CHAPTER THIRTEEN

International Energy Transformation: Bright Future and Tortuous Road

Since the beginning of the 21st century, under the impetus of high energy prices, global warming, and other factors, the global upsurge of developing new and renewable energy has been set off. The development and utilization of clean energy such as solar energy, wind energy, and biomass energy have attracted great attention from the international community, whose development speed and market scale have grown rapidly. Its scale and strength obviously exceeded the new energy development upsurge that appeared after two oil crises in the 1970s, and many analyses suggest that it can hopefully start the prologue of new energy revolution and energy transformation. Overall, the transformation of world energy structure from traditional fossil energy to new and renewable energy sources, from the high carbon to the low carbon becomes the general trend. The new energy system, new technology-supported energy utilization modes, and new energy utilization concepts will eventually replace the traditional energy utilization. However, energy transformation will still be restricted by many uncertainties, such as the trend of world economy and energy price, the magnitude of technological progress, so it will face many difficulties and challenges.

Different from how coal replaced firewood and oil substituted coal in history, the current energy transformation is mainly driven by political factors, and policy support is the main driving force for the development of current new and renewable energy. Getting rid of dependence on fossil energy to develop low-carbon economy is the popular sentiment and general the trend of this age, but when and how to complete new energy transformation, to a large extent, is an economic and technical problem, and there are many uncertainties in the short-term and mid-term. The formation of new energy system depends not only on whether and when the new energy itself with potentials can make the revolutionary changes, forming a greater comprehensive competitive advantage over the existing

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dominant energy, but also on the revolutionary changes of demand side, especially the significant breakthroughs in energy utilization equipment.

DEFINITION OF CONCEPTS

Considering the current international energy situation, energy transformation mainly refers to the independence of traditional fossil energy system characterized by the dominance of coal and oil and gas and large amount of non-renewable and greenhouse gas emission. The new energy system is a broad concept, including many aspects, not only limited to wind energy, solar energy, geothermal energy, biomass energy, and other new renewable energy. The large hydropower generation in renewable energy has long been applied in practice, not new technology, but because it belongs to clean renewable energy, it is also included in the new energy category. Nuclear energy is not renewable energy due to the use of uranium resources but is clean energy and is generally included in the new energy category. New sources of energy also include the reuse of the traditional energy and even fossil energy through the development of new technologies and new materials, such as extraction of hydrogen from fossil energy sources, dimethyl ether (DME), methanol, etc. In addition, high efficiency, comprehensive utilization of energy resources, and energy saving (such as distributed energy, smart grid) are also regarded as indispensable parts of the new energy system.

On the whole, the new energy system is also called alternative energy, clean energy, or green energy. Its core, against the traditional energy (mainly fossil energy), is demonstrated by the advancement and alternativeness in terms of energy utilization modes, with the features like cleanness, widespread and high efficiency, and with the focus on sustainable utilization. The new energy system is also an important prerequisite and an indispensable part for human society to realize sustainable development, toward low-carbon or green economy. It includes not only energy transformation, technological progress, but also a shift in development concept.

Due to different stances and perspectives, there are still many differences in the definition and understanding of energy transformation. Some analyses from the perspective of energy security put emphasis more on the diversification of energy sources, highlighting the alternativeness to the oil supply from the Middle East and other special countries and

regions. In this sense coal has also become one kind of alternative energy and energy transformation means stepping into the post-oil era. Some analyses from the perspective of climate change and environmental security, place more emphases on greenhouse gas emission, highlighting the substitution for fossil fuels of more greenhouse gas emission, such as coal and oil. Here energy transformation means getting rid of the dependence on fossil fuels, and any energy and technologies that can reduce greenhouse gas emissions can be included into the new energy system.

THE HISTORY OF ENERGY TRANSFORMATION

In view of the development history of human society, the energy pattern, which was based on firewood, supplemented by animal power, water, and wind, lasted for thousands of years. Until more than a century ago, the energy use of mankind entered the fossil energy-dominated landscape, and two major transformations and changes took place, that is, from the age of firewood to coal and from coal to oil. In general, the energy development and utilization in human society has undergone a long process, with the types from single to diverse, the utilization efficiency and technical content from low to high, and carbon content from high to low. The energy structure has become increasingly diverse and complex.

After two energy transformations, the energy system led by fossil energy, such as petroleum, coal, and natural gas, has greatly promoted the development of human society and made mankind transition from agricultural civilization to industrial civilization with continuous progress. However, with the passage of time and the sharp increase of energy consumption, the problems of energy security caused by the nonrenewability of fossil energy, the uneven geographical distribution of fossil energy, and the environmental pollution due to the utilization of the fossil energy are becoming increasingly prominent. In this context, the voice for developing alternative energy sources and promoting new energy transformation has been growing.

The efforts of the international community to get rid of the dependence on fossil energy can be traced back to the rise of nuclear power in the 1950s and 1960s. After the World War II, nuclear energy came onto the historical stage as an efficient and environmentally friendly new energy source. In June 1954, the Soviet Union built the world's first nuclear power plant with a power generation capacity of 5000 kW in Obninsk, Moscow. In 1956, the United States built a 7500 kW nuclear

