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Thinking on General Trends of Energy Development and Directions of Energy Science and Technology

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Abstract

The development of energy science and technology has profound impacts on the future energy pattern, and the outlook of energy development is of great significance to national policy-making and corporate strategic planning. Based on the analysis of the current situation and development trend of energy sector, this study summarizes the five characteristics of energy transformation: diversification, decarbonization, decentralization, digitalization, and globalization, and points out three new features in respect of the trade war between China and US, low oil price, and application of artificial intelligence technology that emerged since 2016. A few thoughts concerning low-cost technology, information technology, and subversive technology are presented for analyzing the development trend of science and technology in energy sector, actively responding to energy transformation and formulating development strategy of energy science and technology.

Keywords

energy transformation; technology being king; low-cost technology; information technology (IT); subversive technology

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Abstract: The development of energy science and technology has profound impacts on the future energy pattern, and the outlook of energy development is of great significance to national policy-making and corporate strategic planning. Based on the analysis of the current situation and development trend of energy sector, this study summarizes the five characteristics of energy transformation: diversification, decarbonization, decentralization, digitalization, and globalization, and points out three new features in respect of the trade war between China and the US, low oil price, and application of artificial intelligence technology that emerged since 2016. A few thoughts concerning low-cost technology, information technology, and disruptive technology are presented for analyzing the development trend of science and technology in energy. We hope to provide reference for China's active response to energy transformation and the formulation of development strategy of energy science and technology.
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Keywords: energy transformation; technology being king; low-cost technology; information technology (IT); disruptive technology

Energy, food, and water are three necessities for human today. Energy, vital to the full development of human society, is inseparable from gross domestic product (GDP) [1] (Figure 1).

The development of energy science and technology has profound impacts on the future energy pattern. The outlook of energy development is of great significance to national policy-making and corporate strategic planning. Science and technology determines the future of energy and creates the future energy [2]. Therefore, all countries attach great importance to the development of energy science and technology and make energy strategic plans, such as the Comprehensive Energy Strategy of the United States, the EU Energy Roadmap 2050, and Japan's 2030 National Energy Plan.

China's *Energy Technology Revolution and Innovation Plan*: *2016–2030* proposes to build a perfect energy technology innovation system suitable to the national conditions and with the international level of energy technology by 2030. This system can support the coordinated and sustainable development of China's energy industry and environment and make China an energy technology power. The Plan includes 15 key fields: green coal mining, development for unconventional, deep-layer, and deep-sea oil & gas, clean and efficient coal utilization, carbon dioxide capture, utilization, and storage, advanced nuclear energy, reprocessing of spent fuel and safe treatment of high-level radioactive wastes, efficient utilization of solar energy, large-scale wind power, hydrogen energy and fuel cell, utilization of biomass energy, ocean energy, and geothermal energy, high-efficiency gas turbine, advanced energy storage, modern grid, energy internet, and energy conservation and energy efficiency improvement, comprehensively expounding the future development of China's energy technology system.

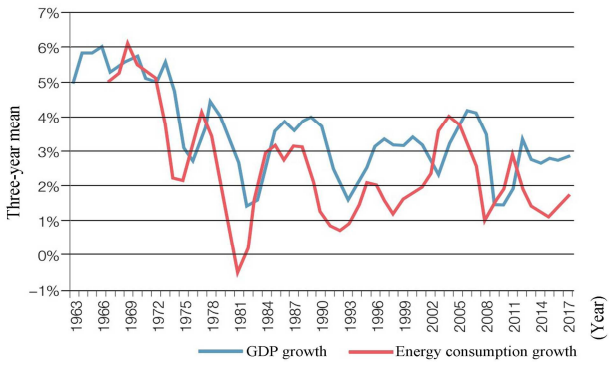

Figure 1 Relationship between global GDP growth and energy consumption growth in 1963–2017

Data were from *BP Statistical Review of World Energy* (*2018*) and the World Bank, GDP was in 2010 US dollars [1].

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Chinese Academy of Engineering (CAE) started the major project of Strategic Research on China Energy Technology Revolution System in 2015 [3] and conducted the research in the nine major energy technology fields: nuclear energy, wind energy, solar energy, stored energy, oil & gas, coal, hydroenergy, biomass energy, and integration of smart grid and energy grid. In addition, a three-stage development route for energy technology has been planned, which includes forward-looking technology stage (2020), innovative technology stage (2030), and disruptive technology stage (2050).

