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Strategic Pathways for Energy Revolution in Northwestern China in the New Era

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Abstract: Both energy security and climate change are key challenges for China in the New Era. Northwest China, especially the "Energy Golden Triangle" and Xinjiang Uygur Autonomous Region, is playing a significant role in China's energy supply owing to its rich energy resources. However, protecting the vulnerable ecosystems of this region is increasingly challenging. Therefore, developing a performance improvement plan for energy revolution become urgent in this region. In this article, we first analyze the unique competencies and challenges regarding resource, industry, and location; considering the requirements of energy revolution, we propose that the Northwest China should be established as a national multi-energy integration energy technology demonstration base, a national coal-to-fuel strategic reserve base, and a national comprehensive energy supply base. As a strategic path for promoting energy revolution in Northwest China, multi-energy integration consists of three main themes and six integration demonstration measures. The three main themes are the clean and efficient use of fossil resources and coupling substitution, multi-energy complementarity and large-scale application of renewable energy, and the low-carbon intelligent multi-energy integration. Adopting these measures, a Northwest China approach to energy revolution can be formed that is characterized by multi-energy integration and led by the energy technology revolution.

Keywords: Energy Golden Triangle; energy revolution; multi-energy integration; strategic path

1 Introduction

The current period is important as China finds itself at the intersection of the Internal and International Imperatives and Two Centenary Goals. At this time, China is facing intensified energy security risks due to such exogenous shocks as the global COVID-19 pandemic, aggravation of the anti-globalization trend, unstable international geopolitics, and increasing uncertainties. The development of China and its energy entered a new era following the 18th National Congress of the Communist Party of China (CPC). On September 22, 2020, General Secretary Xi proposed at the UN General Assembly that China would strive to peak its carbon dioxide (CO_2) emissions before 2030 and achieve carbon neutrality before 2060. Furthermore, he repeatedly reiterated China's target in dealing with climate change and proposed clear requirements for its low-carbon development. *China's Energy Development in the New Era*, the White Paper issued by the Information Office of the State Council in December 2020, stated that China's energy development in the new era should actively adapt to domestic and international situations and should unswervingly follow a new path of high-quality development [1]. Therefore, China's energy revolution should focus on building an independent and controllable energy supply system and on improving its capability to ensure energy

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security and address climate change.

Northwest China, specifically the areas of the Energy Golden Triangle and Xinjiang, plays a significant role in China's energy supply owing to its rich energy resources. This region is also an important energy-chemical industry base, as the source of the West–East Coal Transportation Project, West–East Natural Gas Pipeline, and West-to-East Power Transmission Project. Northwest China, which comprises less than 18.6% of country's area, contains 70% of China's coal resources and nearly 1/3 of the nation's oil-gas resources. It also provides 1/3 of China's raw coal, 1/5 of its crude oil, and nearly half of its natural gas [2–8]. One third of China's large-scale coal-based power plants [9] and over 1/3 of the nation's modern coal chemical projects [10] have been built in the Energy Golden Triangle area, which can effectively guarantee the security of energy supply in China. Therefore, based on its abundant resource reserves, industrial foundation, and strategic mission, Northwest China should fully mobilize multiple forces and take opportunities for industrial restructuring and development under the guidance of national policies on energy. This will help the region to meet the requirements of the national energy development strategy in the New Era.

2 Present situation and trend of energy development in Northwest China

In addition to the region's rich fossil fuel resources, such as coal, oil, and natural gas, there are various renewable energy resources (wind and solar energy) that can provide a basis for multi-energy integration. After over 20 years of development, the exploitation and utilization of energy resources in the region have shifted to a new trend towards green exploitation, high-end industry, and a low-carbon energy structure.

2.1 Transforming exploitation of fossil resources from scale expansion to quality promotion, leading to a new trend of green exploitation

Coal is currently the most advantageous energy resource in Northwest China; it has the highest degrees of exploitation and utilization of all of the region's energy resources. The region's coal reserves buried shallower than 2000 m comprise approximately 2.6 trillion tons, accounting for more than 70% of the nation's total. Furthermore, proven coal reserves amount to approximately 875.87 billion tons, accounting for 51.3% of the nation's total [2]. Owing to their simple geological structure and suitable mining conditions, these reserves are convenient for large-scale mining. Coal production in Northwest China has thus increased from 75 million tons (5.4%) in 2000 to 1.45 billion tons (37.7%) in 2019 [3–8] (Fig. 1). Ordos and Yulin, the two cities with the highest coal outputs, provide high-quality feed coal for chemical engineering; this coal features low ash, phosphorus, and sulfur contents and has a high calorific value and oil content.

