive the entire industrial chain; in other words, the mining techniques, safety measures, intelligent technologies, and relevant equipment could be migrated to other mining industries. A competitive coal industry would be part of the global industrial chain of coal development and utilization. All of these features would contribute to the mutual complementation and deep infusion between related industries.

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2.2 Analyzing the main elements of GPCR

According to the definition of the term, the core elements of a GPCR are green coal resources, coal-engineering technology, coal workforce education, economy of coal enterprises, and the "Belt and Road" coal resources. Referring to the relevant studies [1,10], Table 1 lists the specific elements involved and the associated quantitative or qualitative indicators.

Table 1. The elements of GPCR and their associated indicators

GPCR elements	Level 1 indicators	Level 2 indicators
Green coal resources	Seam occurrence condition	Burial depth of seam
		Structural complexity
	Coal quality assessment	Coal quality and classes
	Degree of exploration	Seam thickness and pitch
		Amount and proven degree of coal resources
	Hydrogeology	Availability of water resources and hydrogeological types
	Geological safety	Condition of engineering geology
		Gas condition
Coal-engineering technology	High efficiency	Degree of geological support
		Degree of mechanization and automation
		Ergonomics
	Safety	Degree of protection for workers' occupational health
		Mortality rate per million tonne of coal
	Environmental friendliness	Ecological protection and recovery rate
		Comprehensive utilization rate of resources
	Clean utilization	Rate of cascade utilization
		Level of high-efficiency coal-fired power generation
		Level of coal chemical technology
Economy of coal enterprises	Advantages of resources and location	Economically recoverable reserves
		Coal quality
		Transport condition
	Capability of scientific production	Mortality rate per million tonne of coal
		Financial investment in energy efficiency and environmental protection
		Level of coal mining mechanization
		Raw coal productivity per worker
		Raw coal yield
	Business capability of enterprises	Marketing rate of products
		Asset-liability ratio
		Total asset turnover
		Operating cost of enterprises
	Enterprises' level of international development	Contribution by overseas assets
	Enterprises' potential of sustainable development	Percentage of research investment
		Enterprises' patents
		Profitability from main operation

Table 1 (*continued*)

GPCR elements	Level 1 indicators	Level 2 indicators
		Net return on assets ratio
		Ratio of profits to cost
Coal workforce education	Age structure (young, middle aged, aged employees)	Professional employees
		Business management employees
		Skilled workers
	Education structure (junior college, undergraduate, graduate)	Professional employees
		Business management employees
		Skilled workers
	Professional title structure (junior, intermediate, senior)	Professional employees
		Business management employees
		Skilled workers
	Remuneration level	Average remuneration per employee
"The Belt and Road" coal resources	Resource development	Resource control capability
	Engineering service and equipment technology	Engineering service capacity
		Capacity to export equipment and technology
	Layout of trade and logistics	Ability to maintain market share
		Ability of logistics support
	Arrangement of capital operation	Ability to control capital operation

Green coal resources are those that "under the current condition of advanced technologies, have suitable endowment, facilitate safe and efficient mining and ecological friendliness in the downstream operations, allow for clean and efficient utilization, and are economically competitive" [11]. These resources are generally in suitable endowment to allow safe and efficient mining (having relatively abundant coal resources in a relatively simple geological position that can be easily mined with machines). The development of these resources has a relatively small yet recoverable impact on the ecology; it protects and effectively uses water resources and guarantees ecological friendliness. Hazardous elements are limited, controllable, and removable; therefore, these resources can be used cleanly and efficiently. In addition, favorable conditions of green coal resources ensure not only high-quality resources but also the use of advanced mining technologies and clean utilization downstream, which results in resources of a stable quantity and quality to support GPCR.

Engineering technology elements in terms of coal development involve resource prospection, mine construction, and coal production. These elements make coal production more efficient, safe, and environmentally friendly. Efficiency is an overall indicator of the level of advancement in production elements such as technology, equipment, overall planning, and management of coal mining. Safety is related to advanced production technology and equipment and the level of management. Production safety is mainly benchmarked by engineering technology and the overall safety of the industry. Environmental friendliness refers to the use of advanced and environmentally friendly technology and equipment to minimize negative external effects caused by mining, such as damage to the surface environment, vegetation, or ground water and the emission of hazardous gases. Environmental friendliness involves approaches and measures for clean production and a circular economy to protect the ecology in mining areas. Engineering technology regarding clean utilization involves the use of advanced, environmentally friendly technology and equipment to convert and utilize coal resources. These include the application and development prospects of coal dressing, gasification, direct liquefaction, and indirect liquefaction technology; and the progress and deployment of advanced coal-fired power generation, ultra-low-emission coal-fired power generation, and carbon capture, utilization, and storage (CCUS).

