

# Development Trends and Strategic Countermeasures of China's Emerging Energy Technology Industry Toward 2035

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**Abstract:** Technological innovation is becoming a source of power driving the transition and development of global energy industries. The development of emerging industries in the energy field is rooted in the reality of China's energy status, the major strategic needs of the country, and the demands for innovation-driven energy development. The term "emerging energy technologies" used in herein refers not only to renewable and nuclear energy technologies but also to the ground-breaking or disruptive energy development and utilization technologies, in areas such as the exploitation of unconventional oil and gas resources, the clean and efficient conversion and utilization of fossil fuels, energy transmission, and the end use to which energy is put. After defining the scope and orientation of the emerging energy technology industries, we analyze the current status and development trends of these industries in China and abroad. With a view toward 2035, we propose key areas and technology direction of the emerging energy technology industries. The guideline, objectives, and key tasks for developing China's emerging energy technology industries during the 14th Five-Year Plan period are explored in detail. We propose focusing on the development of 41 new energy technologies in the following 10 areas: advanced coal-fired power generation, unconventional natural gas development, energy Internet and integrated energy services, nuclear energy, wind power, solar photovoltaic power generation, solar thermal power generation, biomass energy, geothermal energy, and hydrogen energy and fuel cells. Furthermore, we recommend the establishment of nine key scientific and technological projects, one major engineering project of multi-energy complementary distributed energy system, and two demonstration zones for emerging energy technology integration and innovation, distributed in Hebei Xiong'an New Area and coastal areas of South China. Corresponding policy implications are also addressed, including the strengthening of top-level design for the development of emerging energy technologies and emerging energy industries, integrating energy-saving industries with emerging energy technology industries, and adjusting the "new energy industries" to "emerging energy technology industries" in the national plan of emerging industries.

**Keywords:** energy industry; emerging energy technology; emerging industry; 2035

## 1 Introduction

Iterative innovation of energy technology has made a significant contribution in promoting the transition and development of global energy industries. As the largest developing country in the world and the country with the largest population and second-largest economy, China is also the largest energy-producing and -consuming country. The sound development of the energy sector is inextricably related to the sustainable development of resources, the environment, and the social economy. To date, the Chinese energy industry has made substantial achievements but

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has also encountered considerable problems, one of the most prominent of which is the huge scale of energy consumption and the critical position of fossil energy reserves with respect to the energy production and consumption structure. In 2018, the total consumption of coal in China was  $2.74 \times 10^9$  tce, with a year-on-year growth of 1.0%, accounting for 59.0% of the total energy consumed [1]. However, in recent times, we have witnessed a continual decline in the proportion of energy generated from fossil fuels. At the same time, the generating capacities of renewable and nuclear energy have risen, although the scale of production is still nowhere near sufficient. A second major problem faced by the Chinese energy sector is related to the potential risk associated with the security of oil gas supplies. In 2017, China surpassed America to become the largest crude oil importer for the first time, and in 2018, China's proportional dependence on foreign sources of oil and natural gas was 72% and 43%, respectively [2]. Furthermore, the high-quality utilization of fossil fuel-derived energy has yet to realize and the clean and efficient utilization of coal is in need of improvement. Compared with other developed countries, the proportion of power generated from coal in China is considerable lower, although large-scale coal development and utilization have brought about serious eco-environment problems [3]. General energy system efficiency in China is also conspicuously low. The energy consumption per unit GDP in China is some 1.4 times as much as that of the world average. In 2018, the average value of thermal power utilization hours was 4361 h and the generating capacity of "three curtailments" (curtailment of hydro, wind and solar power) was  $1.023 \times 10^{11}$  kW·h. Finally, reduction in greenhouse gas emissions and coping with the repercussions of ongoing changes in global climate are presenting considerable challenges. Currently, China's emissions of carbon dioxide account for 30% of those the entire world and the country is ranked first with respect to the emission of methane rank.

In addition to guaranteeing the security of the national energy supply, adopting measures to preserve the eco-environment and addressing the challenges posed by climate change will be critical long-term issues for the future development of the energy sector in China. Along with the increasing growth and future development of the economy and society, there will be increasing demands for energy resources for upgrading traditional industries and sustaining infrastructure construction, and thus the total energy consumed in China is also set to rise. It is anticipated that these demands will be met by an expansion in the renewable energy, natural gas, and nuclear power industries, along with further development of the relevant emerging industries. Indeed, the development of emerging industries in the energy field is closely related to national strategic needs. It will accelerate the energy production and consumption revolution, optimize the energy structure, contribute to ensuring energy safety, and facilitate greenhouse gas reductions and eco-environment preservation. Moreover, it will lead to improvements in the level of national industrial equipment manufacturing technology, foster a new economic growth drive, and promote the sustainable development of economic society [4].