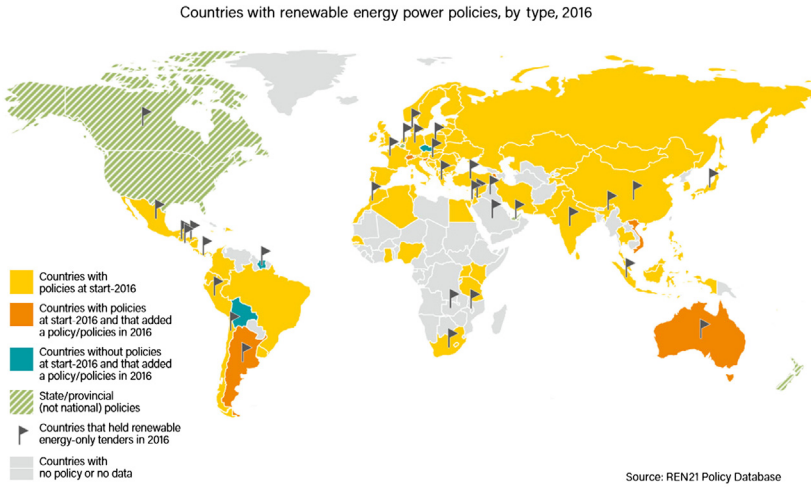
power plant. Since then, nuclear power generation in western countries such as Soviet Union and the United States has made fairly rapid progress. The world nuclear power installed capacity increased at an annual growth of more than 20%. In the 1960s, the western countries were generally bullish on nuclear power, believing it could challenge oil and become a new dominant energy source. But what took place later on was beyond people's expectations. Because of the widespread concerns about nuclear proliferation and nuclear accidents, the international community's opposition to nuclear energy became increasingly strong and the development of nuclear power was restricted by many factors.

The second wave of alternative energy development came after the two oil crises in the 1970s. New and renewable energy, including solar energy, wind energy, water power, geothermal energy, and other energy sources, underwent great development. Nuclear energy entered climax of the second development wave. The first oil crisis in 1973 made a greater impact on western countries. In order to reduce dependence on oil, western countries began to develop alternative energy sources vigorously and embarked on large-scale research and development on new energy sources. The second oil crisis in the late 1970s further enhanced the willingness and determination of Western countries to develop alternative energy sources, and the United Nations adopted the *Nairobi Programme of Action for the Development and Utilization of New and Renewable Sources of Energy* in August 1981, promoting the development of new and renewable sources of energy worldwide. But since the mid-1980s, as international oil price entered the downturn which lasted for more than 10 years, the pace of alternative energy development slowed down to some extent for some time.

DEVELOPMENT TREND

After entering this century, under the impetus of energy demand, rising oil price and the increasingly prominent problem of climate change, new and renewable energy have again aroused the attention of all countries in the world. At present, many countries, such as Europe, the United States, and Japan, consider renewable energy as the main strategic measure for future energy substitution and emission reduction of greenhouse gases, and put forward ambitious development targets. The EU proposes that by 2020 and 2050 renewable energy will account for 20% and 50% of energy consumption, respectively; Japan suggests that alternative energy sources such as renewable energy will account for more than

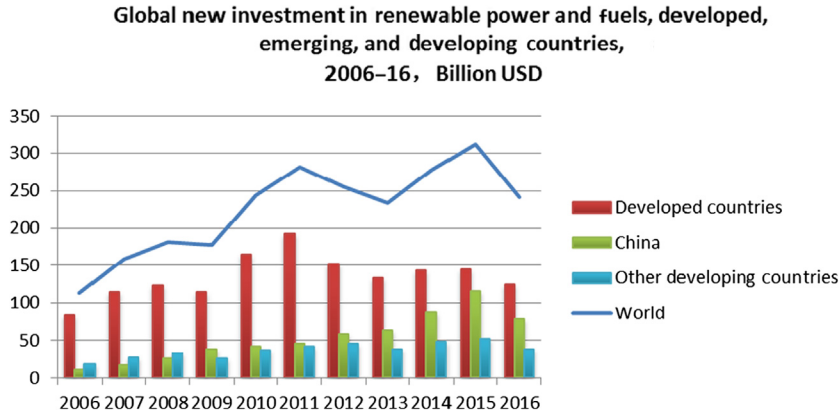
50% of its energy supply by 2050; America asserts that the proportion of renewable energy such as solar energy, wind energy, and geothermal energy in the American electric power will be increased from 8% to 25% by 2025; China plans that renewable energy, including hydropower, will account for 20%–30% of the national energy demand by 2030. Countries such as Brazil and India also put forward their ambitious goals for renewable energy development [1]. Globally, the development and utilization of new and renewable energy have become a strategic choice for most countries. By the end of 2016, 176 countries around the world had set goals for renewable energy development [2].



Note: Figure shows countries with Renewable Portfolio Standards, feed-in tariffs/premium payments and net metering policies. Countries are considered to have policies when at least one national-level policy is in place; these countries may have state/provincial-level policies in place as well. Diagonal lines indicate that countries have no policies in place at the national level but have at least one policy at the state/provincial level.

Spurred by the stimulus of high energy price, the promotion of governments, and the clean energy development mechanism, the global development and utilization of new and renewable energy resources has accelerated, the investment has increased rapidly, and the market scale has been expanding. From 2002 to 2006, the global renewable energy grew rapidly, with an annual growth rate of 15%–30%, of which solar photovoltaic power generation grew by up to 60% annually, and wind energy increased by 25%. In 2007, bioethanol production increased by 27.8%, and wind power and solar photovoltaic power generation by 28.5% and 37%, respectively. In 2007, global renewable energy investment increased from $40 billion in 2005 to $71 billion in 2006, with wind power, solar photovoltaic, and solar water heaters accounting for 47%, 30%, and 9%, respectively. Wind power has been popularized to more than 70

countries. Solar photovoltaic power generation is becoming one of the fastest-growing and most profitable industries in the world.