With the dual restraints of resources and environment and the progress of energy science and technology in recent years, the cost of new energy has reduced rapidly and the accelerated transformation toward clean and low-carbon energy has become a global development trend. Energy transformation, accompanied by industrial restructuring, drives the progress of energy science and technology. Mutual promotion of science and technology progress with energy transformation is profoundly changing the energy development.

We have participated in the strategic studies supported by the 14th Fiver-Year Plan Projects of Ministry of Science and Technology, National Energy Administration, and National Natural Science Foundation of China, as well as the strategic studies toward 2035 in the past two years. A few thoughts concerning the future energy development are presented based on the analysis of the current energy situation and development trend. We hope to provide reference for China's active response to energy transformation and the formulation of development strategy of energy science and technology.

1 Current situation and development trend of energy

1.1 Current situation

In 2019, the total global energy consumption reached 13.862 billion tons of oil equivalent, of which the consumption of petroleum, coal, and natural gas was 4.47 billion tons of oil equivalent, 3.83 billion tons of oil equivalent, and 3.43 billion tons of oil equivalent, respectively. The consumption of fossil energy accounted for 84.62% [4], 2 percentage points down from that in 2010. The consumption of natural gas in 2019 was 6.35 times of that in 1965, with the share grow to 24.7% from 15%. Cleaner natural gas was taking place of plenty of petroleum and coal.

1.2 Development trend

We analyzed the changed and unchanged factors in the development of energy since 2016 and suggested to keep the unchanged ones and adjust the changing ones.

The major trend of global energy development has not changed in the last decade. (1) Many famous research institutions in the world have predicted the growth of energy demand in the future (Figure 2). Renewable energy and natural gas will become the main sources satisfying the growing demand of global energy, and decarbonization and diversification are the important trends and characteristics of future energy development. With the rapid development of new energy such as solar energy, wind energy, geothermal energy, ocean energy, and stored energy, the centralized energy supply from coal, oil & gas, and power is switching to the balanced supply in both manners of centralization and decentralization. (2) With the application of information technologies in energy field, the digitalization technology, in particular, has gradually broken the barriers between different varieties of energy and taken a part in the future development. "No country can be alone in energy issues" and "technology has no borders" have become common views. (3) The proposal of the concept Global Energy Interconnection (GEI) and the establishment of the Global Energy Interconnection Development and Cooperation Organization (GEIDCO) are important symbols of the internationalization of energy. Jeremy Rifkin, a famous American scholar, first proposed the vision of energy Internet in his *The Third Industrial Revolution* [5], causing wide attention. General Secretary Xi Jinping, on September 26, 2015, delivered a keynote speech at the UN Sustainable Development Summit where he proposed to discuss the establishment of global energy Internet and promote a clean and green manner of satisfying global power demand. This is a historical breakthrough and a major innovation of the traditional energy development. International cooperation in energy science and technology is becoming wide and strong. The International Thermonuclear Experimental Reactor (ITER), a cooperative project with the investment of 10 billion US dollars, is a typical case. Decarbonization, diversification, decentralization, digitalization, and globalization will become the main trends of energy development in the future.

While fully recognizing these unchanged factors, we should identify the changed factors and development trend. (1) Since 2018, the United States has identified China as a competitor and the Trump administration has provoked the trade war between the two countries. Subsequently, a great clamor has arisen in the United States on decoupling, or even fully decoupling the United States and China in science and technology, which has posed a great challenge for China's science and technology including the energy science and technology. We should make preparations early and devote to independent research and development while insisting on initiative and embracing openness and cooperation. (2) COVID-19 pandemic and oil price war make a superimposed impact on the oil price. International oil price has been falling from March to April in 2020, and the forward price of West Texas Intermediate (WTI) in the United States even retreated to 37.3 US dollars per barrel on April 20, which has been never seen before. In the next period, oil price below 60 US dollars per barrel is highly probable. (3) Technologies such as artificial intelligence and blockchain are advancing rapidly, profoundly impacting the energy development and altering