In the next 10 to 15 years, and indeed the longer term, China will enter a crucial period characterized by an acceleration of the cultivation and development of strategic emerging industries, which will also be a significant period of opportunity for developing green and low-carbon industries. The inevitable way forward will be to promote development of the emerging energy technology industries that is commensurate with the development demands and resource features in China. Previous studies [5,6] have discussed the general framework of development for strategic emerging industries, development trends, and path choices for the new energy industries or particular energy sectors, and the policies and regulations of strategic emerging industries, and have comprehensively analyzed regional industrial clusters, strategic layout, innovative features, and development modes. However, research that focuses on the future development of emerging energy industries has yet to emerge, notably with respect to a systematic assessment of industrial positioning, developmental paths, and detailed measures from the strategic perspective.

In this paper, we define the salient features of emerging energy technologies and the industrial connotations, clarify the variation tendencies of the competitive landscape for the global emerging energy technology industries, as well as international and domestic development trends, and examine the development direction of emerging energy technology industries toward 2035, particularly with respect to the developmental goals and key tasks enshrined in the 14th Five-Year Plan. We also present details of future trends in technological innovation development and propose key scientific and technological projects, significant projects, and demonstration area construction requiring advanced layout, as well as relevant policies and suggestions.

## 2 Features of emerging energy technologies and the industrial connotations

### 2.1 Features of emerging energy technologies

Emerging energy technologies are generally characterized by certain common features [4]. First, these technologies are based upon the assumption that innovation in technological principles can solve all the restrictive

development problems in technological fields. Second, emerging energy technologies have good technical competitiveness or advantages. Third, the relevant mature technologies are regarded as the basis for development, providing sound technical feasibility. Finally, the combination of large cost reduction potential and a higher rate of technical learning will contribute to promoting a rapid expansion in the scale of technical development, thereby building the capacity to compete with the traditional technologies and garner a large fraction of the market share. On the basis of definitions proposed in relevant research [7], we further define the emerging energy technologies as “not only the renewable and nuclear energy technologies but also the ground-breaking or disruptive energy development and utilization technologies, in areas such as the exploitation of unconventional oil and gas resources, the clean and efficient conversion and utilization of fossil fuels, energy transmission, and the end-use to which energy is put.”

## 2.2 Scope and orientation of an emerging energy technology industry

The orientation of emerging energy industries reflects the objective laws of energy development, conforming to the significant national demand of “promoting the energy production and consumption revolution and constructing clean, low-carbon, safe, and efficient energy systems.” It also fully presents the new trend, vigor, and business form of energy industries, and effectively promotes low-carbon green energy generation as a new driver of economic growth. *The Decision of the State Council on Accelerating the Cultivation and Development of Strategic Emerging Industries* (GF [2010] No. 32) divided strategic emerging industries into seven classes, including “new energy industries” and “energy conservation and environmental protection industries”, the latter of which only refers to high efficiency and energy conservation in the process of traditional industrial utilization in the energy field. *The 13th Five-Year Plan for the Development of Strategic Emerging Industries* included new energy industries, energy conservation, environmental protection industries, and new energy automobile industries among the “green and low-carbon industries.” Thereafter, the emerging industries in the energy field mainly used to be represented by “new energy industries.”

Although the energy generated from new energy industries or traditional energy industries are not different, the associated energy technologies are distinct owing to the advanced level [7–9]. “New energy industries” cannot directly reflect the smart grids, energy storage, distributed energy resource, micro-grid, and other industries. Furthermore, the development of renewable energy industries also needs to take into consideration the advancement of technologies. Given that the orientation of “new energy industries” over-emphasizes the importance of energy generated from nuclear, solar, wind, and biomass sources, the revolutionary function of new technologies for generating energy from fossil fuels (e.g., large-scale development technology of shale oil and gas and advanced clean coal technology) can easily be neglected, and thus the cooperative and coordinated development of new technological systems for energy generated from fossil fuels and non-fossil fuel sources is excluded. Although The National Energy Administration and other government departments have included shale oil development and smart grids among the strategic emerging industries, the detailed scope of emerging industries in the energy field is poorly defined. The orientation of “new energy industries” is currently too narrow to fully represent the energy transformation and industrial revolution brought about by emerging energy technologies. To a certain extent, the restriction of current industrial division and orientation hinders promotion of the integrated innovation of emerging energy technologies and the coordinated development of energy industries, which restricts progress in a comprehensive promotion of the energy production and consumption revolution.

Under such circumstances, we propose an expansion in the scope and connotations of the previously defined “new energy industry” [7] to “emerging energy technology industry”, and advocate paying equal attention to the clean and efficient utilization of fossil fuel-derived energy and the large-scale development of nuclear and renewable energy. The emerging energy technologies related to the development of emerging industries cover the areas of energy conservation and energy efficiency improvement technology, new technologies for clean and efficient development and utilization of fossil fuel-generated energy, smart grids, energy storage technology, large-scale development, technologies associated with the utilization of unconventional oil and gas resources and renewable energy, self-innovative nuclear power technology and nuclear waste treatment technology, hydrogen energy, fuel cells, nuclear fusion energy, hot dry rock, natural gas hydrate, and other relevant advanced technologies.

