Engineering 19 (2022) 11–13

Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

Views & Comments

An Approach to Achieve Carbon Neutrality with Integrated Multi-Energy Technology

Wanjun Li, Hanxiong Zhu, Yu Xiao, Rui Cai, Zhongmin Liu

Dalian Institute of Chemical Physics, Chinese Academy of Sciences, Dalian 116023, China

1. Introduction

At the 75th session of the United Nations General Assembly on 22 September 2020, President Xi Jinping pledged that China would peak its carbon emissions before 2030 and achieve carbon neutrality by 2060 (hereinafter referred to as "peak carbon emissions and carbon neutrality"). This statement indicated that China would contribute to the global community in order to aim toward a shared future for humankind and would establish a schedule for the promotion of green, low-carbon, and high-quality development, which will benefit China's overall and long-term development. China's total carbon dioxide (CO_2) emissions surpassed those of the United States in 2005, making China the world's largest carbon emitter. Due to the nation's rapid and sustained economic growth, China's emissions reached 9.83 billion tonnes in 2019, accounting for 28.8% of the global total [1]. China's per capita carbon dioxide emissions also increased rapidly, reaching 6.8 t per person in 2018 [2]—about 1.5 times the global average. Therefore, it is a challenging and formidable task for China to achieve carbon neutrality on a stricter timeline than developed countries while ensuring sustained economic growth.

Energy-related carbon emissions in China account for almost 90% of the national total carbon emissions [3]; therefore, low-carbon development in the energy sector is the key to carbon neutrality. Carbon emissions are directly associated with the types, usage patterns, and total utilization of energy resources. Due to the structure of China's energy resources, which are rich in coal while lacking in oil and gas, and the high dependence of the energy and energy-related industrial systems on fossil energy, the carbon intensity of energy consumption remains high in China. Moreover, the incompatibility between the relatively independent subsystems of coal, oil, natural gas, renewable energy, and nuclear energy may further increase China's carbon intensity due to energy consumption. Therefore, it is necessary to get rid of the segmentation of energy types and energy-related industries, break down independent institutional barriers, and restructure the energy and energy-related industrial systems in China [4]. In this way, China can gain overall advantages from multi-energy system integration, promoting low-carbon and green development.

To construct a clean, low-carbon, safe, and efficient modern energy system, it is essential to further strengthen top-level design and systematic planning, and to give full play to the driving role of scientific and technological innovation. The development of science and technologies—especially that of transformative technologies—will be a crucial factor in breaking industry barriers and promoting the multi-energy system integration of various types of energy and industries, thus achieving the prospective goal of carbon neutrality and supporting China's sustainable development.

2. Promote breakthroughs in key technologies through innovation

During the period of the 13th Five-Year Plan, China carried out many major tasks in the fields of clean and efficient energy conversion, coal utilization, renewable and hydrogen energy, nuclear safety and advanced nuclear energy, smart power grids, and new energy vehicles. The overall aims were to resolve key scientific issues in energy utilization, promote breakthroughs in key technologies, drive the development of the new energy industry, and upgrade technologies involving the use of fossil energy, thereby promoting the reduction of carbon emissions. During the period of the 14th Five-Year Plan, China will further strengthen its innovation and carry out in-depth research and development of novel materials, technologies, and processes. The technological development of large-scale energy storage, hydrogen energy, and the smart regulation of modern grids will be accelerated to form a new power system that can enable a large scale and high proportion of renewable energy in power generation, transmission, grid connection, and consumption, thus reducing coal consumption for electricity generation and realizing the decarbonization of the power system. Technologies for the clean and efficient utilization of coal will also be developed and demonstrated; for example, breakthroughs will be achieved in the one-step synthesis of high-value chemicals from syn-gas, the production of aromatics from coal, and the hierarchical and qualitative utilization of coal.

In the medium and long term, it is important to accelerate the development of key technologies to reduce coal utilization by achieving breakthroughs in zero-carbon/low-carbon process reengineering technologies in the iron and steel, chemical, cement, and

https://doi.org/10.1016/j.eng.2021.09.024

non-ferrous metal industries, which are challenging to decarbonize, in order to promote the deep decarbonization of the industrial system. In addition, several cutting-edge and disruptive technologies will be proactively deployed, such as those involving advanced nuclear energy, photocatalytic hydrogen production, cross-system coupling integration and optimization, and large-scale and low-cost carbon capture, utilization, and storage (CCUS), in order to provide technical support for the deep decarbonization of society as a whole.