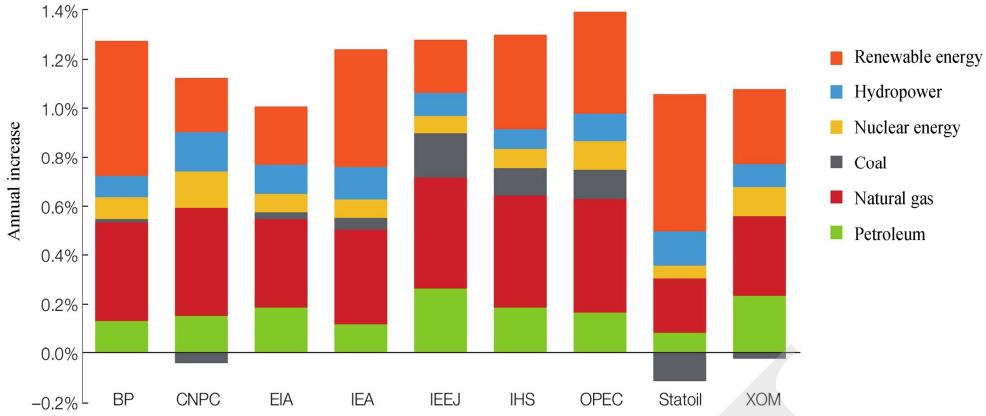

Figure 2 Energy demand growth in different companies and institutions from 2016 to 2040

BP, British Petroleum; CNPC, China National Petroleum Corporation; EIA, Energy Information Administration; IEA, International Energy Agency; IEEJ, Institute of Energy Economics, Japan; IHS, IHS Markit; OPEC, Organization of Petroleum Exporting Countries; XOM, Exxon Mobil Corporation.

the energy pattern and industry conditions. Disruptive technology appearing along with the history of science and technology progress is unpredictable. Only when we make clear these development trends can we accurately grasp the future development trend of energy science and technology.

2 Low-cost technology will be the core competence of enterprises

In 1967, Hubbert [6], an American petroleum geologist, established a bell-shaped model to predict the cumulative production and the final recoverable reserve of an oilfield. Since then, the peak oil theory has prevailed and the scarcity of oil resources has been overemphasized. In this context, acquiring more oil & gas reserves becomes a strategic target for oil companies, especially the international majors. This is an era of "resources being king."

The shale revolution in the United States eliminated public concern about the scarcity of oil & gas resources. The evaluation results of Energy Information Administration (EIA) show that the total recoverable resources of the global oil and natural gas are 3 357 billion barrels and 648 trillion cubic meters, respectively [7], suggesting that the oil & gas resources are no longer scare. In addition, solar energy and wind energy are renewable and inexhaustible. Whoever owns technology will own energy resources. This is an era of "technology being king."

In the era of "technology being king," the cost or efficiency of acquiring energy resources is the key to success. Therefore, developing the low-cost technology is an important trend in the future. The rapid development of renewable energy in recent years is attributed to its low cost. The weighted means of levelized cost of energy (LCOE) of utility-scale photovoltaic power and onshore wind power in 2018 were 77% and 35% lower than those in 2010, respectively [8]. EIA predicts that the LCOEs of the wind power and solar power projects that will be put into operation in the United States, 2022 will be lower than that of gas power [9]. With the sharp cost reduction and rapid development of centralized renewable energy power generation, decentralized power generation is also accelerating. According to the data from China Photovoltaic Industry Association (CPIA), China in 2018 had 23.2 million kilowatts of power from newly installed distributed photovoltaic power systems, which accounted for 52.7%, exceeding that from centralized photovoltaic power systems for the first time. This tendency continued in 2019 to the extent that there were nearly a half of small-scale household distributed photovoltaic power systems.

Low-cost renewable energy technology is a key field for the development of energy science and technology. Solar energy and wind energy are the main parts of the renewable energy in the future. Cost reduction, technology improvement, and building of a proper business model are the development trends of renewable energy in the future. In the field of wind energy, the dominant technologies in the future mainly involve the design of complete high-power wind turbine, fan operation & maintenance and fault diagnosis, and high-altitude wind power technology with high-power wireless power transmission. In the field of solar energy, priority should be put on the development of technologies such as solar thermal power generation, thin-film battery, solar hydrogen production, and solar battery for wearable flexible devices [3].