Consequently, the emerging energy technology industries will mainly encompass the clean and efficient transformation and utilization of coal (with a particular focus on advanced coal-fired power generation), unconventional development and utilization of oil and gas (with a focus on unconventional natural gas sources, i.e., shale gas, coal bed gas, and natural gas hydrate), the energy internet and comprehensive energy services (with a

focus on the energy internet, advanced power transmission, energy storage, and comprehensive energy services), nuclear and renewable energy generation (with a focus on wind power generation, solar photovoltaic and thermal power generation, biomass energy, geothermal energy, hydrogen energy, and fuel cell development).

### **3 Trends in the development of international and domestic emerging energy technology industries**

#### **3.1 The current situation**

##### **3.1.1 Global emerging energy technology industries**

Over recent years the global energy scene has undergone considerable changes. The “energy independence” achieved by US has been dependent on the large-scale development of unconventional oil and gas resources, whereas the nuclear power supply capacity of some developed countries has continued to decline. The rapid development of renewable energy industries represented by wind and solar energy power generation and the globalization trend in the conversion to unconventional oil and gas resource production have radically altered the global pattern of energy supply and demand [10]. Overall, there has been a global trend toward the development of low-carbon green energy generation characterized by the “energy structure transformation toward low-carbon energy, a transformation in energy development toward climate stabilization and eco-adaptability, and the smart transformation from the guarantee of energy supplies to the realization of energy services.” All countries are endeavoring to foster innovative developments in energy technology and promote low-carbon energy and sustainable green development. Concerted technological innovation will contribute to revolutionizing current patterns in energy development and utilization. Technological advances will lead to a significant growth in global energy supply capacity, whereas developments promoting the clean and efficient generation and utilization of fossil fuel-derived energy will enhance the competitiveness of industries based on conventional fuel sources, although polluting emissions, particularly carbon-based emissions, will remain a source of concern. Moreover, gradual reductions in the costs of implementing technological development will facilitate the wider application of renewable energy technology. Nevertheless, the conversion to a situation where energy production is based largely on renewable sources will present a long-term challenge for energy systems in the future [11]. In this regard, it is worth noting that hydrogen energy generation has emerged a promising industry that covers electric power, heat supply, and fuel production.

##### **3.1.2 Emerging energy technology industries in China**

To date, energy development in China has largely been pursued with an emphasis on quality [11]. The energy consumption structure is optimized, and despite the continued reliance on coal and petroleum, clean energy accounted for 22.1% of the energy consumed in 2018. Moreover, the energy supply structure is becoming increasingly more diversified. As the largest producer of renewable energy, renewable energy industries in China are developing rapidly and the newly installed capacity of power generation has exceeded that based on fossil fuels. In 2018, energy generated from renewable sources accounted for 26% in the overall power supply structure [2], with an enhanced substitute effect. With respect to wind power generation (accounting for 5.2%) and solar photovoltaic power generation (accounting for 2.5%), China ranked first in the world in terms of scale. Wind curtailment and power shortage issues have been significantly improved and the solar power curtailment capacity and ratio have decreased in China. The scale of nuclear power generation (accounting for 4.1%) has shown a steady rise and the multi-purpose utilization of nuclear power offers considerable potential. Moreover, there have been vigorous developments in the energy internet and comprehensive energy service industries and construction of the energy infrastructure has accelerated, promoting the implementation of the Belt and Road initiative and regional integrated development.

From the perspective of technologies, the energy technology and innovation capacity of China are continuously developing, and have gone some way in achieving an international advanced level [12]. The development and utilization efficiency of fossil fuel-derived energy has been further improved and the coal-fired power generation technology with ultra-low emission has been widely promoted. There have also been a number of important breakthroughs with respect to unconventional natural gas development and utilization technology, as well as technological advances in the grids and energy storage engineering. The energy internet and energy storage industries are now at an internationally advanced level in the large power grid technology field, with a gradual enhancement of technical innovation capacity in the nuclear power and renewable energy industries.

Despite these promising advances, however, there remain substantial problems that need to be overcome if the emerging energy technology industries are to realize their full potential [13]. General improvements are required in

the levels of clean and efficient coal transformation and utilization and there is a desperate need of further research, development, demonstration, and promotion with respect to advanced coal utilization technology. Moreover, security regarding the supply of oil and gas is currently unsatisfactory. There has been no large-scale and commercialized development of unconventional oil and gas reserves and the associated key technologies, systems, and mechanisms remain limited. The nuclear power industry is in need of further scale development to guarantee safe and efficient growth, whereas technical and market issues still pose substantial obstacles prohibiting the development of the energy internet and comprehensive energy service industries. In addition, renewable energy industries are having to contend with insufficient core technologies, grid-connection absorption, and other problems and challenges.