In 2017, a strategic priority project known as the Transformational Clean Energy Technology and Demonstration was launched by the Chinese Academy of Sciences (CAS) to promote innovation and demonstration for a revolution in energy technology. The project now boasts numerous achievements; for example, with the development and massive production of key materials of flow batteries, a 100 MW vanadium flow battery demonstration has been constructed in Dalian, China [5,6]. Chen et al. [7] achieved breakthroughs in key technologies of compressed air energy storage, and a 100 MW/400 MW·h demonstration based on these developments is currently under construction. An oxide–zeolite (OX-ZEO) catalytic system has been developed by Bao [8], which realizes the one-step conversion of coal-based syn-gas for olefin production. This system greatly reduces water and energy consumption and subverts the traditional Fischer–Tropsch (FT) process in principle. The new generation of methanol-to-olefins (MTO) has reduced methanol consumption by 10% and increased the production of olefins from 6×10^5 to 1×10^6 t per year [9]. Li et al. [10] realized the successful demonstration of large-scale methanol production through photovoltaic-water electrolyzer–carbon dioxide hydrogenation technology using $ZnZrO_x$ as a solid solution catalyst [11]. Moreover, a molten salt nuclear reactor is now under construction in Gansu, China [12].

3. Promote breakthroughs in multi-energy system integration through cross-sector research

Multi-energy system integration can break through the existing barriers in the energy sector and promote the integration of the resource advantages of various energy systems. In addition, it can reconstruct the energy and heavy industry system and realize the green and low-carbon circular development of high-carbon industries in China. We have proposed a strategic technology roadmap to achieve carbon neutrality with three main routes and three platforms [13]. A diagrammatic sketch of the proposed multi-energy system integration is provided in Fig. 1.

In the proposed roadmap, Route 1 involves the clean and efficient use of fossil resources and coupling substitutions. CO_2 emissions from coal combustion account for over 70% of the total emissions from energy use in China [14]. According to the *China Energy Statistical Yearbook 2020*, the coal combusted for power generation and heat supply accounted for 60% of the total coal consumption in 2019 [15]. The most effective way to reduce CO_2 emissions is to replace coal combustion with renewable energy or nuclear power for power generation. In addition, a certain number of flexible thermal power plants are still necessary to keep the power system steady and reliable. Coal should play a more important role in chemical production as a resource. Through syn-gas/methanol platforms, the coal chemical industry can complement chemical products from the petrochemical industry through the production of olefins, aromatics, ethanol, and ethylene glycol, for example. In addition, coupling the coal chemical process to the petrochemical process can significantly improve atomic utilization and energy efficiency; one example is the coupling conversion of methanol and petroleum naphtha to light olefins [16].

Route 2 involves the large-scale application of renewable energy. China has committed to increasing the share of non-fossil fuels in primary energy consumption to around 25% by 2030 [17] and to what is expected to be more than 70% by 2050 [18]. Here, the development of large-scale renewable energy is the priority, as it will account for 60% of China's energy mix. However, the primary drawback of renewable energy (e.g., wind and solar energy) is its intermittent nature, due to its dependence on the weather. A large-scale energy-storage platform will be essential for promoting the large-scale and high-proportion development of renewable energies.