The growth of coal enterprises is essential in achieving GPCR. In today's competitive environment, these enterprises must be able to compete in a dynamic market environment. They should control resources and use them in an integrated manner to maximize the value of coal resources and products and to minimize operating cost for earning the highest possible benefits. By doing so, they can grow their competitive advantages and meet social requirements [5,12]. Additionally, a strong coal enterprise should be a competitive player in the international

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market, making considerable investment in overseas operations to provide a new thrust for its growth. Economically competitive advantages cannot be globally realized without world-leading coal enterprises featuring industrial concentration; scaled operations; profitability; growth driven by technical innovations; safe, energy-efficient, and high-efficiency production; a sophisticated modern management system; and strong scientific management capability.

A technically skilled and educated workforce is the key to the GPCR strategy. In particular, industry professionals need increasingly higher competency to match the increasing automation and intelligence in the industry [13]. Hence, specialized and skilled engineers and technicians are urgently needed to deploy new equipment, technology, and process; so, professionals with business and management expertise must be available to introduce new business concepts and modern management methodologies.

In addition to engagement in global technology, resources, and markets, the Belt and Road initiative covers the drive that coal development and utilization would have on the Chinese society and economy (especially on the northwest provinces and regions of Inner Mongolia, Shaanxi, Gansu, Ningxia, and Xinjiang; and the southwest provinces of Yunnan and Guizhou). Cooperative development in the coal industry as part of the Belt and Road initiative will help supply energy and chemical materials for China's economic growth. It will also enable China to use global resources and participate in the international market. The ultimate result will be higher dominance and influence of China in the global coal resources, industry, and market [14].

3 Gap analysis for constructing GPCR

3.1 Coal resources

China has abundant green coal resources, of which the explored and evaluated amount is up to 9.989×10^{11} t, accounting for 51% of the country's total coal resources [11]. Most reserves are located in Shanxi, Shaanxi, Inner Mongolia (especially the western part), Ningxia, and North Xinjiang. These resources can be steadily developed for a long time, given the yield of 4×10^{9} t per year. However, because coal resources are generally under-surveyed, the basic reserves available for planning and construction are low. Consequently, the recoverable reserves should be increased as soon as possible. According to a preliminary estimate [5], the basic reserves are approximately 8.764×10^{10} t, and the economically recoverable reserves are about 4.575×10^{10} t, of which Shanxi—the top hosting province—contributes 2.062×10^{10} t, followed by Shaanxi and West Inner Mongolia, which contribute 9.781×10^{9} t and 9.393×10^{9} t, respectively, and North Xinjiang, with 3.294×10^{9} t. Therefore, the survey of coal resources, especially the exploration and detailed reconnaissance of green resources, should be improved in the near future [15]. Additionally, it is necessary to enhance the survey and assessment in green mining areas in terms of hydrogeology, environmental geology, and engineering geology and to provide geological support for efficient development of green resources.

3.2 Engineering technology

In other countries, coal is primarily mined in open; however, in China, a more complex system of underground mining is prevalent. Although the underground mining technology in Shanxi, Shaanxi, Inner Mongolia, and Ningxia is internationally competitive and generally on the same level as that of the US and other advanced coal producers, China's coal industry is inferior to that of foreign players in terms of overall efficiency, safety, and environmental friendliness. This is reflected not only in insufficient original innovation but also in the indicators of technologies and equipment in some fields. Generally, China is deficient in the scope of deployment and in the precision and intelligence of its world-leading technology in efficient mining and clean utilization [16,17], thereby making the overall indicators of safety and environmental friendliness lag behind those of foreign countries.