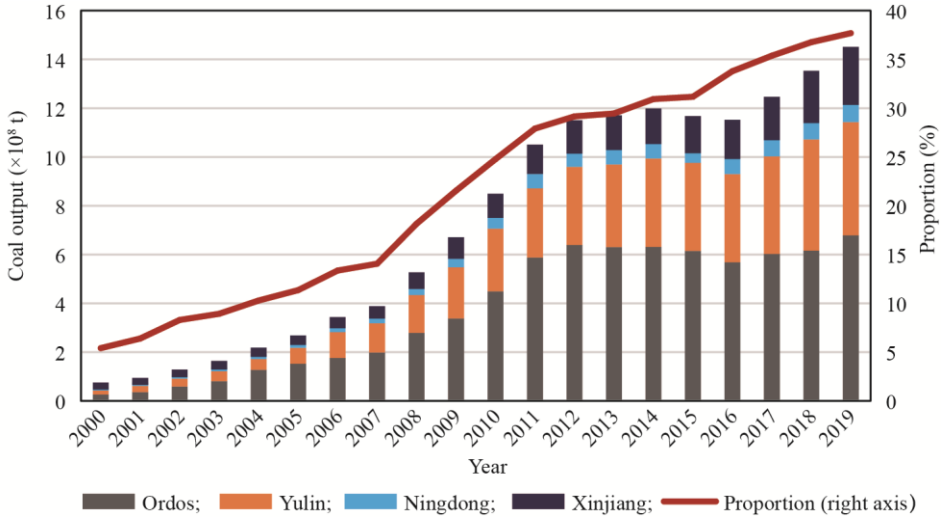

Fig. 1. Coal output in Northwest China as an absolute value and as a proportion of national total output (2000–2019).

Reform of the supply side of coal in China has continuously progressed, and in the future, coal production bases will be transferred to the Western Continuing Area at an accelerated rate. Northwest China can maintain its existing capacity and output and could even further expand its capacity and increase production. However, considering the limited increase and even decrease in the total coal consumption in China, as well as the region's vulnerable ecological systems, it will be difficult to further develop the scale of the region's coal production. Overall, the ratio

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of coal output in Northwest China will continue to increase; therefore, the new trend of coal exploitation in Northwest China should focus on improving the level of high-quality production capacity and achieving green exploitation at the current production capacity scale.

In addition to coal, Northwest China is rich in oil and gas resources (Fig. 2). In 2013, the region's crude oil output exceeded 40 million tons; this annual level has been maintained at over 38 million tons as of 2019, accounting for 19.9% of the total output in China. Regarding natural gas production, Yulin, Ordos, and Xinjiang represent 10-billion-m^3 natural gas production bases; they produced 17.64 billion, 30 billion, and 33.99 billion m^3 of gas in 2019, respectively, together accounting for 46.3% of the nation's total output. Increases in the natural gas outputs of other regions have meant that the region's proportional production has gradually dropped annually after reaching its peak (58.6%) in 2011 [3–8]. In conclusion, the total oil and gas production in Northwest China has stabilized under existing technologies and management systems. In the future, oil and gas exploitation will focus on improving the green production level, including improving the production efficiency, minimizing the impact of production on the ecological environment, and promoting CO_2 flooding and storage.