Low-cost technology in the field of oil & gas is also the focus in the development of energy science and technology. The proportion of oil & gas in energy consumption will remain around 50% by 2050, which has been a consensus in the industry. In the field of deepwater oil & gas with the rapid growing reserves recently, the application of floating liquefied natural gas (FLNG) and seabed production equipment, as well as the continuous optimization of the structure, can reduce the production cost to less than 50 dollars per barrel.

Shale oil & gas is another important area for increasing the reserves and production. In 2012–2016, the balanced oil price for the shale oil development of the United States was reduced by 50%, one third of which was benefited from technological progress [10].

Low-cost oil & gas technologies are developing in many directions. (1) In geophysical prospecting, the technologies involve intelligent and efficient acquisition, deep learning-based automatic treatment and interpretation of geophysical data, and intelligent management of geophysical prospecting. (2) In drilling and well completion engineering, the technologies involve precise intelligent automatic drilling and well completion, integration of drilling and well completion engineering, wellbore integrity, and intelligent fracturing. (3) In production and management of oil & gas fields, the low-cost oil & gas technologies involve big data- and deep learning-based new-generation artificial intelligence applied in oilfield, cloud network of oil industry, and artificially intelligent robot.

3 Information technology will rebuild the future of energy

The fourth industrial revolution is underway in the world, which is characterized by the burgeoning information technology, big data, artificial intelligence, and blockchain. These emerging technologies create opportunities for the development of energy industry, and their integration with energy industry paves the way to low-cost technology which will change the world energy development pattern and further rebuild the energy industry [11].

Energy industry is the first to benefit from digitalization. Information technologies such as computer have been applied very early in power plant, coal mine, and oil & gas field to improve the automation and management. The emerging digital power plant, digital mine, digital oilfield, and digital refinery tremendously increase labor productivity and reduce labor cost. The present and the next period mark the transformation from digital to intelligent. Intelligent power plant, mine, oilfield, and refinery plant will optimize the production process and simplify organization and personnel to realize the basic mode of unmanned management of factories, thus dramatically changing the industry ecology.

Information technology is restructuring the energy system. Digitalization will systemically change the entire industrial chain and ecosystem of energy from production to consumers, so that all links of the chain are combined to significantly improve the energy utilization efficiency. Emerging technology companies such as Huawei, Alibaba, Tencent, Google, and Tesla are marching towards the energy field—improving the flexibility of the whole system by big data and artificial intelligence, thus improving the energy efficiency and changing the industrial chain structure and business model of energy industry [12].

Blockchain technology will invigorate the energy industry. With increasingly wide application in the energy sector, blockchain technology has emerged in energy trading platform represented by crude oil, point-to-point trade in renewable power, charging of electric vehicle, management of power grid assets, tracking of green power certificate, and even virtual energy currency, which will bring profound changes in the energy sector.

Digital transformation will rebuild the oil & gas industry. The comprehensively integrated innovation and application of the new-generation artificial intelligence technology in the upstream sectors of oil industry will produce a new-generation oilfield technology involving artificial intelligence to realize the upgrading, optimization, and organization restructuring of the traditional process in the oil & gas industry, sharply reduce the cost of the oil & gas industry, and strengthen the enterprise competitiveness and the sustainability of oil & gas industry.

4 Disruptive technology is the biggest variable in the future energy

Energy science and technology, one of the active fields of innovation today, may appear in the fields of oil & gas, hydrogen energy, stored energy, and nuclear fusion energy, any of which will dramatically alter the world energy supply and demand pattern.

4.1 Disruptive technology in the oil & gas field

Horizontal well staged hydraulic fracturing technology will achieve economical and effective exploitation of shale oil & gas. This disruptive technology will greatly change the global energy pattern. The combination of physical and chemical methods in the in situ modification of low-maturity shale oil and thickened oil may be another revolution after the shale revolution. Another huge oil & gas resource will be economically and effectively developed and utilized following the success of the disruptive technology. Nanotechnology and new materials may create disruptive technologies for enhancing the recovery of oil & gas, such as the reservoir oil-displacing nanorobots and the technology for separation of underground oil and water. The integration of multipurpose laser tool and drilling technology may replace the traditional drilling method. That is, laser can melt rocks, instead of machinery breaking rocks, thus improving the drilling efficiency.