3.3 Education

Compared to major coal producers of the world, China has an excessively large but lower-educated workforce in its coal industry. Most coal enterprises face shortages and interruption in the supply of HRs; they suffer a low percentage of high-level employees and an absence of intermediate and senior inter-disciplinary employees, especially management elites with international perspectives and strategic insights. Because intelligent mining technology tends to require fewer workers, there is a higher demand for a professional workforce. Presently, the graduates from Chinese universities and colleges cannot satisfy the industrial demand for inter-disciplinary professionals. Among these institutions, those related to coal mining fail to differentiate from one another in their educational programs, causing their education offering to be misaligned to the demand.

3.4 Corporate economy

Despite remarkable achievements in the scale, strength, production, operation, industrial layout, technical level, safety capacity, and environmental friendliness, Chinese coal enterprises are inferior to advanced companies in developed countries in terms of industrial concentration. By the end of 2015, the top ten large-scaled Chinese enterprises had contributed only about 40% of the country's raw coal yield. As conventional organizations, coal enterprises are generally extensive in their management concept and approach. With a changed macro environment, inferior information management and formalistic performance management have hindered their core competitiveness. Most average coal mines, in addition to some large-scale ones, have much poorer internal management than their leading domestic and advanced international counterparts; many are uncompetitive because of outdated operating models. By contrast, most foreign coal enterprises have adopted proven development models featuring low operating costs, flexibility, and efficiency because management is separated from ownership, and production and operation are divided in a specialized manner.

3.5 The Belt and Road initiative

Compared to their large-scaled multinational counterparts in the US, UK, and Australia, Chinese coal enterprises have only recently become international players, albeit small-scaled. This is not congruent with China's position as the largest coal producer and consumer. China does not have a national top-level design for overseas development of coal resources, let alone plans or guidance for a target, direction, or development path. Moreover, it has not established an integrated system of supporting policies covering financing, taxes, and insurance for overseas investments, especially those suffering from high costs and risks inherent in the coal industry; moreover, China has not emphasized building an intermediary service system for such investments. Particularly, its domestic investment banking, financial, legal, and consulting organizations do not have the experience or strength to satisfy the demand of investments. Another problem lies in industrial associations failing to provide adequate coordinating and service support. To a certain extent, this results in disordered competition among Chinese enterprises in overseas markets. Additionally, China has not built its own system to effectively and sophisticatedly source and filter information on overseas investments and to support decision-making, which also has a negative impact on investment decisions. Thus, despite certain advantages in technical exports, China still has to enhance its dominance and influence in the global coal market.

4 Strategic goals and a development path for constructing GPCR

4.1 Strategic thinking and objectives of GPCR

According to the report on the 19th National Congress of the Communist Party of China, China "will promote a revolution in energy production and consumption, and build an energy sector that is clean, low-carbon, safe, and efficient." This implies that the important position of coal resources in safeguarding China's energy security and economic and social development will not be overthrown. Therefore, GPCR should be a major long-term strategy for energy development. In fact, China should build a strong coal industry system at the earliest by taking advantage of the Belt and Road initiative and by fully exploiting its domestic and overseas markets, provided that it ensures the security of energy, the state, society, and economy as well as the safety of the industry and ecology. To this end, China should transform; upgrade; and structurally adjust, refine, and enhance its coal industry so that the system is commensurate with coal as a primary form of energy and is safe; environmentally friendly; state-of-the-art; rational in its workforce portfolio; and adaptive to industrial reforms and economic competition. This effort would convert China from a giant of coal resources to a GPCR. Table 2 envisages the strategic objectives of GPCR construction by two milestones: the years 2025 and 2035.

4.2 Strategic tasks and implementation path of GPCR

The following sections, 4.2.1–4.2.5 describe tasks that are needed to implement GCPR.

4.2.1 Speeding up the survey and assessment of green coal resources to guarantee their supply

China should more quickly shift the focus of its geological reconnaissance to provide geological support to the reconnaissance and development of green coal resources. The paramount task of coal geology should be to increase the green reserves that are economically recoverable through fine, supplementary reconnaissance for green coal resources and coordinated reconnaissance of coal basins and symbiotic and associated minerals. The bases of uncompartmentalized green coal resource should be surveyed and assessed, and faster and finer

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reconnaissance technology for uncompartmentalized coal fields should be studied and deployed. Finding new green, or quasi-green, coal resources also serves as a direction of resource prospection. Water resources have become one of the decisive restrictors for coal development in Northwest China, where geological assessment for water-efficient or water-retaining coal mining, as well as rational diversion of external water resources, remains important for the development of green coal resources.