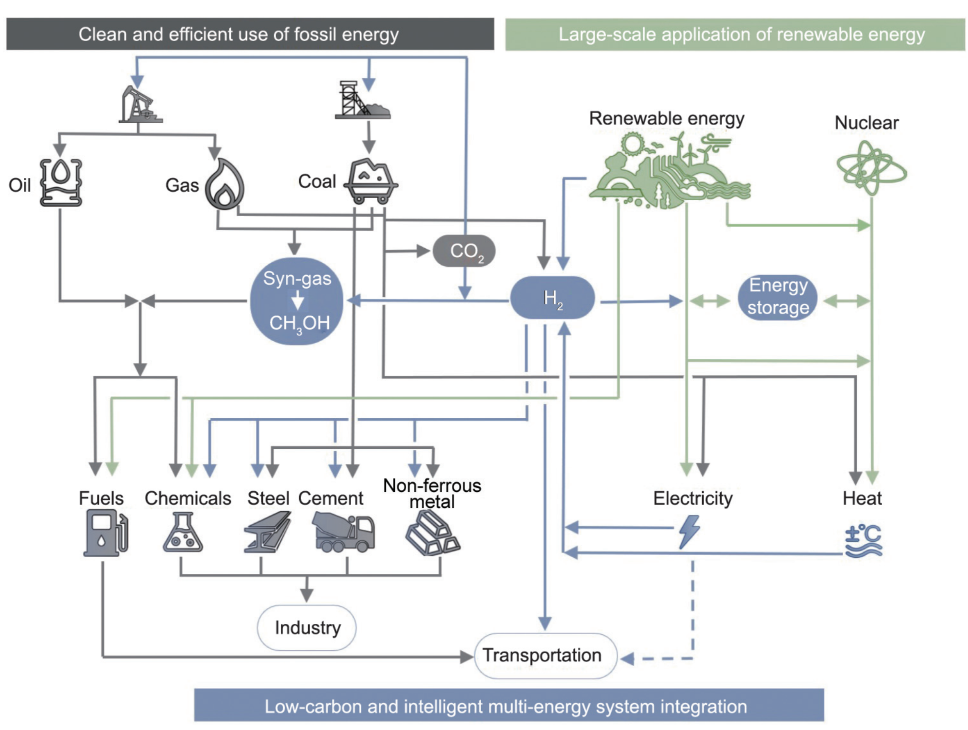

Fig. 1. Schematic diagram of the proposed multi-energy system integration.

Route 3 involves low-carbon and intelligent multi-energy system integration. Although continuously increasing the use of renewable energy for power generation will greatly decrease the CO_2 emissions of the energy system, another major problem is the decarbonization of carbon-intensive industries, such as the iron and steel, cement, chemical, and non-ferrous metal industries. Aside from innovative technological developments and synergies among different industries, the green hydrogen produced by water electrolysis using renewable or nuclear energy is another platform that can facilitate the industrial transition. For example, we can connect the steel to chemical industry to produce ethanol by using the tail gas of steel plants as a carbon resource, which is economically feasible and can be integrated into a new type of circular value chain [19]. It has been calculated that the conversion of 25% of the tail gas of China's steel plants will produce around 10 million tonnes of ethanol, which can reduce China's CO_2 emissions by about 20 million tonnes. Moreover, the use of green hydrogen for metallurgy will cut around 80% of CO_2 emissions in comparison with the traditional blast furnace process [20]. Another example is coal chemistry: A sufficient supply of green hydrogen for a coal-to-olefin process will reduce the carbon emissions of the process by around 70% [21]. At the same time, digital technologies such as big data and artificial intelligence will have a tremendous impact on the entire energy value chain, from generation, transportation, and distribution to consumption.

4. Establish a new pattern of low-carbon development through regional demonstrations

In view of the complex scenarios of energy application in China, no universal model can resolve all the problems encountered in the process of achieving peak carbon emissions and carbon neutrality in China. Therefore, cross-domain demonstrations in typical regions or industries can effectively promote technological iteration, systematically innovate within institutional mechanisms, and explore paths for the construction of a national modern energy system, thereby promoting the establishment of a new pattern of low-carbon development. At present, together with the government of Shaanxi Province and industrial partners, the Dalian National Laboratory for Clean Energy, CAS is planning a national-level energy revolution and innovation demonstration zone in Yulin [22]. They will establish and demonstrate an integrated multi-energy system conforming to the characteristics of the resources and environment in west China, with the aim of realizing the low-carbon development of a city that is heavily reliant on its fossil energy resources.

5. Conclusions

To achieve peak carbon emissions and carbon neutrality in China, it is important to create an overall plan aimed at establishing a clean, low-carbon, safe, and efficient energy system. By breaking down the barriers between all energy-related industries to form a resultant force, and with the support of local governments, regional low-carbon and clean energy supply systems will be established according to local conditions. With breakthroughs in key technologies, we can promote a national energy revolution based on successful and revolutionary regional energy demonstrations to resolve systematic energy problems. Therefore, top-level design should be strengthened in order to establish a beneficial mode of sustainable development involving joint efforts.