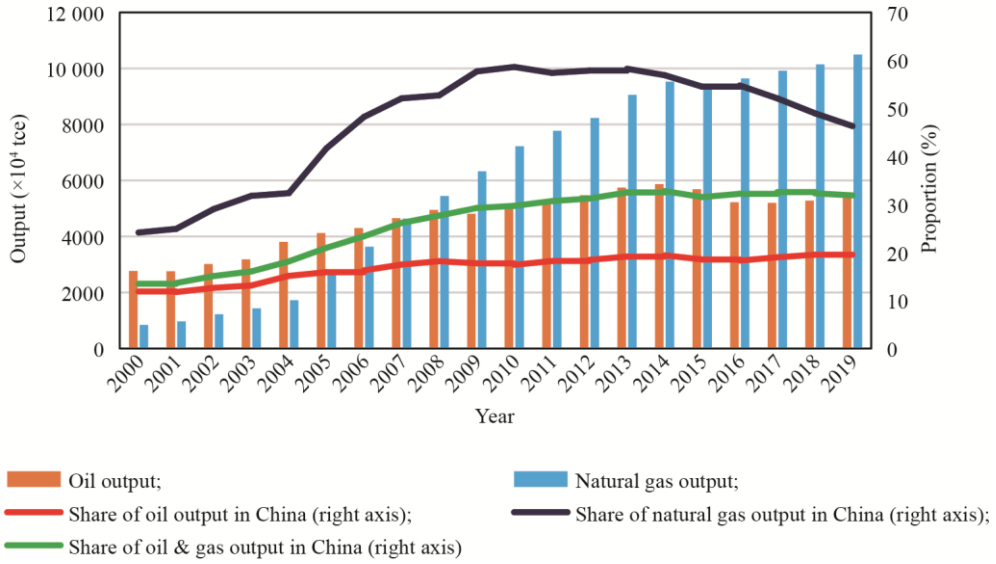

Fig. 2. Northwest China's oil and gas output proportional to total output in China (2000–2019).

2.2 Clustered development of modern energy and chemical industries and high-end development of the energy industry

In March 2017, the National Development and Reform Commission and the Ministry of Industry and Information Technology chosen four demonstration areas for the modern coal chemical industry (Ordos, Yulin, Dingdong, and Zhundong Xinjiang) in the *Layout Plan for Innovative Development of Modern Coal Chemical Industry*. The recent promotion of ultra-high-voltage (UHV) power transmission and distribution technologies, including numerous modern coal chemical technologies, have upgraded primary energy products, such as coal and gas, to high value-added products, such as electricity and chemicals, in regions near the market in Northwest China, thereby preventing "resource trap." Excluding Xinjiang, where coal is mainly supplied for local consumption due to the limitation of transportation distance, other regions have listed their *in-situ* conversion rates of coal as targets to further promote the development of electricity transmission and coal chemical industry bases. In 2019, the *in-situ* conversion rate of coal in the Energy Golden Triangle area was approximately 23% [11].

At the end of 2019, the production capacities of direct coal-to-liquids (CTL), indirect coal-to-liquids (ICTL), coal-to-gas (CTG), coal-to-olefins (CTO), and coal-to-ethylene glycol (CTEG) in Northwest China comprised 100%, 79%, 74%, 44%, and 18% of the national production capacity, respectively [10]. In addition, the production capacities of under-construction and proposed projects account for large proportions of the national totals, as shown in Fig. 3.

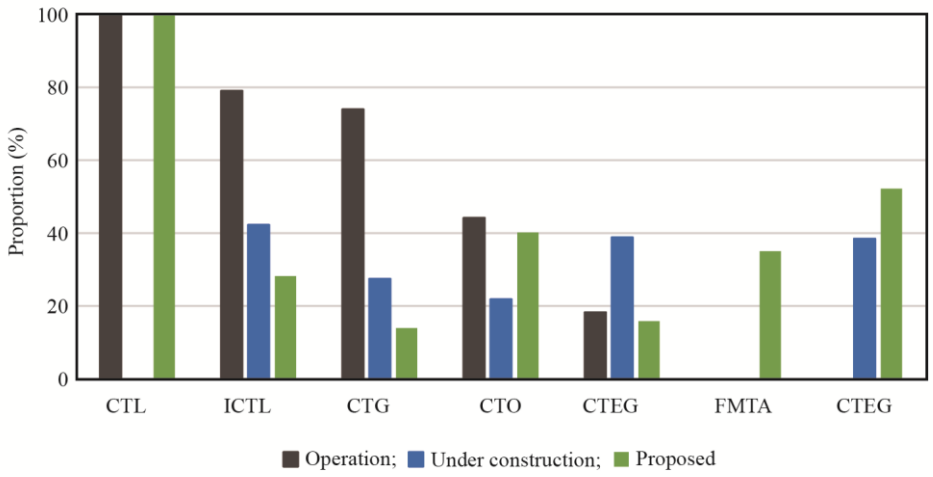

Fig. 3. Ratio of modern coal chemical production capacity in Northwest China to total national capacity in 2019.

2.3 Accelerated development of renewable energy and low-carbon energy structure

There is a suitable resource foundation for the development and utilization of renewable energy resources in Northwest China. In most regions of Ningxia and Xinjiang, the annual sunshine duration exceeds 3000 h, with an annual average radiation of approximately 5900 MJ/m^2, which are favorable conditions for the utilization of solar energy. Xinjiang also contains relatively abundant wind energy, and its wind energy reserve could reach 390 GW [12]. Furthermore, the region's vast territory and low development cost can provide a solid foundation for the large-scale development of renewable energy sources, such as wind and solar energy.