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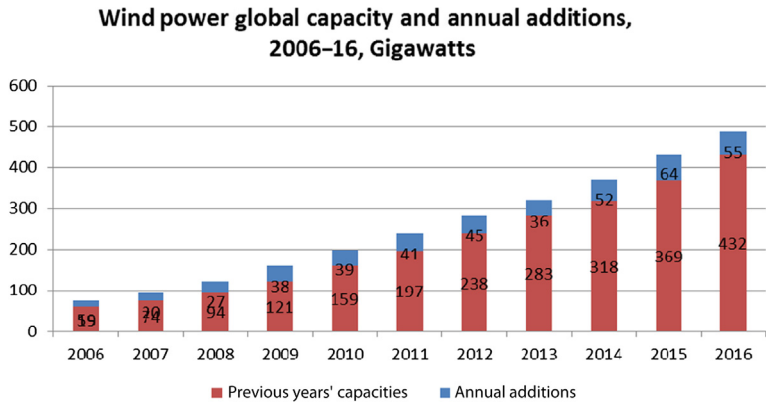
The financial crisis in 2008 and the subsequent outbreak of the European debt crisis resulted in some governments' subsidy reduction, some industries' production overcapacity, and some world-known new energy enterprises' bankruptcy. However, it did not change the overall growth of international clean energy investment. In response to climate change, energy security, and economic recovery, all countries have been devoted to developing clean energy sources. Global financing and investment growth of clean energy rose by 30% in 2010, reaching $243 billion. In 2011, the total global clean energy investment increased by 5% more than last year, reaching $260 billion, up nearly four times more than $53.6 billion in 2004. After the Fukushima nuclear accident in 2011, countries such as Germany and Japan proposed to increase the proportion of renewable energy generation.



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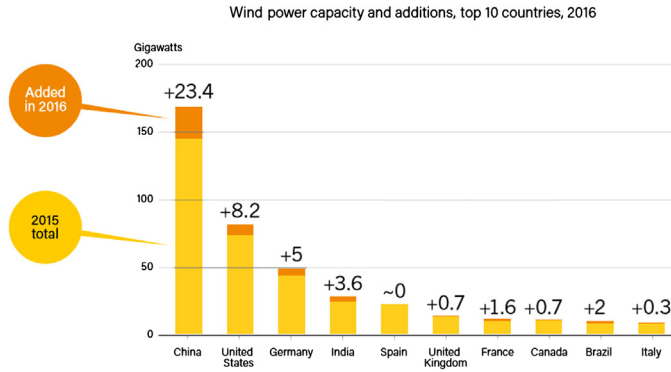

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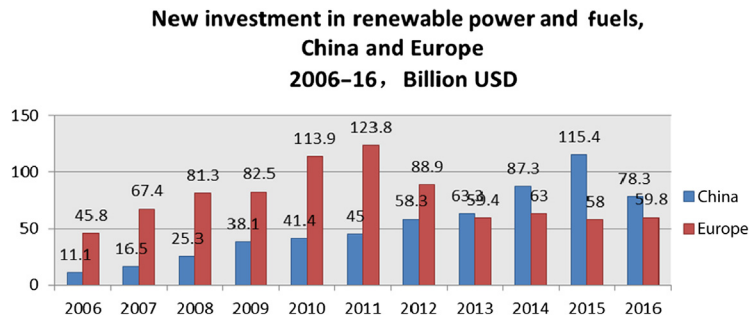
Under the impact of unconventional energy sources such as shale gas, the global clean energy development has decelerated and fluctuated to some degree compared with the previous rapid development. On one hand, the overcapacity in PV and other fields has made their prices continue to fall and subsidies provided by the governments of developed countries tended to reduce. Due to financial difficulties, the United States and the European Union cut the subsidies for renewable energy, such as photovoltaic. On the other hand, compared with renewable energy, unconventional oil and gas resources, such as shale gas, oil sands, and super-heavy oil, have cheaper costs, more flexible applications, and more obvious benefits. They have attracted large amount of investment and restricted the development of renewable energy. According to the statistics released by Bloomberg, on the basis of 11% decrease in 2012, the global clean energy investment in 2013 dropped again by 12% from 2012 down to $254 billion, of which in Germany it dropped to $14.1 billion, the lowest level since 2006, in the United States it dropped by 32%, and in China clean energy investment also dropped for the first time in 10 years [3].

Meanwhile, in order to protect domestic enterprises, Europe and America have launched anti-dumping and countervailing investigation into the export of solar energy and wind power products from developing countries, and the international clean energy trade frictions have intensified. On November 7, 2012, the US International Trade Commission finally decided to impose an anti-dumping duty of 18.32%–249.96% on Chinese PV products and countervailing duty of 14.78%–15.97%. On November 8, 2012, the European Union announced a countervailing investigation into China's photovoltaic products. On June 4, 2013, EU

Commission decided to impose a provisional anti-dumping duty of 11.8% on photovoltaic products produced in China from June 6 to August 6. If the two sides failed to reach a settlement by August 6, the anti-dumping duty rate would rise to 47.6%. On July 27, the two sides reached a compromise through negotiation and the dispute was finally eased.

However, overall, the global clean energy development continues to maintain an acceptable momentum. According to *BP Statistical Review of World Energy 2017*, renewable energy is still the fastest growing energy source in all types of energy. In 2016, the consumption of renewable energy excluding hydropower increased by 12%, equivalent to 55 million tons of standard coal, exceeding the amount of coal consumption reduction, accounting for one-third of the total energy demand. At the same time, carbon emissions grew by only 0.1% in 2016, the third consecutive year for steady or even declining carbon emissions. In June 2017, Renewable Energy Policy Network for the 21st Century (REN21) released *Renewables 2017 Global Status Report*. It points out that the global newly installed capacity of renewable energy reached 161 GW, surpassing the net increase in installed capacity of all fossil energy sources in that year, accounting for 62% of the global newly installed capacity. The global new investment for renewable energy reached $241.6 billion, of which about $187.1 billion flew to large-scale wind farms and photovoltaic power plants [2].