Acknowledgments

This study was supported by the Consulting Research Project of the Chinese Academy of Engineering (2020-XY-6).

References

[1] BP, p.l.c.. Statistical review of world energy 2020. 69th ed. London: BP, p.l.c.; 2020.
[2] International Energy Agency. CO_2 emissions from fuel combustion, 2020 edition. Paris: International Energy Agency; 2020.
[3] Chen JH. An empirical study on China's energy supply-and-demand model considering carbon emission peak constraints in 2030. Engineering 2017;3(4):512–7.
[4] Xiao Y, Peng ZL, He JD, Liu ZM. Science and technology innovation promotes construction of new national energy system. Bull Chin Acad Sci 2019;34(4):385–91. Chinese.
[5] Chen DJ, Qi HN, Sun TT, Yan C, He YY, Kang CZ, et al. Polybenzimidazole membrane with dual proton transport channels for vanadium flow battery applications. J Membr Sci 2019;586:202–10.
[6] Lu W, Li X, Zhang H. The next generation vanadium flow batteries with high power density—a perspective. Phys Chem Chem Phys 2018;20:23–35.
[7] Zhou XZ, Xu YJ, Zhang XJ, Xu DH, Linghu YQ, Guo H, et al. Large scale underground seasonal thermal energy storage in China. J Energy Storage 2021;33:102026.
[8] Bao XH. Nano confinement and catalytic conversion of energy molecules. Chin Sci Bull 2018;63(14):1266–74. Chinese.
[9] Yang M, Fan D, Wei Y, Tian P, Liu Z. Recent progress in methanol-to-olefins (MTO) catalysts. Adv Mater 2019;31(50):1902181.
[10] Wang J, Li G, Li Z, Tang C, Feng Z, An H, et al. A highly selective and stable ZnO–ZrO_2 solid solution catalyst for CO_2 hydrogenation to methanol. Sci Adv 2017;3(10):e1701290.
[11] Han YM. ["Liquid sunshine" makes us closer to "carbon neutrality"]. China Science Daily 2020 Nov 11;Sect 3:1. Chinese.
[12] Wang JQ, Dai ZM, Xu HJ. Research status and prospect of comprehensive utilization of nuclear energy. Bull Chin Acad Sci 2019;34(4):460–8. Chinese.
[13] Zhu HX, Geng XY, Xiao Y, Cai R, Liu ZM. Strategic path for energy revolution in northwest China in the new era. Strateg Study Chin Acad Eng 2021;23(1):92–100. Chinese.
[14] Wang JN, Yan G. [Accelerate to peak the carbon emissions and promote high-quality economic development]. Economic Daily 2021 Jan 4;Sect 1:3. Chinese.
[15] Department of Energy Statistics, National Bureau of Statistics. China energy statistical yearbook 2020. Beijing: China Statistics Press; 2021.
[16] Ye M, Zhu WL, Xu SL, Liu ZM. Coordinated development of coal chemical and petrochemical industries in China. Bull Chin Acad Sci 2019;34(4):417–25. Chinese.
[17] China Global Television Network. President Xi's speech at Climate Ambition Summit 2020 [Internet]. Beijing: China Daily; [updated 2020 Dec 13; cited 2021 Aug 15]. Available from: http://www.chinadaily.com.cn/a/202012/13/WS5fd575a2a31024ad0ba9b7ac.html.
[18] Project Report Preparation Team. Comprehensive report on China's long-term low-carbon development strategy and transition path. China Popul Resour Environ 2020;30(11):1–25. Chinese.
[19] Wu ZL, Wang H, Yang PZ, Ren XG. Commercialization progress of ethanol production from tail-gas of steel plants. China New Technol New Prod 2019;13:133–4. Chinese.
[20] Griesser A, Buergler T. Use of HBI in blast furnace. Berg Huettenmaenn Monatsh 2019;164:267–73.
[21] Jin GZ, Zhang X, Zhu HX, Li JJ, Zhang MZ, Xiao Y, et al. Research on multi-energy and innovation integration development of modern coal chemical industry to meet the challenge of carbon emission reduction. China Coal 2021;47(3):15–20. Chinese.
[22] The Publicity Department of the CPC Yulin Municipal Committee. Shaanxi Yulin: construct demonstration zone for energy revolution innovation. People's Daily 2019 Dec 11;Sect 13. Chinese.