In the New Era, renewable energy sources have played a vital role in optimizing national and regional energy structures. Northwest China has accelerated its development of renewable energy sources under the conditions of rapid cost reductions and national and local requirements for building a clean energy production and consumption structure. Taking Yulin, a city within the Energy Golden Triangle, as an example, its installed capacities of wind and solar energy tripled during the 13th Five-Year Plan Period; they will be multiplied again during the 14th Five-Year Plan Period and beyond.

3 Problems and opportunities for energy development in Northwest China

3.1 Urgent challenges

In 2012, the Chinese Academy of Engineering summarized six development problems for Northwest China, which was represented by the Energy Golden Triangle in the Key Consulting Project "Development Strategy of Energy Golden Triangle." These problems are: severe industrial homogenization, extensive mining of energy resources, disordered competition in the coal conversion industry, high pressure regarding energy transportation, water shortage, and a vulnerable ecological environment [13]. These problems have developed further to different extents after several years of development, specifically due to ecological civilization and energy revolution strategies in the New Era.

Problems such as the extensive mining of energy resources and high pressure regarding energy transportation have been alleviated. Owing to supply-side structural reform and high-quality capacity policies, a new trend of green exploitation has developed. Regarding energy transportation, increases in the *in-situ* resource conversion rate and the construction of new railways have relieved said pressure, and bulk energy resources have been shifted to energy chemical products.

However, the issues of water shortage and vulnerable ecological environment remain severe. Northwest China suffers from severe water shortage, with little potential for the development of water resources, as it is located inland. In addition, as the region's loose soil is unsuitable for the growth of vegetation, the low vegetation coverage weakens the regional ecological environment. In the New Era, the red line of ecology will be a rigid restriction, which will further aggravate the conflict between Great Development and Great Conservation in Northwest China.

Severe industrial homogenization and disordered competition have recently become more prominent in the coal conversion industry. There are several provincial administrative units in Northwest China, which have formed a

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highly homogeneous industrial structure under similar energy resources and development conditions due to the lack of integrated development. Industrial homogenization has still not been effectively resolved after years of development.

In addition, Northwest China, as an energy supply base, has faced common problems in the development of the national energy system, such as the difficulty of merging similar and independent subsystems, prominent structural contradictions, and low overall efficiency. These issues are likely caused by inadequate key technologies for breaking down system barriers and promoting multi-energy integration and due to obstacles to linear management in institutional mechanisms.

3.2 Potential opportunities

Northwest China is the core region of the Belt and Road Initiative and of the Great Western Development Strategy, as determined by the CPC Central Committee and the State Council. In the *Guidelines on Building a New Pattern of Great Western Development in the New Era*, which were issued on May 17, 2020, Northwest China's position in national strategies and its related requirements were further determined; this can provide policy incentives for energy revolution in Northwest China.

4 Suggestions on the strategic path for energy revolution in Northwest China in the New Era

To guarantee energy security and deal with climate change during national energy development, the function and demonstration layouts should be planned in an innovative, forward-looking, scientific, and systematic manner, based on the foundation and status quo in Northwest China. Furthermore, the technical, industrial, and institutional systems of energy development should be reconstructed. Therefore, Northwest China should be transformed into a national multi-energy integration technology demonstration base, national coal-to-fuel strategic reserve base, and national comprehensive energy supply base.

4.1 Building a national multi-energy integration technology demonstration base to promote regional capacity regarding energy technology innovations

In view of inadequate multi-energy integration technologies in the field of energy, a national multi-energy integration technology demonstration base should be built in Northwest China to promote the implementation of national major research and development projects. This would also drive the construction of a regional industry–college–institute–application innovation chain. National strategic technological forces and major enterprises should be guided to settle in Northwest China through major demonstration projects, as well as energy innovation centers and laboratories. In addition, an industrial alliance should be established to promote technology integration and innovation and accelerate the transfer and conversion of major scientific and technological achievements applicable to Northwest China. Pilot test bases and service platforms should be established in suitable regions to promote pilot tests, engineering, and the industrialization of advanced and applicable technologies.

Considering institutional problems during the application of the multi-energy integration technology, pilot reforms should be implemented to form a long-term mechanism, based on the technological innovation law. These reforms should be conducted in aspects of technological innovation, land policy, environmental protection policy, and government management systems to improve the region's capacity to apply new technologies and construct new industries.

4.2 Building a national coal-to-fuel strategic reserve base to improve China's capacity to safeguard oil and gas security

Based on the scale of coal resources and the oil-rich coal in Northwest China, a national coal-to-fuel strategic reserve base should be established to explore the diversified technological path of storing oil in coal and storing oil in technology. Major demonstration projects should be used to foster the capacity to design, manufacture, and completely produce major equipment. Furthermore, a reproducible and popularized process design and engineering manufacturing system should be formed, a national coal-to-oil and gas strategic technology reserve base should be established, and a technological and industrial system that can replace an equivalent weight of 100-million-tons of oil and gas should be built.