## 3.2 Development trends

### 3.2.1 Emerging energy technology industries around the world

By 2035, the coordinated development of energy derived from fossil fuel and alternative sources will be the mainstream for future trends in global energy development [13]. The renewable energy sector is still lacking in terms of stability, economy, and availability, and thus for the near future at least, the global energy demand will continue to be met primarily by fossil fuel-derived energy generated using well-established technologies. Green and low-carbon energy will be the long-term development orientation for energy technology innovations, and energy generation will become increasingly more integrated with information, materials, and other fields, which will lead to the development of a smart energy internet with considerable potential. Technological innovations in the energy field will also provide a new impetus for the transformation and upgrading of traditional industries, and promote the rapid development of smart manufacturing, architecture, transport, and other emerging fields [11].

### 3.2.2 Emerging energy technology industries in China

Over the next 10 to 15 years, there will be a continual optimization of the energy production and consumption structure in China, although given the considerable scale, the development and utilization of traditional fossil fuel-derived energy will continue to play a key role in ensuring the security of energy supplies. Shale gas, coal bed gas, and other unconventional oil and gas resources will serve as strategic alternative resources of considerable importance in China's oil and gas industries. Given the relatively advanced technology associated with nuclear energy generation in China, international competitiveness, research and development, and multi-purpose utilization are all likely to continually improve. Replacing fossil fuel-derived energy with clean energy generated from renewable sources will enhance the energy supply capacity, meet the demand for sustainable energy, and contribute to the maintenance of a stable environment and climate. Currently, the amounts of energy generated from renewable sources are rising rapidly in China, and ongoing developments with respect to the energy internet hold considerable promise for revolutionizing the country's modern electricity industry and comprehensive energy system.

## 4 Development strategy countermeasures of emerging energy technology industries toward 2035

### 4.1 Development strategy thinking of the emerging energy technology industries

On the basis of the prevailing situation in China, objective law of energy development, and innovative trends in energy technology at home and abroad, the development of emerging energy technology industries necessitates that equal attention be devoted to the revolutionary functions of new technologies for energy derived from fossil fuels and alternative sources, continuous optimization of the energy production and consumption structure, and a focus on improving the utilization efficiency and consumption of energy derived from non-fossil fuel sources. It also requires an enhancement of foundational research on energy technologies and vigorous development of frontier technological innovation, particularly with respect to inter-disciplinary and revolutionary technologies. Furthermore, there is a need to promote a more close integration of energy, material, and information, as well as the development of smart grids and smart energy to establish a clean, low-carbon, high-efficiency, and smart comprehensive modern energy system [7,11].

### 4.2 Development goals and tasks for emerging energy technology industries during the 14th Five-Year Plan period

According to the nine sub-industries constituting the emerging energy technology industries, the detailed development goals and key tasks for industries during the 14th Five-Year Plan period based on the development

conditions of the 13th Five-Year Plan period are as follows.

#### 4.2.1 Clean and efficient coal utilization industry

Development goals: An average coal consumption for coal-fired power generating units of less than 300 gce/(kW·h) and a reduction in carbon intensity of approximately 825 g/(kW·h). A 5–10-MW integrated coal gasification fuel-cell combined cycle system (IGFC) power plant demonstration project is expected to realize. A 600-MW 700°C ultra-supercritical demonstration project and a megaton CO<sub>2</sub> capturing, displacement, and sealing demonstration project are to be completed.

Key tasks: (1) to comprehensively improve the efficiency and pollutant discharge control level of coal-fired power generating units, and develop high-efficiency and low-cost carbon capturing, utilization, and sealing technology; (2) to develop a highly flexible coal-fired power generating technology and study coal and renewable energy coupling power generation technology; (3) to research and develop a smart power generation technology with the significant features of digitalization, self-learning, self-adaption, and interaction; and (4) to accelerate the key project of “clean and efficient coal utilization,” and expand the research and development input on integrated coal gasification combined cycle systems (IGCC)/IGFC.

#### 4.2.2 Unconventional natural gas development and utilization industry

Development goals: A shale gas yield of  $3 \times 10^{10}$ – $5 \times 10^{10}$  m<sup>3</sup> and ground coal-bed methane drainage of  $1.3 \times 10^{10}$  m<sup>3</sup>; the natural gas hydrate industry is equipped with a forward-looking layout, and resources are further explored in accordance with technological breakthroughs.

Key tasks: (1) to accelerate the construction of a commercialized shale gas development base in Sichuan and Chongqing, and realize the rapid growth of shale gas yield; (2) to accelerate the construction of normal pressure, deep layer, continental facies and other types of shale gas demonstration areas and promote development of the shale gas industry toward multiple areas and fields; (3) to continuously propel construction of an industrialized coal bed gas base in the Qinshui Basin and east of the Ordos Basin; (4) to accelerate the development and testing of new areas and new bed series, e.g., the Permian system in the south and low-rank coal in the Ordos Basin, and develop new industrialized coal bed gas bases; and (5) develop gas exploitation both at sea and on the land, establish a forward-looking program for the natural gas hydrate industry, and accelerate resource evaluation and technical research and development.