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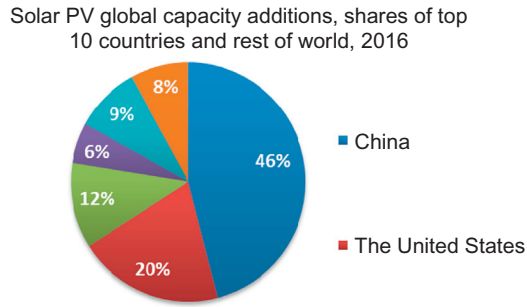
Emerging economies have begun to lead global clean energy investment, and the investment enthusiasm has shifted to Asia-Pacific regions and developing countries. In 2015, total investment of developing countries in renewable energy exceeded the developed countries for the first time, with China's investment accounting for more than one-third of

global renewable energy investment. In 2015 and 2016, the newly added and accumulative installed capacity of Chinese PV ranked first in the world. India's renewable energy industry has grown rapidly. By the end of December 2016, the installed generating capacity of Indian renewable energy was more than 50 GW, and the Indian government proposed to raise it to 175 GW by 2022 and 275 GW by 2027 [4]. In addition, clean energy investment in emerging economies such as South Africa, Morocco, Mexico, Chile, and Kenya has also increased significantly. According to statistics released by Solar Power Europe, the global installed capacity of solar power increased by 76.1 GW in 2016, up nearly 50% more than 2015, of which in China there was the largest increase in installed capacity, up 125% more than 2015, followed by the United States, Japan, and India. In contrast, the installed capacity of solar energy in continental Europe decreased by 20% from 8.6 GW in 2015 to 6.9 GW.



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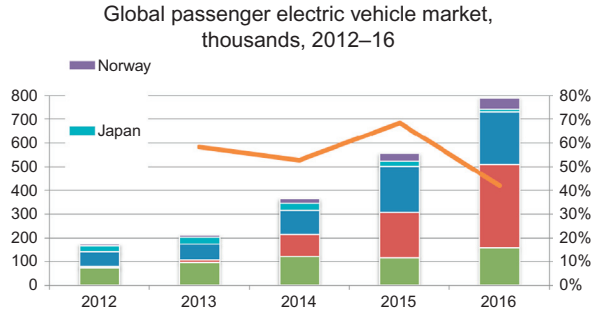
With technological advances, renewable energy costs continue to decline. Renewable energy is already cost-competitive in many countries compared with fossil fuels. In 2016, the report of *New Energy Outlook 2016* by Bloomberg New Energy Finance (BNEF) predicts that the future costs of wind power and photovoltaic power generation will drop significantly. By the 2020s, these two power generation technologies will be the cheapest way to generate electricity in many countries. Onshore wind power cost is expected to drop 41% by 2040. Continued decline in renewable energy costs will spur investment surges. The global renewable energy sector will attract $7.8 trillion investment from 2016 to 2040. According to the International Renewable Energy Agency (IRENA), the average power generation cost for offshore wind farms will decrease by 57% in the future, down from $170 kWh in 2015 to $74 kWh in 2045.

The development momentum of new energy vehicles is good. The global cumulative sales of electric vehicles increased by 683,000 in 2015 from 136,000 in 2012, of which China's growth rate exceeded 300% more than that in the past 2 years, surpassing Japan and the United States as the world's largest electric vehicle market and accounting for more than half sales in 2015. According to a study released in early 2016 by BNEF, the sales of new energy vehicles in the future may skyrocket. It is expected that the cost of new energy vehicles will be lower than that of traditional fuel cars in 2025, and in 2040 it will account for 35% of global passenger car sales.



From Electronic Vehicle World Sales Database. http://www.ev-volumes.com/.

The development of alternative energy is the inevitable outcome of market price, cost push, and global industrial competition. Historically, low price, high energy density, and low transportation cost are important driving forces and incentives for new energy sources to replace traditional energy sources. The two climaxes of clean energy development after entering the industrial society all took place after the oil price had risen sharply. Especially since the beginning of this century, the high energy price cycle has greatly enhanced the economical efficiency of the global new energy and renewable energy, and their development and utilization has been remarkably accelerated. At the same time, clean energy will become a huge global industry in the future, which will directly affect the competitiveness of countries in the future global economy. Since 2008, while many countries have been improving employment and stimulating economic recovery by means of developing clean energy industries, they focus on enhancing the long-term future competitiveness in new energy, environmental protection technology, and low-carbon economy.

At present, it has become a common choice for many countries and a major trend in international community to attach great importance to the development of new energy industries and to devote to energy transformation. Fossil energy, such as petroleum, with its unique advantages like high efficiency, economical and extensive use, completely changed human's production and life style and became the mark of modern industrial civilization, but it has also made the modern society excessively dependent on it. With the large increase of global energy consumption, the large-scale use of fossil energy brought about many problems and thus exacerbated human's concerns about society's future sustainable development and strengthened the widespread desire for energy transformation and new energy system.

The fear of resource exhaustion has been aggravated by the contradiction between the large oil demand, the wide range of uses, and limited resource reserves and non-regeneration. As the dominant energy resource in the world today, oil has obvious advantages in efficiency and environment protection compared with firewood and coal but is relatively insufficient in resource reserves. As a result of large-scale use, fears of oil shortage or depletion have always followed. The problem of energy security caused by the limitation of oil and gas resources, and geographically uneven distribution has become the main reason and impetus for many oil and gas consuming and importing countries keen on energy transformation and developing alternative energy.

The imbalance of resource consumption and oil supply region is another weakness of oil compared with firewood and coal. Oil consumption is mainly concentrated in economically developed countries or emerging markets, while oil supply is mainly concentrated in developing countries or economies in transition, so oil has become the most controversial resource in history. In this case, in order to reduce the security risk of energy supply, many oil consuming and importing countries have taken measures to promote the diversification of the import resources. At the meantime, they also make great efforts to diversify energy types and vigorously develop alternative energy resources.