Table 2. Strategic objectives of GPCR

2025	2035
To become a great power of coal production and coal-related engineering technology.	To realize GPCR encompassing the entire industrial chain.
To significantly boost the total base volume of green coal resources and the precision of resource volume on each reconnaissance level and realize the production of green coal resources of more than 80%.	To boost the reserves of all green coal resources and realize the production of these resources of more than 90%.
To increase the mechanization rate of coal mines to more than 90% and workforce productivity to 2 000 t/worker, as well as decrease the mortality rate per million tonnes of coal to less than 0.05. To remarkably improve the ecology and environment in mining areas, with all discharge-control indicators of primary pollutants from coal-fired power generation meeting the discharge standards of gas-fired generation and generally-world-leading, safe, green, and clean utilization.	To make coal production generally intelligent; increase workforce productivity to 5 000 t/worker; and have zero mortality in coal mine accidents. To decrease ecological damage and pollutant discharge to nearly zero; significantly reduce carbon emissions; and build a green, safe, and efficient system of coal development and utilization.
To reduce the workforce by 20%–25% from that of 2015; increase employees of junior college or higher levels to more than 80% of the workforce; and maintain the same remuneration level as that of the electric power industry.	To reduce the workforce by 30%–40% from that of 2025; increase employees of junior college or higher levels to 90% of the workforce; and maintain a remuneration level that approaches that of the finance industry.
To cultivate two or three world-influencing enterprises and elevate the contribution by the top ten coal enterprises to no less than 70% of the total yield.	To foster five to eight advanced enterprises that will dominate the growth of the global coal industry and elevate the contribution of the top ten coal enterprises to no less than 90% of the total yield. All coal enterprises should be upgraded to be profitable, occupationally attractive, and competitive in multiple dimensions of the industry.
To make evident achievement in the layout of development and utilization of the “Belt and Road” coal resources. The seven major coal-producing provinces (autonomous regions) in western China should output approximately 2.27×10^9 t of coal, of which 1.19×10^9 t is consumed and 1.08×10^9 tons is exported. Resource development should be arranged in several countries, including a massive export of engineering technology and equipment manufacturing to coal-producing countries, participation in international coal trading and logistics, and export of capital to the coal industry and processing and conversion industries in certain countries.	To generally complete the layout of the development and utilization of the “Belt and Road” coal resources. The seven major coal-producing provinces (autonomous regions) in western China should output approximately 2.35×10^9 t of coal, of which 1.23×10^9 t is consumed and 1.12×10^9 t is exported. An integrated global network of industry covering coal exploration, development, conversion, utilization, logistics, trading, and financing should be formed, and the global operating capacity of the coal industry should be elevated.

4.2.2 Focusing on building uncompartmentalized coal development bases and large-scaled integrated energy and chemical bases to establish precise development models oriented toward green coal resources

China should optimize the layout of its coal development on the basis of the distribution of green coal resources. To this end, it should turn to a hybrid model that is mostly focused on green resources but is supplemented by, in some special regions, quasi-green ones. Thus, grasping the opportunity of “capacity reduction,” the country should identify the capacity and the green portion of the yield for each mining area, and it should cut down, or even exit from, non-green areas. In Shanxi, Shaanxi, Inner Mongolia, Ningxia, and North Xinjiang, where resources are certainly advantageous, uncompartmentalized coal development bases and integrated large-scaled energy and chemical bases may be built to establish precise development models oriented toward green coal resources [16]. To help drive a clean, efficient development and utilization of coal for higher competitiveness in the market, China

should enhance its development of green coal resources, support the optimal utilization of premium coal, and ensure that coal is appropriately consumed by type.