#### 4.2.3 Energy internet and comprehensive energy service industry

Development goals: To construct a ubiquitous power Internet of Things and essentially form a co-construction, co-governance, and all-win energy internet ecosphere to guide the energy production and consumption revolution and realize the goal of conducting more than 90% of business online.

Key tasks: (1) to research the new infrastructure system of smart cities adapting to global energy internet development characteristics; (2) to adopt superconducting transmission technology for upgrading and transformation of transmission lines; (3) to comprehensively perceive the operation, status, and environmental information of source network load storage equipment, and improve the grid-friendly connection level of distributed energy and the adjustable capacity proportion of grids through a virtual power plant and multi-energy complementation; (4) to adopt optimal dispatchment for the regional coordinated control of sending and receiving ends and realize integrated inter-province transactions and distributed intra-province transactions based on the grid market to promote the absorption of clean energy; and (5) to develop a multi-type, high-capacity, low-cost, high-efficiency, and long-life advanced energy storage systems.

#### 4.2.4 Nuclear energy industry

Development goals: The installed capacity of nuclear power reaches  $9.4 \times 10^7$ – $1 \times 10^8$  kW, with a pressurized water reactor commissioning capacity of  $7.2 \times 10^6$ – $9.6 \times 10^6$  kW, and that of the advanced reactors of  $6 \times 10^6$  kW.

Key tasks: (1) to realize development of the type spectrum and mass production for nuclear technology of independent third-generation pressurized water reactors; (2) to develop the scope of nuclear power application and application fields for small-sized multi-purpose nuclear reactor technology; (3) to implement the harmonious development of fourth-generation advanced nuclear energy technology and pressurized water reactors to establish a sustainable development mode; and (4) to develop a stable, high-efficiency, safe, and practical nuclear fusion technology.

#### 4.2.5 Wind power industry

Development goals: The accumulative installed capacity reaches  $3.5 \times 10^8$  kW, including  $2 \times 10^7$  kW of offshore

wind power; ensure that onshore wind power projects are available for comprehensive electric power bidding and the levelized cost of electricity of offshore wind power projects is significantly reduced.

Key tasks: (1) to optimize the industrial spatial layout and accelerate the development of onshore-distributed wind power; (2) to actively and systematically promote offshore wind power construction; (3) to enhance point and local utilization and solve problems relating to absorption; (4) to strengthen basic and generic technological research and establish a comprehensive research, development, and manufacturing system for industrial development; and (5) to enhance market competition mechanisms and actively promote the integration of wind power industry and financial systems.

#### 4.2.6 Solar photovoltaic industry

Development goals: The accumulative installed capacity of solar photovoltaic power generation reaches approximately 400 GW; the accumulative installed capacity of solar thermal power generation reaches 5 GW.

Key tasks: (1) to vigorously develop the distributed solar photovoltaic power generation; (2) to improve the absorption mechanism, with absorption and installed unit guaranteed; (3) to further improve the efficiency of solar batteries and components, and reduce the cost per kilowatt; (4) to develop molten salt tower technology with long heat storage hours at a large scale and further reduce the cost pricing of heat transfer oil for groove-type power plants; and (5) to develop trans-seasonal solar energy heat storage and heating technology; and (6) to actively participate in the global market.

#### 4.2.7 Biomass energy industry

Development goals: Power generation through refuse incineration to realize clean operation and dominance in the biomass power generation industry; the annual utilization amount of biomass briquette fuel reaches  $4 \times 10^7$  t and the biomass power generation and heating costs approach those of coal-fired power generation and heating.

Key tasks: (1) to establish biomass resource distribution and a physiochemical properties database; (2) to research and develop high-efficiency and combined biomass heat and power generation, combined generation of multiple heat and power products, and clean waste incineration power generation combined with multi-product production; (3) to focus on the research and development of industrial production key technologies and the efficient and clean utilization of biomass briquette fuel; and (4) to promote the industrialization of cellulosic ethanol for biomass transport fuel, establish a mature business operation mode for biodiesel, and develop an efficient biomass transformation technology.

#### 4.2.8 Geothermal energy industry

Development goals: The newly increased geothermal energy heating (refrigeration) area reaches  $1 \times 10^9$  m<sup>2</sup>; the newly installed capacity of geothermal power generation realizes 500 MW, and the annual utilization amount is equivalent to  $1 \times 10^8$  tce.

Key tasks: (1) to initially conduct geothermal resource potential investigation and target area evaluation; (2) to actively promote geothermal heating (refrigeration) and improve the heating structure to meet clean energy consumption requirements; (3) to deal with the technical difficulties relating to different heat storage types and achieve breakthroughs in common and key technologies; (4) to strive to solve technical issues in geothermal power generation technology and promote the efficient utilization of geothermal energy; and (5) to vigorously develop gradient utilization and “geothermal+” and improve the market competitiveness of geothermal energy.