Different from the energy transformation in history, the environmental problem plays a very important role in the current energy transformation process, and it will be more and more important. Since the mid-1980s, with the global warming and the decline of atmospheric environment quality, developed countries began to look at energy security in the light of sustainable development. In 1997, a conference on global climate

change was held in Kyoto, Japan, where the *Kyoto Protocol* on restricting greenhouse gas emissions from developed countries was enacted. Since then, developed countries have taken the lead in introducing "safe use" into the concept of national energy security, stressing that energy consumption and use should not constitute a major threat to the ecological environment of human survival and development. Since the beginning of this century, the rapid growth of global energy consumption has led to the intensified greenhouse gas emissions, and climate change has become a focus of public concern. In December 2005, the Montreal Conference opened the second phase of the *Kyoto Protocol* negotiations concerning emission reduction, and in December 2007 in Bali Climate Change Conference a "road map" was reached. In December 2015, 190 parties of the *United Nations Framework Convention on Climate Change* reached *The Paris Agreement* at the Paris Climate Conference to make arrangements for global response to climate change after 2020.

At present, the international community, especially western countries, regards whether and how much greenhouse gases emit as an important criterion for energy classification. At the same time, the problem of global climate change makes clean energy technology and alternative energy technology a great attraction to many investors. The International Energy Agency's *World Energy Outlook 2008* points out that long-term goal for stabilizing greenhouse gas concentrations will determine the pace of global energy system transformation [5]. In March 2017, *Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy System* released by IRENA states that currently renewable energy generation accounts for 24% of the world's total power generation and 16% of the primary energy supply. In order to achieve low carbonization, renewable energy should account for 80% of generating capacity and 65% of primary energy supply by 2050.

OPTIMISTIC OUTLOOK

Energy conservation, efficiency promotion, and the development of clean energy are fundamental ways to reduce greenhouse gas emission and then to mitigate global warming. In recent years, the international community's emphasis on climate change has undeniably promoted this process. But the low-carbon economy is fundamentally what social progress and economic development requires. Even without climate change,

countries around the world would strive to get rid of their dependence on fossil fuels and continue to propel the low carbonization and diversification of energy sources.

First, low carbonization and diversification are the inevitable trend of energy development and evolution. Historically, the main energy resources for human social development has evolved in accordance with the trend of lower and lower carbon content, from wood (110 g CO_2/million joules) to coal (97 g CO_2/million joules), and now predominantly oil (73 g CO_2/million joules) and natural gas (56 g CO_2/million joules), and in the future it is likely that dominant energy is carbon-free solar energy, hydrogen, and the like. After coal replaced firewood as the main energy source in the late 19th century, the world's average carbon content dropped to 97.7 g CO_2 per million joules in 1900. In the late 1960s, oil became a major source of energy, and in 1970 the average carbon content of the world energy was further reduced to 75 g CO_2/million joules, and in 1988, it is 67.1 g CO_2 per million joules [6]. At the same time, the types of energy consumption have gradually increased, the structure has become increasingly diversified, and the proportion of dominant energy has declined. Wood and coal accounted for more than 70% of world energy consumption in the age of their dominance, compared with 45% in oil-dominated age. In 2006, the proportion of coal and oil in world energy consumption fell from 84.6% in 1950 to 60.4% (26% and 34.4%, respectively) [7].

Clean energy is indispensable to meet human sustainable development and guarantee energy security. The global population is projected to exceed 9 billion by 2050. At the meantime, more and more people's living standard is moving closer to that of the developed countries, which will inevitably bring about a sharp rise in energy demand. In view of the limited and nonrenewable nature of fossil energy, people have been preparing earlier for the post-oil and post-gas age. Naturally, they have turned their attention to alternative energy resources, especially renewable energy resources which can never be exhausted. According to the analyses of Japan Energy Economics Research Institute, the technological progress in increasing energy efficiency and developing new energy resources is expected to make the global primary energy demand in 2035 lower by 14% than the reference scenario, that is, reduction of the oil equivalent by 2.3 billion tons.

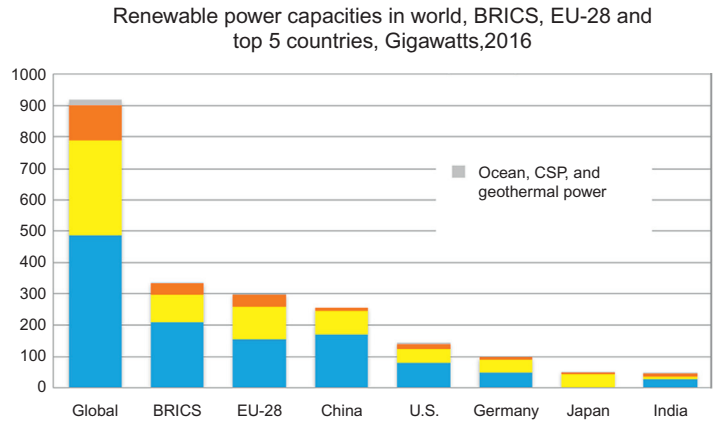
The energy security and geopolitics problems caused by the unbalanced geographical distribution of oil and gas resources have become the main driving force for the large oil and gas consuming countries such as

America and Europe to devote themselves to energy transformation and developing clean alternative energy. From the economic point of view, the high cost of traditional energy system is the important motive and inducement of new energy development in the early stage of energy transformation. In the 15th century, population growth and industrial development led to a shortage of wood in Europe, which was in some ways ultimately attributed to the economically superior coal (low price, high energy density, and low transportation costs) that replaced wood as the world's main energy resource. In the 1850s and 1860s, as the whale oil, the world's leading fuel for lighting, was getting more and more expensive because of the decrease in the number of whales, kerosene was greatly promoted for they are cheaper, safer, and more user-friendly than any other lighting materials in the United States at that time, thus opening the prelude to oil industry. After entering the industrial society, both the two climaxes of new energy and renewable energy development have occurred after the sharp increase in oil price.