4.2.3 Driving the industrial transformation and upgrading through the deployment of advanced engineering technology and technical innovations

Coal-engineering technology is moving toward green development and clean, efficient, and low-carbon-footprint conversion and utilization [18]. As such, coal should be developed in a safe, environmentally friendly, and efficient way by taking the following measures: (1) developing intelligent, safe, and green mining technology; (2) boosting the efficiency, safety support, and ecological friendliness of industrial production; (3) establishing a safe and green model of development in major producing regions of western China; (4) enhancing the automation and intelligence in mine production; (5) protecting the ecology and environment in coal development (including protection of water resources, subsidence control, land reclamation and ecological remediation); and (6) recovering coal resources efficiently. Coal should be converted and utilized by deploying clean and efficient coal-fired power generation and low-pollutant discharge. Advanced coal-fired power generation will generally improve the generation efficiency of China's coal-fired power generator units; will significantly reduce and control the discharge of conventional pollutants; and will minimize carbon emission. Moreover, the modern coal chemical industry should be upgraded on an ongoing basis to demonstrate a reduction in water consumption and environmental pollution. Intensive research should be conducted on key technologies, covering the assessment and detection of the geological condition of coal mining; safe mining of deep and ultra-large wells; coal dressing and upgrading; coal mining and ecological and environmental protection; coordinated and intelligent mining of coal and of its symbiotic and associated minerals; the new-generation integrated gasification combined cycle (IGCC), integrated gasification fuel cell cycle (IGFC), and coproduction technologies; advanced 700° C supercritical coal-fired power generation technologies; advanced circulating fluidized bed (CFB) power generation technologies; cascade coal conversion and utilization technologies; and advanced carbon capture, utilization and storage (CCUS) technologies [17].

4.2.4 Optimizing coal workforce by reshaping its development and cultivation system

Admittance of new recruits should be controlled to optimize the scale and structure of the coal workforce. Reassignment of employees, which will be a long-term task for coal industry management, should be conducted without losing high-level elites so that they can be stabilized. The remuneration system should be optimized as a key task to embody the HR development cycle of "potential, performance, remuneration, and development." Enterprises may implement a recruitment system comprising "chief engineer," "chief staff member," "chief technician," and "lead professional" for major professional jobs and should define policies to pay more to these "chief" staff members. This should help expand the skilled—especially the highly skilled—workforce.

Industry, enterprises, and colleges and universities should work together to swiftly adjust the direction of human cultivation and development. They should speed up the fostering and output of graduate students with practical skills and feed highly demanded recruits to the industry in a targeted manner; in other words, students are separately admitted through request by specific employers. To this end, international HR communication and cooperation should be enhanced, and joint certification by Chinese and foreign organizations should be explored to expand the source of their education and training.

4.2.5 Enhancing the economic vitality of coal enterprises and promoting technical innovation as the main drivers of the coal industry

The coal industry should be reformed to accommodate mixed ownership so that enterprises can be made more dynamic by running on more flexible mechanisms by fusing internal and external drivers. It should transform traditional connectivity between production, transportation, and consumption to a modern trading model by setting up and improving the basic trading system for the coal market and by establishing an e-trading market. Thus, various market players should be encouraged to help build coal trading markets. Regional coal trading markets should be established at a quicker pace. Open, fair, and just markets for spot, mid-term, and forward coal contracts should be set up and improved. A modern coal futures market should be established gradually. Several large-scaled, specialized, and world-leading coal and energy groups should be fostered. Advanced coal-engineering technology and equipment should be supported to extend to the coal industry and relevant mining industries.

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4.2.6 Using coal resources as a key to implement the Belt and Road initiative and manipulating global coal resources, industry, and market

Coal enterprises and other relevant market players in China should be encouraged to cooperate with other countries along the Belt and Road (especially countries in South Asia, Southeast Asia, Central East Asia, Europe, and Australia). This cooperation should be based on international free trading rules and centered on resource development and capital operations, and it should cover the coal industry chain comprising exploration, design, capital construction, production, development, conversion, utilization, marketing, logistics, transportation, equipment manufacturing, and infrastructure. To this end, Chinese coal industry players should be more engaged in coal development by purchasing resources, exploration rights, and development rights of coal in developed countries such as Australia. They should obtain rare types of coal resources when international coal giants are reconfiguring their assets to get out of business pits and should focus on Indonesia, Vietnam, Pakistan, and Bangladesh to develop a coal processing and utilization industry in relation to "coal, electricity, and building materials," "coal, coke, and steel and iron," and "coal and synthetic ammonia (methanol)" and use these downstream operations to drive upstream coal development. Advanced and proven engineering services, mining machinery and equipment, and coal-fired power generation technology—especially the advantageous technology in coal equipment manufacturing and ultra-low-emission coal-fired power generation—should be exported to facilitate the reorientation of China's upstream and downstream coal operations toward an export economy; turn from the export of products to that of labor, equipment, and technology; and increase the global market share of China's coal equipment. Overseas patent applications should be enhanced, especially in countries that are closely related to China's export, to prevent risks of intellectual property right disputes and trade frictions.