#### 4.2.9 Hydrogen energy and fuel cell industry

Development goals: Hydrogen manufacturing and fueling and other supporting infrastructures should be improved, with the construction of more than 300 hydrogen fueling stations and basic balance of the supply and demand of hydrogen; the mass-production technology of core parts should be substantially improved, and the core technologies in hydrogen energy industrial chain should be essentially grasped; realization of a diversified hydrogen energy application scene in cities.

Key tasks: (1) to conduct the overall planning, reasonable layout, standardized construction, and large-scale development of hydrogen energy infrastructures; (2) to enhance the system integration of fuel cells; (3) to demonstrate the by-product hydrogen + carbon dioxide capturing and sealing technology, hydrogen fueling stations, and fuel cell freight vehicles in large industrial parks: demonstrations; (4) to develop water electrolysis based on renewable energy for hydrogen production, hydrogen filling station, and fuel cell bus and coach demonstrations in coastal cities; (5) to construct fuel cells for specific transportation demonstrations; and (6) to realize the application of million-kilowatt fuel cell distributed power stations at the edge cities and industrial and mining enterprises.

### 4.3 Innovation direction and engineering technology support for emerging energy technologies toward 2035

#### 4.3.1 Key technical directions

The key technical directions for the emerging energy technology industries in China towards 2035, covering 41 technologies, are presented in Table 1.

**Table 1.** Key technical directions for emerging energy technology industries in China.

Industry	Key technical direction
Advanced coal-fired power generation	Advanced 700°C ultra-supercritical coal-fired power generation technology (IGCC/IGFC) CO <sub>2</sub> utilization and treatment technologies
Unconventional natural gas development	Ultra-deep and deep shale gas exploitation and utilization technology Low-cost normal-pressure shale gas exploitation and utilization technologies Continental shale gas exploitation and utilization technologies Exploitation and utilization technology for coal bed gas with high stress and in area of complex structure, soft coal beds and multi-layer ultra-thick coal beds
Energy internet and comprehensive energy service	Smart terminal, cloud computing, artificial intelligence, and other foundational technologies Power transmission, substation, distribution, and application technologies Grid safety control and automatic dispatching technologies Electric power market transaction technology Renewable energy absorption technology Flexible DC power transmission technology Wireless power transmission technology Large-scale and high-safety new chemical energy storage body technologies High-efficiency and low-cost physical energy storage technologies Integrated application technology for energy storage system
Nuclear energy	Nuclear energy safety technology for pressurized water reactors Accident-tolerant fuel element technology Small-sized modular reactor technology Digital nuclear power technology
Wind power generation	Ultra-large offshore wind power units and the key technologies of core parts Hazard-free recycling technology of waste wind power equipment High-altitude wind power development and utilization technologies
Solar photovoltaic power generation	Study on commercialized high-efficiency crystal silicon solar battery technology Hazard-free treatment technology for waste photovoltaic modules Industrial membrane solar battery technology
Solar thermal power generation	Tower-type solar thermal power generation technology with ultra-high parameters Low-cost groove-type technology Trans-seasonal solar energy heat storage and heating technologies
Biomass energy	The combined production of cooling, heating, and power products and high-efficiency and clean biomass power generation technologies Low-cost and high-efficiency transformation technologies for cellulose-derived liquid transport fuel Low-cost and high-efficiency reforming and purification technologies for bio-syngas and biomethane
Geothermal energy	Hot dry rock exploration and development technologies High-efficiency development technology for geothermal resources of the hydrothermal type Gradient utilization of geothermal energy and “geothermal+” technologies
Hydrogen energy and fuel cells	Catalyst, membrane, polar plate, carbon paper, and other mass technologies Low-energy consumption, high-reliability, and low-cost fuel cell system integration technologies Precise fueling technology for hydrogen dispensers Low-energy consumption, low-cost, and smart hydrogen fueling station control technologies Low-cost, high-efficiency, and long-life water-electrolytic hydrogen generation technologies

#### 4.3.2 Establishment of key scientific and technological projects

The key scientific and technological projects are supported and promoted from the national perspective (Table 2). The information thus generated can be utilized to provide foresight and guidance in solving problems associated



with the significant and key technologies, for exploration in the energy field, and to improve technical levels and self-innovation capacity in order to provide a solid foundation for the medium- and long-term development of emerging energy technologies and industries.