For some countries, the development and utilization of new and renewable energy sources are not only related to energy and environmental security but also directly affect their status in future industrial and technological revolution and low-carbon economic development. Since the second half of 2008, clean energy has become the focal point of investments in many countries in response to the current financial and economic crisis of the world. Many countries, while increasing employment and stimulating economic recovery by developing new industries such as new energy and renewable energy sources, focus on enhancing their long-term competitiveness in new energy and environmental technologies and low-carbon economy in the future. To some extent, the current boom behind the clean energy industry is a new round of competition in science and technology, international rules, markets, and many others. The developed countries with leading energy technologies, such as the European Union, have sought to become leaders of low-carbon technology markets and post-oil economy, and continue to maintain their strengths in relevant fields. Some emerging developing countries, however, hope to catch up and narrow the gap with the developed countries in the new energy and industrial revolution, and thus strive for more discourse power.

Overall, under the promotion of international climate change negotiation pressure and technological progress, the prospects for future international clean energy development are relatively optimistic and the prospects for long-term development are promising. The report of *Global*

Renewable Energy Market Outlook 2030 by BNEF predicts that renewable energy investments in annual newly installed capacity will double by 2020 compared with the $195 billion in 2010, reaching $395 billion and increasing to $460 billion by 2030. The total investments of the United States and Canada will reach $50 billion by 2020. The fastest growing markets are India, the Middle East, Africa, and Latin America, which are expected to grow 10%–18% annually from 2010 to 2020. BP predicts that by 2030, the share of renewable energy power generation in non-OECD countries will increase from the current 22%–43%. The International Energy Agency forecasts that renewable energy will account for half of the global growth in power generation capacity in 2035, with wind and solar power generating accounting for 45%. China will be the country with the largest growth in absolute amount of renewable energy generation, surpassing the total sum of EU, the United States, and Japan.



From Renewables 2017 Global Status Report, REN21, Page 34.

In July 2016, the German Federal Parliament adopted the new Renewable Energy Law, which prefers to introduce the renewable energy power generation bidding system from 2017 to formally end the government pricing system based on the fixed grid electricity price, thus it is expected to comprehensively promote the renewable energy generation market. The German government proposes that renewable energy generation will account for 40%–45% of Germany's total electricity consumption by 2025, and it will be further increased to 55%–60% by 2035. In March 2017, the IRENA's report, *Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy System* concludes that with the continued rapid development of renewable energy resources, especially

solar and wind energy, together with favorable grid environment and operational practices, renewable energy will become the primary source of electricity by 2050.

In June 2017, *New Energy Outlook 2017* released by BNEF predicts that global solar and onshore wind costs will fall by 66% and 47% by 2040, and that renewable energy would achieve lower operating costs than those of most fossil energy plants by 2030. Solar and wind power will dominate the future power system. By 2040, it is estimated that new investment in renewable energy will reach 7.4 trillion, accounting for 72% of the total new investment in global generation. Wind and solar power will account for 48% of global total installed capacity and 34% of electricity generation.

On April 25, 2017, the Global Wind Energy Council issued *Global Wind Report: Annual Market Update*, and it points out that in 2016 the new global installed capacity of wind power in the world exceeded 54 GW, with accumulated installed capacity of 486.8 GW. It is predicted that the newly installed capacity of wind power in the world will rise to 75 GW by 2021, and the accumulated installed capacity will exceed 800 GW.

In general, the development and utilization of clean energy has become a strategic choice for most countries, with the scale of the global new energy industry expanding and the private sectors and venture capital significantly increased. Compared with the past, new energy technologies such as wind energy, solar energy, and biomass energy have been significantly improved and costs of new energy have been greatly reduced. On January 20, 2017, after the US President Trump came to power, he released a plan in favor of fossil energy, "America-First Energy Plan," and subsequently announced the withdrawal from the *Paris Agreement*, sparking the heated international discussions and concerns about the clean energy outlook. It is undeniable that Trump's new policy will have a negative impact on the new energy development in the United States, but it cannot change the global trend of low carbonization.

PROBLEMS AND CHALLENGES

Although the new energy system is highly expected by many countries, the current global clean energy development is still at its primary stage as a whole, with its proportion in energy total still at a low level. In the short and medium term, there will be many problems and challenges

such as weak market competitiveness and environmental and ecological problems, so there is still a long way to go for the international energy transition.

At present, the main clean energy resources are nuclear energy, hydropower, and biomass energy, but their proportion is are still very low, though there is a substantial growth for wind power, solar energy, geothermal energy, and other new renewable energy sources. Clean energy has great advantages such as low greenhouse gas emissions and abundant sources, but, from the perspective of market, the current development cost is too high and the comprehensive competitiveness is too weak compared with traditional fossil energy sources. First, it is disadvantageous in cost and price. The new renewable energy technologies have been difficult to make a breakthrough and been invested with a lot of R&D inputs, and most technologies are still in the growth phase of industry cycle with limited scale and higher utility costs. Second, in terms of effect, new energy, mostly with low energy density, is still unable to compete with traditional energy such as oil. What's worse, it occupies large land area, requires numerous auxiliary equipments, and features poor effectiveness and efficiency in utilization. Currently, the rating productivity of large wind turbines is 2 MW, compared with 1000 MW for typical nuclear power plants. In normal circumstances, nuclear power can generate electricity for more than 90% of the time, while the effective time of the wind power is only 30%, which means 1500 wind turbines are needed to produce the electricity equivalent of a nuclear power station's power generation [8]. In addition, the stability and continuity of new energy is generally poor. Wind and solar power has the disadvantages such as intermittence, randomness, and poor adjustment. Only when the wind direction and wind power are suitable or when it is sunny can electricity be generated. In situations where the wind speed is low or even wind is absent, or the sunlight is weak, power reserves or other energy resources are needed to supplement or replace it. In addition, most renewable energy production is subject to geographical constraints with great storage difficulties and high transportation costs.