5 Conclusions and policy implications

China is one of the largest countries in terms of coal resources in the world, but it cannot currently be called a global GPCR owing to the considerably imbalanced distribution of coal resources among different regions; the huge variation in tectonic conditions; inadequate technology in exploration, development, and utilization; differences among enterprises in economic competitiveness and development level; unsophisticated management systems and mechanisms; and an irrational workforce structure. However, China is ready to become a global GPCR in terms of resources, market, engineering technology, HRs, and enterprises by combining competitiveness in some domains.

The key to constructing GPCR is a reform in the enterprises' management systems and mechanisms, innovations in institutions [19], and improvements in top-level design for coal energy development. To this end, the following policy recommendations are proposed.

(1) China should build a legal system for the coal industry, based on the *Law of the People's Republic of China on the Coal Industry*; improve the standards and specifications in coal mine construction, coal products, ecological and environmental protection in coal mine areas, clean development and utilization of coal, and coal logistics; speed up the reform in the fiscal and tax system of the coal industry to eliminate unreasonable charges; and set up an integrated tax control system with wide coverage and multiple links. It should also set up a development funding system to support the closure, exit, and transformation of coal mines using the resource tax revenue, state-owned capital gains, and VAT refunds. When a mine is closed or discarded, the ecology should be managed well and recovered. Moreover, ecological development and resource utilization should be tailored for discarded coal mine areas. Industrial heritage should be protected, and industrial tourism should be developed in such areas. Integrated industrial policies should be defined to protect and develop coal resources in East China and South China, and several bases for coal resource protection should be planned in the eastern part of China. Differentiated policies, such as subsidies on railway freight, state tax refund, and favorable treatment for underdeveloped regions, should be implemented to support the continued westward shift of coal development.

(2) When it defines its coal industry policies in future, China should set up technical standards for the assessment of green coal resources and thus prioritize the development of green coal resources. It is recommended to designate state-level green coal resource areas and identify regions for development of such resources. Fine reconnaissance and development of green coal fields and mine areas should be enhanced to increase the contribution of these fields and areas to the base volume and yield. Entry to the coal industry should be further tightened on the basis of the occurrence condition, distribution pattern, and development potential of green coal resources. Accordingly, the issuance of mining rights and the mining license conditions should also be adjusted. Eventually, assessment of green coal resources should become the primary criteria to optimize the structure and to

curtail the outdated capacity of the coal industry. A development roadmap should be plotted for the coal industry. Based on the advantages in coal resources, this should help with the benign growth of the economic system, minimize the comprehensive energy cost, and reduce the environmental impact of coal development and utilization down to threshold values.

(3) China should emphasize top-level design on the growth of new technology for fossil energy, which is primarily coal. Research and development and industrial application of advanced technology for clean and efficient coal conversion and utilization should be emphasized and supported by industrial policies [20]. An innovation program on major technologies for the exploration and development of green coal resources should be implemented. Policies should be defined to normalize the admittance of recruits for the coal industry. The industry, enterprises, and colleges and universities should be supported to realign the cultivation and development of the workforce so that the industry can progress toward a digital, mechanical, and intelligent one. A system to foster coal engineers and technicians with international perspective and specialties should be established; it should be characterized by professional students receiving practical and engineering education provided at coal colleges and universities. Policies should be enacted to stimulate exchange of professionals between coal enterprises and universities, thereby building an integrated education and training channel comprising "student recruitment, cultivation, and utilization."