Based on the large-scale modern coal chemical enterprises in the region, a production capacity agglomeration place should be established for coal-based fuels (such as national coal-to-oil, coal-to-methanol fuel, and coal-to-ethanol fuel). Furthermore, a national production capacity reserve should be formed that can support liquid fuel supplies under extreme conditions. Through the agglomeration of various energy and chemical industries, the production technologies and paths for flexibly adjusting coal-to-fuel products should be explored to improve the competitiveness of the industrial market.

4.3 Building a national comprehensive energy supply base to improve China's capacity to balance energy supply and demand

To meet the new requirements for energy supply in the New Era, the positioning of the national comprehensive energy supply base should be stabilized based on Northwest China's resource advantages, thus further improving the diversified and clean energy supply. Efforts should be made to promote the large-scale popularization and application of green mining technologies, such as water-preserved mining and filling mining, thereby stabilizing the national quality coal supply base. Regarding oil and gas, efforts must be made to improve the construction and layout of oil and gas pipe networks; strengthen the capacities of natural gas extraction, treatment, and transportation; increase the liquefaction and coverage of natural gas; and expand the grid-connection delivery of coal-based natural gas. In terms of power delivery, efforts should be made to promote the construction of extra-high voltage power delivery channels as well as to establish a 10-GW-scale power delivery base and a 10-GW-scale multi-energy complementary base for wind energy, solar energy, thermal power, and stored energy. Collaborative and complementary technologies and mechanisms for large-scale, high-proportioned renewable energy sources and coal and electricity bases should also be explored to improve the green and stable delivery of power. Regarding the energy and chemical industries, efforts should be made to promote the end-use, fine, high-end, and high-value development of a modern coal chemical industry. Furthermore, efforts should be made to establish a recycling and resource utilization system for intermediate products, by-products, and waste in the production process. A circular economic system should also be established with regional industrial characteristics.

5 Suggestions for promoting energy revolution in Northwest China in the New Era

For the New Era, General Secretary Xi Jinping has proposed new energy security strategic requirements ("four revolutions and one cooperation"). Based on Northwest China's energy characteristics and actual situation, this paper suggests that the region should promote energy revolution. The region should build a suitable energy revolution model using a method characterized by multi-energy integration and led by the energy technology revolution.

5.1 Concept of multi-energy integration

Multi-energy integration aims to achieve multi-objective optimization of energy efficiency, environmental benefits, economic costs, and social benefits in a comprehensive energy system through the complementary integration of traditional fossil fuel and non-fossil fuel energy systems. This integration is possible through new technologies and processes and through the integrated coupling of energy, material, and information flows. Moreover, the energy and material attributes of energy resources should first be comprehensively reviewed.

Multi-energy integration can be realized at multiple levels and scales, such as molecules, reactions, processes, products, energy systems, and regions. This can promote the transformation of energy resources from single energy utilization to comprehensive energy and raw material utilization, and from single product production to tiered- and grade-based co-production. These transformations can improve the overall energy utilization efficiency, thus relieving the contradiction between energy supply and demand and reducing the environmental impact of energy utilization. Compared with the current isolated operation of energy subsystems, multi-energy integration requires both technological and institutional innovations. These innovations can break down the technological and institutional barriers that isolate energy sources and make them mutually independent, thus achieving coordination and taking advantage of the complementarity among energy subsystems.

According to China's current energy system division, multi-energy integration has three main themes: the clean and efficient use of fossil resources and coupling substitutions, multi-energy complementarity and the large-scale application of renewable energy, and low-carbon intelligent multi-energy integration [14] (Fig. 4).

Theme 1: promoting the clean and efficient use of fossil resources and coupling substitutions. China is rich coal and poor in oil less gas resources, and fossil energy dominates the nation's current energy production and consumption system. Thus, promoting the clean and efficient utilization of fossil energy, particularly coal, is the

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current focus of technological innovation and industrial development and will likely remain so for a long time to come. With the synthesis gas/methanol intermediate conversion platforms and the adoption of revolutionary technologies for the synthesis of bulk chemicals/fuels (such as olefin, arene, and oxygenated chemicals), Theme One realizes product coupling and thermal coupling in the coal chemical and petrochemical industries. Furthermore, it promotes the clean and efficient transformation of coal; promotes the end-use, high-end, and differentiated development of the energy and chemical industries; achieves the partial substitution of coal for oil and natural gas; and forms a coordinated development relationship with the oil refining and chemical industries. These changes can improve China's energy security while furthering the clean and efficient utilization of fossil fuel energy.