In terms of environmental impact, new and renewable energy resources are cleaner than fossil fuels, but they cannot completely solve the problems of environmental pollution and may lead to new ecological destruction, such as a large-scale occupation of land. Building large hydropower requires draining the river and flooding large tracts of land. Wind energy, solar power, and biofuels all need to take up large tracts of

land. Under the current technical condition, a complete shift to "renewable energy" will need to change numerous forests and lands to wind farms, photovoltaic power plants, and biofuels land, which may result in the deforestation of forests equivalent to the size of South America (220 million km^2) and the occupation of land equivalent to the sum of the area of China and India (about 13 million km^2) [9].

Most new and renewable energy resources have little or no greenhouse gas emissions during their use, but they still have emissions in the course of production and may emit certain harmful substances. Solar photovoltaic power generation is pollution-free, but the production of photovoltaic cells does not only consume high amount of energy, but also uses cadmium, arsenic, and other toxic materials, which results in chemical pollution to water, land, and so on. At present, hydrogen is mainly extracted from fossil energy, and its process is energy-intensive and still has emissions. For every unit of heat generated, extracting hydrogen from fossil fuels produces more carbon dioxide than direct burning of fossil fuels [10].

The use of geothermal energy also produces solid waste and discharges toxic gases. Compared with thermal power generation, wind power generation does not emit or seldom emits carbon dioxide in the process of power generation, but it inevitably emits carbon dioxide in the process of manufacturing wind power equipments and their maintenance, and the utilization of wind energy also brings about noise pollution and landscape destruction. Hydropower development still has to pay enormous environmental and social costs. Regardless of world heritage, culture, landscape, and other soft elements, the environmental damage caused by hydropower development also makes the argument "hydropower is clean energy" greatly discounted [11]. Some biofuels emit more greenhouse gas than oil (gasoline) or diesel, for example, the use of nitrogen fertilizers results in the release of nitrous oxide (a powerful greenhouse gas). Furthermore, the disorderly development of biofuels can not only exacerbate food crisis but also destroy fertile farmland, grasslands, wetlands, and forests, endangering biodiversity at all levels.

In the current energy transition process, whether the government's active political promotion or enterprises' high investment enthusiasm is, to a large extent, related to high oil price. While high oil price promotes the development of clean energy and the energy transition, it also brings about another dilemma that runs counter to getting rid of the dependence on fossil fuels, that is, the consumption of cheap coal also rises

sharply. In view of the increased magnitude and gross volume of coal, it will inevitably offset the emission reduction caused by the rapid growth of new and renewable sources of energy. If we cannot get out of the dilemma, then energy transformation will be embarrassed by the replacement of oil, the energy with high efficiency and less greenhouse gas emission, by coal, the energy with considerable greenhouse gas emission. In that case, it is impossible to get rid of the dependence on fossil energy.

In addition, at present the development of new energy resources in the world depends largely on government policy support and a large amount of financial subsidies. Although government support and subsidies are indispensable in the initial stage of new energy development, but in the long run, the new energy revolution is a long-term and arduous task. It is difficult to rely solely on the governments' efforts to make new energy acquire the same abilities or even stronger abilities for survival and competing than those of the traditional energy resources.

TORTUOUS ROAD

In contrast to the two energy transformations in the history of coal replacing firewood and oil replacing coal, the "energy transformation fever" in the previous years can be recognized to be largely driven by political factors. Whether it is for energy security or for climate change or for the sake of sustainable development, it has a strong subjective color. In practice, policy support remains a major driving force for current development of new and renewable energy resources [12]. However, considering historical experience, one resource substituting for another resource is determined by economic rather than political factors. Politics helps one resource catch up with the dominant resource only when this resource is going to catch up with another resource [13]. For example, at the beginning of the 20th century, to maintain maritime superiority the British navy chose oil, the energy with less self-sufficiency and higher efficiency at the local, thus accelerating the pace of oil instead of coal becoming the dominant energy resource.

What pushed oil to replace coal as the world's dominant energy resource is that oil is more economical and efficient. Similarly, the future energy transformation will depend on when a type or several types of energy will come into being that can exceed oil or fossil energy in comprehensive indicators such as efficiency and price and also depends on the

market and economy of this new energy or combination of different types of energy. Oil can be used for longer periods of time, especially because of the encouragement of investment in oil exploration and development, energy conservation, and rapid development of alternative energy resources when oil price rose sharply, the period of oil use will be even prolonged. Energy security and climate change have provided a sense of urgency and political impetus for energy transformation, strengthened the willingness and consensus of the international community to develop new energy resources and formed an atmosphere of strong political and public opinions. In this case, whether we talk about energy transformation or developing a low-carbon economy has become a political issue or even a myth or a religion, but whether a low-carbon economy can be achieved or in other words, whether and when the energy transformation can and will be completed, is a technical and even an economic issue. For some countries, it is a worthwhile goal from a political and security point of view to get rid of the dependence on oil in the near and medium term, but it is not necessarily a realistic goal.

In the long run, with the deepening of human understanding of sustainable development, the new and renewable energy has good prospects for development, and new energy transformation with getting rid of dependence on fossil energy as the mark becomes inevitable. But currently clean energy is still just a supplement to conventional fossil fuels, and there is a long way to go for clean energy to become the real alternative energy and mainstream energy. New and renewable energy resources have attracted unprecedented attention all over the world, but there are still many uncertainties in the near future, such as the development of technology and industry, government policy support, social recognition, and the international cooperation, among which the most significant factor is the trend of energy prices.