(4) From the prospect of global governance and state intention, China should support its domestic enterprises to speed up their engagement in overseas resources, technical equipment, intellectual property rights, and infrastructure in coal and associated industries under the Belt and Road initiative. An integrated coal and energy corridor centered in China and comprising trading, engineering technology, and industrial radiation of merchantable coal should be built in the Asia–Pacific region. Establishment of Asia–Pacific coal trading centers in Shanghai and Guangzhou should be particularly supported to increase China's dominance in the Asia–Pacific energy market. Assisted by the Asian Infrastructure Investment Bank (AIIB), the Silk Road Fund (SRF), BRICKS Development Bank (BDB), and other specialized financial institutions, contractual joint ventures; joint-stock joint ventures; strategic alliances; or capital operations may be set up or performed with selected countries having abundant coal resources, stable politics and economy, favorable backdrops of policies and laws, and steady downstream markets. Qualified large-scale coal groups should be supported to conduct overseas investment and financing by absorbing investments or by issuing shares or bonds.

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References

[1] Xie K C. Strategy research on clean, high-efficiency and sustainable coal development and utilization in China [M]. Beijing: China Science Publishing & Media Ltd (CSPM), 2014. Chinese.

[2] Wang X Z. Strategic consideration of China coal industry development during energy revolution and new normal of economic development [J]. China Coal, 2015 (4): 5–8. Chinese.

[3] Peng B, Guo D, Qiao H, et al. Bibliometric and visualized analysis of China's coal research 2000—2015 [J]. Journal of Cleaner Production, 2018, 197: 1177–1189.

[4] Wang Xi Z. World coal outlook [M]. Beijing: China Coal Industry Publishing House, 2011. Chinese.

[5] Peng S P. Research on development strategy of great power of coal resources [M]. Beijing: China Science Publishing & Media Ltd (CSPM), 2018. Chinese.

[6] Peng S P. Coal resources and water resources [M]. Beijing: China Science Publishing & Media Ltd (CSPM), 2014. Chinese.

[7] Peng S P, Zhang B, Wang T. China's coal resources: Octothorpe shaped distribution characteristics and sustainable development strategies [J]. Strategic Study of CAE, 2015, 17(9): 29–35. Chinese.

[8] Fan J L. Study on China clean coal technology system under the background of the energy revolution [J]. Coal Economic Research, 2017, 37(11): 11–15. Chinese.

[9] Peng S P. Research on sustainable development strategy of China's coal [M]. Beijing: China Coal Industry Publishing House, 2015. Chinese.

DOI 10.15302/J-SSCAE-2019.01.013

[10] Zhang Z Q, Tian Q F, Chen Y W. Research on main scientific and technological indicators of science and technology power [J]. Bulletin of the Chinese Academy of Sciences (BCAS), 2018 (10): 1052–1063. Chinese.

[11] Wang T, Zhang B, Wang Q W, et al. Green coal resources in China: Concept, characteristics and assessment [J]. Coal Geology & Exploration, 2017, 45(259): 1–8. Chinese.

[12] Cheng L, Sun C S. International comparison with China coal enterprises and implementation of powerful nation strategy [J]. Coal Economic Research, 2017, 37(11): 21–26. Chinese.

[13] Song M, Liu Q Y, Li Y. Construction achievements and requirement analysis on human resources of China coal industry [J]. Coal Economic Research, 2017, 37(11): 16–20. Chinese.

[14] Shen W. Risk and countermeasures of overseas coal investment along “the Belt and Road” [J]. Coal Economic Research, 2017, 37(11): 27–31. Chinese.

[15] Wang T, Shao L Y, Xia Y C, et al. Major achievements and future research directions of the coal geology in China [J]. Geology in China, 2017, 44(2): 242–262. Chinese.

[16] Yuan L. Scientific conception of precision coal mining [J]. Journal of China Coal Society, 2017, 42(1): 1–7. Chinese.

[17] Zhang B, Guo D N, Peng S P. Development trends and strategic research for China’s energy engineering science and technology to 2035 [J]. Strategic Study of CAE, 2017, 19(1): 64–72. Chinese.

[18] Chang S Y, Zhuo J K, Meng S, et al. Clean coal technologies in China: Current status and future perspectives [J]. Engineering 2016, 2(4): 447–459.

[19] Guo J L, Zhang P. Analysis on restrictive factors and reform orientation of system mechanism in China coal industry [J]. Coal Economic Research, 2017, 37(11): 44–50. Chinese.

[20] Peng S P. Research on fostering and developing strategic emerging industries in energy field during the “13th Five Year Plan” period [M]. Beijing: China Science Publishing & Media Ltd (CSPM), 2017. Chinese.