**Table 2.** Key scientific and technological projects related to emerging energy technology industries.

Name of key scientific and technological project	Description of key tasks
Key Scientific and Technological Project for IGCC and IFGC High-Efficiency Power Generation Systems	Develop a new generation of coal-fired power stations and multi-generation technology of near zero-emission, and make significant breakthroughs in the key technologies of IGCC and IGFC power generation and multi-generation. Accomplish the demonstration of significant 450–600-MW IGCC projects with F or H level gas turbines and the development of a 100-kW high-temperature fuel cell system (including solid oxide fuel cells and molten carbonate fuel cells), and conduct a demonstration of a 100–100-MW IGFC power generation system. Promote the further development of IGCC/IGFC power generation technologies and lay a solid foundation for future large-scale and commercialized development.
Key Scientific and Technological Project for Effective Development of Deep and Ultra-deep Shale Gas in Sichuan and Chongqing	Conduct research on deep and ultra-deep marine enrichment mechanisms and resource potential; make breakthroughs in rapid and efficient drilling technologies and high-efficiency fracturing technology for deep and ultra-deep marine shale gas horizontal wells in the long horizontal section; and realize the large-scale and commercialized development of 3500–5000-m deep and ultra-deep shale gas.
Key Scientific and Technological Project for Accident-tolerant Nuclear Fuel Element Development and Serious Accident Mechanisms and Mitigation	Ensure the capacity to control the impact of extremely serious accidents and release of radionuclides into the environment, as well promoting environmental safety; accomplish the development of accident-tolerant nuclear fuel elements and research and development of serious accident mechanisms and mitigation by 2035.
Key Scientific and Technological Project for Large-scale and Hazard-free Recycling of Waste Wind Turbine Blades	Establish efficient separation and recycling technologies and appropriate materials for wind turbine blades, hazard-free treatment technology, and equipment for non-recyclable materials and the new and easy recovery and degradation environment-friendly blade material systems and a molding technology based on modified thermosetting composites, thermoplastic composites, and natural fiber composites.
Key Scientific and Technological Project for Industrialization of High-efficiency (greater than 25%) and Low-cost Batteries	Acquire key technologies for high-efficiency and low-cost solar battery sets with an efficiency greater than 25%; realize the research and development of key technologies for industrialized complete sets from the laboratory through to battery structure innovation.
Key Scientific and Technological Project for Tower Type Solar Thermal Power Generation Based on the Supercritical Carbon Dioxide Thermal Cycle	Construct a demonstration power plant with the installed capacity of no less than 10 MW, a power-generating temperature no lower than 593°C, heat storage hours of no less than 8 h, and a peak efficiency of no less than 24%. The heat storage system and power-generating units of the demonstration power plant should contribute to energy dispatchment and play a role in energy node deployment.
Key Scientific and Technological Project for Industrialization of Cellulosic Fuel Ethanol	Make breakthroughs to reduce the consumption/pollution of pre-processing and the cost of enzyme hydrolysis technology, and reduce the production cost of cellulose-derived fuel ethanol.
Key Scientific and Technological Project for Hot Dry Rock Exploration and Development	Construct a demonstration area for an enhanced geothermal system with a temperature greater than 180°C, and make breakthroughs in the storage layer construction technology of hot dry rocks and efficient heat exchange technology to enable substantial reductions in development and utilization costs.
Key Scientific and Technological Project for Hydrogen Manufacturing with Zero Carbon and Precise Transmission and Distribution	Research and develop the key technologies of the large-scale water-electrolytic hydrogen manufacture of renewable energy; promote development of natural gas/hydrogen mixed transmission technology and mixed fuel burners; focus on the development of key technologies for the distributed power generation based on fuel cells; make breakthroughs with respect to complete set key technologies of the entire industrial chain for hydrogen manufacturing-storage-transmission-application and establish a technical and standard system relating to demonstration projects for hydrogen energy development; implement a large-scale system for hydrogen manufacturing, storage, transmission, and distribution.

#### 4.3.3 Establishment of major multi-energy complementary distributed energy engineering projects

At present, the control of and research on single energy technologies in China are relatively mature. In contrast, there has been comparatively limited development with respect to the integrated application of multi-energy technologies and research on the basic theory and engineering practice of micro-grid based distributed energy system [13]. The distributed energy system is the mainstream development direction for the future energy system. It features environmental protection, economy, dispersion, reliability, and flexibility, and is suitable for the combined generation of multiple energy sources in high energy consumption industries, industrial parks, and public, commercial, and civic buildings. The system has substantial scope for technical improvement and considerable market potential. Consequently, the significant tasks for constructing "Internet +" smart energy systems include the establishment of key projects and construction of multi-energy complementary distributed energy supply systems, based on demonstration projects, which are beneficial from the perspective of enhancing the energy supply and demand coordination capacity, promoting clean energy production and local absorption of renewable energy, and enhancing the comprehensive efficiency of the energy system.

Engineering tasks: (1) to optimize the layout and construction of the infrastructures of distributed energy systems; (2) to conduct integrated research on the basic theory, core technologies, and distributed energy systems; (3) to develop high-end and independent micro-grid converters, controllers, and other key equipment; (4) to realize coordinative multi-energy supply and the gradient utilization of energy through the key technologies of independent micro-grid system integration and energy efficiency management; (5) to develop a multi-energy complementary distributed energy system suitable for end-users and large-scale energy bases; and (6) to provide integrated energy solutions for the cities and towns, islands (reefs), polar regions, and remote and border areas.

Key tasks: (1) to establish multi-energy complementary distributed energy systems for the end uses in the central and east areas of China; and (2) to construct multi-energy complementary distributed energy supply systems in large-scale energy bases.