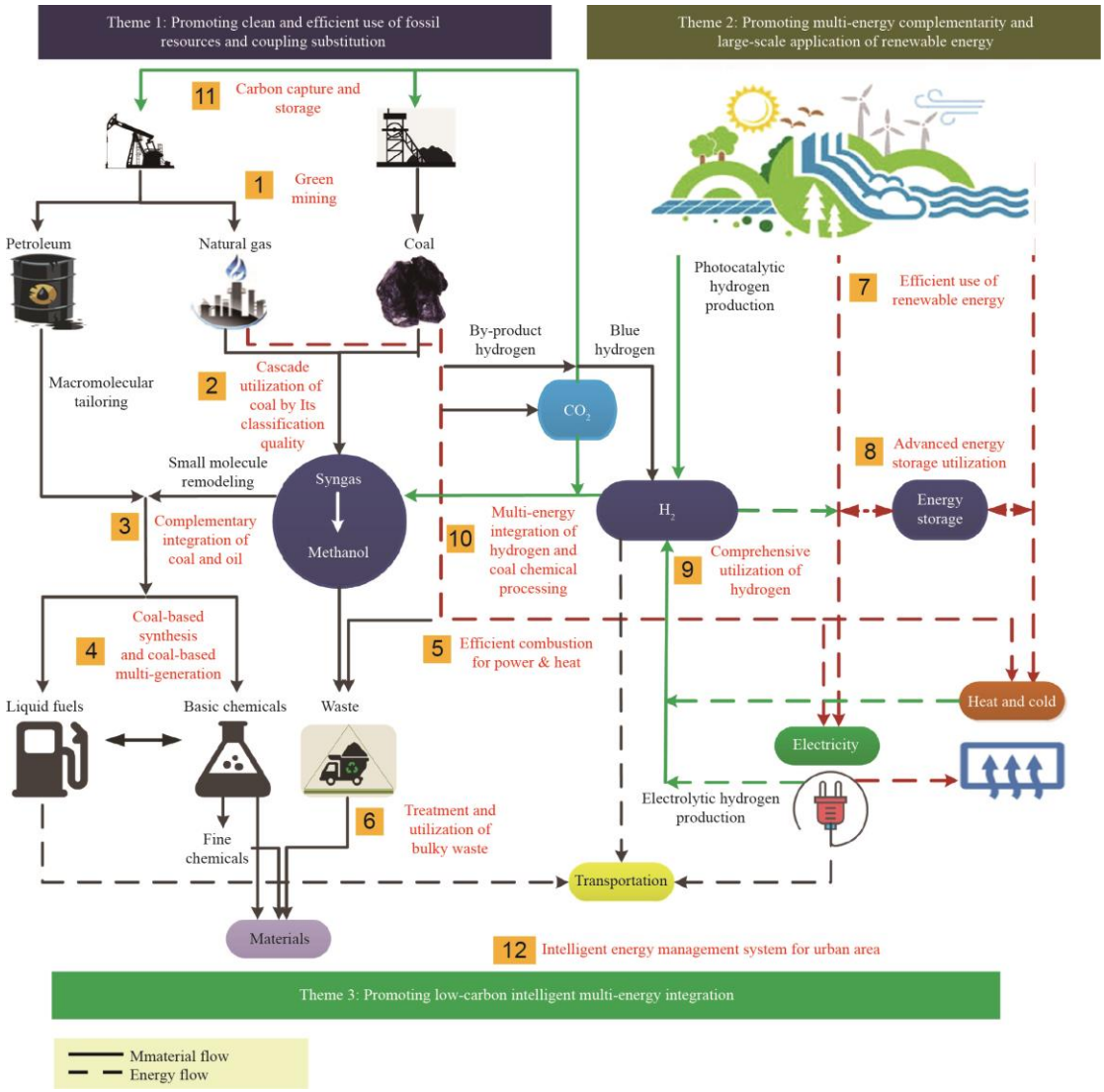

Fig. 4. Strategic technology roadmap for multi-energy integration.