4.2 Hydrogen energy technology

Hydrogen energy technology, with the low-cost and high-performance hydrogen cell technology and low-cost and efficient industrial hydrogen production technology, exerts disruptive impact on energy field. The importance of hydrogen energy as the secondary energy sources in energy transformation has been recognized. Many countries place

great emphasis on the development of hydrogen energy industry, consider hydrogen energy industry as the national energy strategy, formulate hydrogen energy development strategy, and introduce supporting policies to promote its development [13]. Once great breakthroughs are made in the technology of hydrogen production by electrolysis with new materials such as graphene and nanometer metamaterials, hydrogen fuels may on a large scale or even completely replace fossil fuels. With the maturity of new-material polymer electrolyte membrane fuel cell technology and the improvement of relevant infrastructure, the automobile, train, and ship driven by hydrogen energy will replace the oil-powered vehicles and become the main means of transportation. To make preparations for the large-scale development of hydrogen industry, the European countries have conducted pilot projects of delivering hydrogen in natural gas pipelines [14].

4.3 Energy storage technology

Energy storage technology, supporting the energy revolution, will play a role in many ways. (1) In power system, stored energy can service power grid in the regulation of peak load and frequency, peak load shifting, black start, and demand response support, thus improving the flexibility, economy, and safety of traditional power system. (2) In the development of renewable energy, stored energy can improve the accommodation of wind power and solar power, thus supporting the distributed power and microgrid. With the increasing maturity of distributed energy technologies such as distributed photovoltaic generation, small biomass energy, combined cooling, heating, and power (CCHP), and fuel cell, as well as the progress in relevant technologies such as energy storage and digitalization, distributed energy will embrace vigorous growing in the future. (3) In transportation, stored energy will serve intelligent transportation network including energy interconnectivity and new energy vehicles. New materials-based battery energy storage technologies, such as graphene supercapacitor, self-powered device made of carbon nanomaterial, and superconducting magnetic energy storage, may exert disruptive impact on energy industry. The commercial application of low-cost efficient energy storage technology will greatly drive the development of renewable energy and make new energy vehicles replace the oil-powered vehicles.

4.4 Controllable nuclear fusion technology

Nuclear fusion energy, as an ideal ultimate energy, has many advantages. There are two mainstream technical solutions for controllable nuclear fusion, which are magnetic confinement fusion (MCF) and inertial confinement fusion (ICF). There are a number of nuclear fusion-related research programs in the world, such as the International Thermonuclear Experimental Reactor (ITER), the National Ignition Facility (NIF) of the United States, the Levitated Dipole Experiment (LDX) of the United States, the Z-IFE device of the United States, the Lawrenceville Plasma Physics of the United States, the FRX-L research program of the United States, General Fusion of Canada, the High Power Laser Energy Research (HiPER) of Europe, and the Wendelstein 7-X of Germany. China joined the ITER program in 2007 and is vigorously promoting the domestic research on nuclear fusion science and technology. China has completed the concept design of China Fusion Engineering Test Reactor (CFETR) and is working on the engineering design. China's large-scale scientific facilities such as HL-2A and Experimental and Advanced Superconducting Tokamak (EAST) have also been completed in succession, and multiple physical experimental results are in the front ranks of the world. HL-2A realizes the divertor configuration discharge and H-mode operation for the first time in China. In July 2017, EAST became the first in the world to realize the H-mode operation that 50 million-degree plasmas continuously discharge for 101.2 s, another world record of magnetic confinement fusion [15].

5 Conclusions

With the increasingly strict requirement for emission reduction and environmental protection, the progress in new energy and intelligence technology, and the rapid cost reduction, global energy is undergoing an accelerated transformation toward diversification, decarbonization, decentralization, digitalization and globalization. Meanwhile, the trade war between China and the United States, the oil price war between Saudi Arabia and Russia, and the COVID-19 pandemic make the development of energy uncertain. New energy technologies and new business modes will alter the traditional energy supply pattern and integrated energy services will gradually become dominant. Clean energy such as new energy and natural gas will meet most of the new energy demands, and the energy system will be restructured. Low-cost technology will dominate the development of energy science and technology, and information technologies such as artificial intelligence will rebuild the future of energy. New disruptive technologies are likely appear in the fields such as oil & gas, hydrogen energy, stored energy, and nuclear fusion energy, which will fundamentally change the future of energy. An accurate understanding on the development trend of energy technology is of great significance to the scientific and technological innovation as well as the national energy policy-making and enterprise strategic transformation.

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