#### 4.3.4 Establishment of integrated and innovative areas for the demonstration of emerging energy technologies

(1) Integrated and innovative demonstration areas for emerging energy technologies in the Xiong'an New Area, Hebei

The extent of development in the Xiong'an New Area and surrounding areas is currently relatively low, and thus there is abundant space for development and the foundation for a high starting point and high standards of development and construction. The construction of an integrated and innovative demonstration area of emerging energy technologies in the center of the Xiong'an New Area in Hebei will contribute to the construction of a smart new green city, the creation of an eco-city, and the development of high-end and high-tech industries, thereby driving the development of the southern region of Hebei Province and the hinterland of North China, and forming a low-carbon green development mode that meets the requirements of eco-civilization.

Engineering tasks: (1) to construct a comprehensive service platform of smart energy in the Xiong'an New Area, Hebei; (2) to complete planning of the overall heat supply of a new nuclear power plant and a swimming pool-type low-temperature heating reactor; (3) to accelerate the coordinated development of wind power and supporting grid construction; (4) to accelerate the coordinated development of a regional comprehensive solar energy industrial chain; (5) to promote a clean and efficient refuse power project and construct a corn/wheat fuel ethanol and bio-refineries for biogas production; (6) to strive to make achievements in large-scale grid-connection technologies and equipment of distributed renewable energy; (7) to enhance the role of exploration and prioritize the comprehensive utilization of multi-layer hydrothermal heat storage in the Xiong'an New Area [14]; and (8) to develop a complete industrial chain comprising hydrogen manufacturing, transport, fueling, storage, and utilization.

(2) Integrated and innovative demonstration areas for emerging energy technologies in the coastal areas of South China

*The Development Plan for Guangdong-Hong Kong-Macao Greater Bay Area, The Implementation Plan for the National Ecological Civilization Pilot Zone (Hainan), and Opinions on Supporting Shenzhen in Building a Socialist Pioneer Demonstration Zone with Chinese Characteristics* all propose the development of low-carbon green industries. On the basis of excellent regional advantages, policy advantages, and the foundation of energy industries, the construction of integrated and innovative demonstration areas for emerging energy technologies in the coastal areas of South China (mainly southwest of Guangdong, including Hainan Province) will provide a reference for low-carbon economic development in coastal areas.

Engineering tasks: (1) to construct a comprehensive cross-regional "Internet+" energy operation and service platform; (2) to accomplish the construction of existing nuclear power units and select sites for new projects; (3) to

actively and systematically promote the development and construction of onshore/offshore wind facilities, as well as the infrastructure for the local absorption and utilization of wind power; (4) to establish a photovoltaic industry that is complementary to other industries and develop multiple forms solar energy power; (5) to promote clean and efficient waste power generation projects and develop bagasse/rice straw fuel ethanol and bio-refineries for biogas produced from different sources; (6) to survey geothermal resources and distribution characteristics and develop geothermal resource utilization demonstration projects; (7) to prioritize the breakthrough of grid-connection technology and equipment for the large-scale distributed renewable energy use [14]; (8) to create a smart energy system and realize the mutual transformation of multiple energy forms to improve general energy utilization efficiency; and (9) to develop a “Green Hainan” based on the integration of energy (hydrogen and power) and transport, and create smart transport mode with zero emissions in Hainan Island free trade demonstration zone.

## 5 Conclusions

Although the emerging energy technology industries in China have the advantage of a solid developmental foundation, from the perspective of strategic development, they continue to be restricted with respect to a number of factors, notably cost, the market, and policies [15]. With a view toward 2035, there is an urgent need for top-level design and planning in order to promote high-quality development of the emerging energy technology industries in China. These needs can be summarized as follows.

(1) There is a necessity to re-determine the scope and orientation of emerging industries in the energy field. This will entail re-defining “new energy industry” as “emerging energy technology industry” in the development plans of strategic emerging industries published by all levels of governments. The energy conservation industry should be isolated from “energy conservation and environment-friendly industry” and reclassified into “emerging energy technology industry”. Correspondingly, the precise layout of the orientation of development for emerging energy technologies and industries should be established.

(2) There is also a need to clarify the system mechanisms of energy industry management, enhance the construction of a statistical system for the emerging energy technology industries, and to maintain the consistency, continuity, and validity of the goals and policies of energy planning. Furthermore, it is desirable to avoid the frequent adjustment of planning goals and inconsistent industry policies, to guarantee the authority of the planning related to emerging energy technology industries and improve the market access policies [7].

(3) Attention should also focus on highlighting the key scientific and technological projects in the energy field and promoting the “implementation plans” of significant projects, in addition to guaranteeing the feasibility and operability of these projects. Furthermore, there should be an enhancement of the dominant role played by enterprises in innovation decision-making, research, and development investment, as well as the organization of scientific research and application of the advances made in energy technologies. Substantial increases in investment are necessary for research and development in the field of emerging energy technologies, along with an enhancement of the key and core technological breakthroughs and project initiation and approval. Finally, it will be necessary to establish the precise structural organization relating to the construction of significant projects and demonstration areas.

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