Theme 2: promoting the multi-energy complementarity and large-scale application of renewable energy. Renewable energy tends to gradually change from supplemental energy to principal energy. Thus, areas in Northwest China that are rich in energy resources should plan in advance and actively promote the scale and high-proportioned development of renewable energy. This would help to create basic conditions for multi-energy complementary integration. With technological innovation, Theme Two permits the development of large-scale advanced energy storage platforms to solve the problems of low energy density and high fluctuation, which are commonly associated with renewable energy. This could also solve the problems of temporal and spatial misallocation between supply and consumption regarding the large-scale development of renewable resources. Meanwhile, Theme Two also explores

the integration and complementarity of renewable energy and fossil energy systems using several energy storage methods, such as physical, chemical, and hydrogen energy storage. Thus, it can further expand the deep substitution of fossil fuel energy systems with renewable energy.

Theme 3: promoting low-carbon intelligent multi-energy integration. At present, China's energy structure is in a transitional period (from high carbon to low/no carbon). China's energy consumption is dominated by fossil fuels, which inevitably lead to CO_2 emissions. Therefore, CO_2 emissions can only be removed by promoting the raw material utilization of fossil energy and resource utilization of CO_2 through integration. These goals can be achieved using low-carbon energy carriers based on renewable energy. With technological innovation, Theme Three utilizes hydrogen/lower alcohol as a multi-energy carrier to promote the transition of fossil fuel energy (from utilization as fuel to as raw materials), multi-energy complementarity of fossil fuels and renewable energy, and deeply electrified and low-carbon end-use energy consumption. Theme Three is important for realizing the efficient and cyclic utilization of carbon resources and promoting the transformation to low-carbon energy systems.

5.2 Paths and actions to promote multi-energy integration in Northwest China

Based on Northwest China's resource endowment, industrial base, and strategic positioning, this paper suggests that multi-energy integration should be promoted and that energy revolution should be achieved in the region based on the following six aspects.

5.2.1 Promoting and demonstrating the complementary integration of modern coal chemical and petrochemical industries

China's high external dependency on oil induced an energy security problem. Thus, the complementary integration of coal and oil should be promoted. The layout of technology and demonstrations regarding level- and gradient-based utilization of coal, CTL and hydrocarbon basic chemicals, coal-to-basic oxygenated chemicals, coupling technology, coal chemical and petrochemical industries, etc. must be focused on. Strategically, the role of coal should be emphasized in compensating for deficiencies in oil resources. Regarding the market, the role of the coal chemical industry should be stressed in compensating for the deficiencies of the oil industry. Furthermore, the coal chemical industry's importance for bulk chemicals (such as olefins and arenes) and specialty oil products (such as high-end lubricating oils, aviation fuels, and specialised fuel for high altitude regions) should be highlighted. In particular, the industry's special advantages should be emphasized regarding the synthesis of oxygenated chemicals; emphasis should also be given to small-molecule oxygenated chemicals, while consolidating the advantages of methanol. Technologically, the development and application of new transformative technologies must be focused on, such as efficient coal gasification technology, pulverized coal pyrolysis, and technology regarding synthesis gas, for the one-step syntheses of ethanol, ethylene glycol, p-xylene (PX), and olefin.

5.2.2 Promoting and demonstrating full chain and multi-industrial integration in the energy and chemical industries

Energy-rich regions face problems such as a high dependency on resource development, the low added value of products, severe homogeneous competition, and insufficient key technology for the extension of industrial chains. Thus, efforts should be made to promote full chain extension of the energy-chemical industry, multi-industry integration, as well as the end-use, fine, differentiated, and green development of energy and chemical products. The layout and demonstration of the full chain of coal–fine chemical industry, efficient combustion for power generation and heat supply, and the comprehensive utilization of bulk solid wastes must be emphasized. Efforts should be made to promote and demonstrate the industrial development of coal–gas–electricity–heat integration, as well as new coal-based materials and fine coal-based chemicals. Furthermore, the integration of the modern coal chemical industry with electric power, material, chemical fiber, and other industries should be promoted. Efforts should also be made to promote and demonstrate the industrial development and comprehensive utilization of coal gangue, fly ash, industrial chemical residues, industrial waste, and so on. This would improve resource utilization efficiency and mitigate the impact of the coal chemical industry on the ecological environment.

5.2.3 Promoting and demonstrating renewable energy and stored energy integration

Low-carbon transformation development is required in energy-rich regions, based on their rich wind and solar resources. Thus, the integrative development of renewable energy and stored energy should be promoted, and paths for constructing a large-scale, high-proportioned renewable energy system should be explored. The layout and demonstration of efficient renewable energy utilization and advanced stored energy utilization must be emphasized. Active steps should be taken to demonstrate and promote large-scale renewable energy power generation and

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advanced photothermal technology; to improve and promote the application of demand-side interaction technology, power virtualization, and power transaction platform technology; and to construct a new Internet Plus power operation model. These steps should realize the development of 10-GW wind energy, solar energy, thermal power, and stored energy integrated demonstration projects. They should also increase the proportion of renewable energy in China's energy consumption and should reduce the carbon intensity of urban comprehensive energy systems.

5.2.4 Promoting and demonstrating multi-energy integration with hydrogen/lower alcohol as a carrier

China's future energy system requires comprehensive low-carbon and green development. Thus, efforts should be made to promote the construction of a future energy system in which hydrogen/lower alcohol is used as an energy carrier. This would capitalize on the energy and material attributes of hydrogen as a carrier that can connect the coal chemical industry with biomass and renewable energy. Focus should be given to demonstrating the full-chain regional comprehensive utilization of hydrogen energy, integrating hydrogen energy and the coal chemical industry, and capturing and storing CO_2. These actions could capitalize on Northwest China's advantages, such as its diversified and abundant hydrogen energy, large-scale renewable energy resources, and perfect pipe network infrastructure. Thus, the strategic opportunity of marketization of the hydrogen energy industry can be seized. This could primarily be achieved by constructing key links within hydrogen energy industrial chains, such as hydrogen production, hydrogen transportation, hydrogenation, fuel cells, and hydrogen energy automobiles. Furthermore, pilot programs should be conducted to establish a path for hydrogen energy to reduce carbon in high-carbon cities and industries and build a hydrogen energy demonstration region with a national influence. Based on the characteristics of the coal chemical industry, including its extensive CO_2 emissions, large-scale CO_2 capture and storage should be performed. Moreover, research and demonstration in the fields of synthesizing hydrogen and CO_2 into lower alcohols/fuels should be promoted. This could help to develop a prototype gas-to-liquids energy system.

Based on the developed lower alcohol industry and Northwest China's rich methanol and ethanol raw materials, the comprehensive regional application of coal-based alcohol ether fuels should be demonstrated. This would provide multiple choices for the complementary substitution strategy of liquid fuels in China. In particular, in terms of coal-to-ethanol fuels, pilot programs could be conducted regarding the regional comprehensive application of coal-to-ethanol fuels. The half million tons coal-to-ethanol project has already been completed and put into operation in the region.

5.2.5 Promoting and demonstrating intelligent integration supported by intelligent technology

China's energy industry requires digital and intelligent development. Thus, the construction of advanced energy systems (such as comprehensive energy system management platforms and virtual plants) that are supported by intelligent technologies should be promoted. Furthermore, emphasis should be given to the layout and demonstration of intelligent management regarding urban comprehensive energy systems. On one hand, intelligent terminal facilities should be used to strengthen the overall perception and intelligent processing of various links within the energy system, such as raw materials, processes, products, and storage. On the other hand, an intelligent regional comprehensive energy system should be used to promote scientific and fine urban energy utilization and to improve the level of urban energy supervision and overall management.

5.2.6 Promoting regional demonstrations driven by the park-level low-carbon integration of fossil fuel and renewable energy sources

Low-carbon development is required in China's high-carbon energy industries. Therefore, multi-energy integration demonstration projects regarding low-carbon emissions from high-carbon industries should be created in typical parks in China. These projects should be based on several advanced energy integration technology conditions that have accumulated nationally. Through park-level system planning and design and using technological, process, and system integration innovations, barriers between park-level systems should be broken, and material, energy, and information flows should be achieved. By improving the energy use efficiency and atom utilization, a new mode of multi-energy and multi-path coupling utilization should be developed at the park level, aimed at low-carbon production. Emphasis should be given to exploring the coupling integration of hydrogen supplementation in the coal chemical industry and hydrogen production for renewable energy. This would permit the exploration of technological paths for the low-carbon development of the coal chemical industry. The paths for promoting regional multi-energy integrative development should be explored by demonstrating park-level multi-energy integration. This should provide an effective technique to implement a national energy innovation strategy.

6 Conclusion

In its new development stage, China will continue to promote energy revolution and accelerate its construction of a clean, low-carbon, safe, and efficient energy system. Northwest China, as a continuous and core region for energy production, presents the problems and challenges regarding China's future energy transformation. In the New Era, Northwest China must tackle the technical problems and institutional obstacles regarding the multi-energy integration of an advanced energy system. This can be achieved through top-level thinking and design and extensive experimental demonstrations, ensuring clean and efficient utilization of fossil fuel energy, large-scale development of renewable energy, and low-carbon development of high-carbon industries. This approach should also promote the implementation of a regional energy revolution, explore effective techniques to comprehensively implement national energy revolution strategies, and accelerate the improvement of China's capacity to both safeguard its energy security and cope with climate change.

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