In the 1970s, the price of fossil fuels rose sharply, which greatly boosted the interest and investment of all countries in renewable energy and spurred the development of new and renewable energy. However, when oil prices dropped sharply in the 1980s, the 10-year development of alternative energy sources such as new and renewable energy came to an abrupt stop and the development of clean energy sank into a low tide. The US Congress canceled tax rebates on solar energy, so ethanol could not compete with cheap gasoline. Many new energy companies, such as wind power companies, went out of business as a result of the government's repeal of its original support. The fall in oil price in the second

half of 2008 also increased the market risk of new and renewable energy technologies and projects with high capital concentration, which led to excessive capacity.

Governments' investment in energy technology research and development also fluctuates to a great extent with the rise and fall of oil price. In the Carter era after the second oil crisis, the US government's R&D budget reached a high point, and the R&D budget fell in the 1980s as energy prices fell. After the 1991 Gulf War, America's concerns about energy security gradually subsided, so the US government wanted to shut down some research programs to reduce federal deficits. When oil price plunged in 1998, the US Department of Energy's R&D budget hit a low point [14]. Entering this century, the U.S. R&D budget started again, and especially after Obama took office, the US Energy R&D investment increased dramatically.

Historically, it took a long time to realize the substitution in energy sector, and the next energy substitution could not be completed overnight. Compared with the past, now the next generation of dominant energy supply chain based on finding new fuel is much more difficult to accomplish. The current energy transformation will be the most difficult shift in energy consumption in the history of human development. First, compared with the past, the speed of fundamental change in the energy industry is not accelerating but rather slowing down. In the history of energy, the fastest replacement is that of firewood, from firewood to coal for 75 years. Oil replaced most of coal's market share in 1860–1960, which means it took 100 years for oil to replace coal [15]. From firewood to coal, to oil, to natural gas then to nuclear power, each new fuel is cleaner and more energy-intensive than the former but is also more technically demanding and complex. The biggest weakness in this energy transition, different from the previous two energy transitions, is that alternative energy technologies are not yet mature, and it is not yet clear that what kind of energy can be used to replace the conventional fossil fuels.

Second, different from the past, the world's energy demand is unprecedented, and it is more difficult for one or more types of new energy resources to meet the large demand or replace the original dominant energy source. At present, more than 7 billion people live on Earth, and the population will exceed 9 billion by 2050. In order to maintain the life of the new population and to continue to improve the living standards of all countries, mankind will consume about two times as much energy as today. New energy sources, such as solar power, wind power, and

geothermal energy, cannot still put into large-scale use. Even with the breakthroughs in technology and markets in a few years, the scope of their use will be greatly expanded, but it is still very difficult for new energy alone to meet the world's growing energy demand.

Third, historically, the development of new energy sources and the transition to more advanced energy systems and industry are a daunting task, difficult to accomplish by only depending on high oil price and political impetus. Whether by means of government subsidies or corporate investments, the cost of opening up any new energy approach will ultimately be borne by the society. These approaches must be cost-effective, that is, the cost-efficiency of opening up new energy sources must be comparable with or even higher than that of existing approaches to attract capital investment and gain sustainable development momentum.

In the context of market economy, the prospect of new energy transformation depends, to a large extent, on whether or not one or several kinds of energy can obviously exceed petroleum in terms of efficiency, price, environmental protection, resource, output, convenience, and other elements. Although the current alternative energy sources have greater advantages in resource and environmental protection, they are mostly in the research and development stage with various defects and deficiencies in efficiency and economy, which requires revolutionary changes and breakthroughs at the technical level. In the existing alternative energy source, biomass energy, wind energy, and geothermal energy are greatly restricted in resource and scale, and DME, ethanol, coal liquefaction, and so on are not independent of fossil energy.

Relatively speaking, hydrogen, nuclear fusion, solar energy, etc., have the great potential to replace fossil fuels ultimately as the dominant energy source in the future. However, they will only play a more local and limited role in the substitution before they achieve technological and industrial breakthroughs or revolutionary changes. The existing nuclear fusion also needs to overcome many technical problems, and large-scale commercial applications will need to wait for at least decades. The acquisition of hydrogen fuel currently comes mainly from fossil fuels and water electrolysis requires a large amount of electricity. If only more than 230 million cars in the United States changed from using oil to hydrogen, it would require building 350 nuclear plants or more than 1000 thermal power plants [16]. Solar cells have developed rapidly and been highly expected, but there are still many technical problems to overcome.

The prospect of developing new energy depends not only on the supply side, that is, whether and when the new energy with potential will embrace the revolutionary change and whether it can form a larger comprehensive competitive advantage over the existing dominant energy sources but also depends on breakthroughs of the demand side (mainly energy utilization equipments). Historically, the revolution of the supply side—the invention of the Newcomen machinery and screw drill—has made coal and oil cheaper and richer in succession, but ultimately, it is the invention of steam engine and internal combustion engine that have driven the large demand on coal and oil and made them become the world's dominating energy. To some extent, the changes of energy utilization equipments ultimately determine the trend of new energy structure.

The most important prerequisite for the success of a leading new energy-using device is that its utility and economical efficiency must be significantly greater than those currently in use. The steam engine in that age brought a giant leap forward, because a steam engine could be more powerful than a group of horses, but today's fuel cells and other energy conversion equipments have not witnessed such a great advance. The new energy equipment not only needs to be driven by demand at the industrial level such as transportation, electric power, or other industrial power technology but also involve the transformation of more complicated related infrastructure and supporting systems. Among all energy equipment, the fastest replacement may be diesel engine replacing steam engine and ramjet replacing propeller engine, which took 35 years, respectively. Fuel cell vehicles are environmentally friendly and easy to operate, but it will take quite some time to fully surpass the piston engine vehicles in overall performance under the current condition. In May 2009, US Energy secretary Steven Chu said the government had suspended the relevant research and development funds in the annual budget, given that fuel-cell vehicles could not be put into practical use over the next 10—20 years.

In the current context, when to invent an effective alternative to internal combustion engine, to a large extent, is determined by when the mankind can get rid of the dependence on oil. The existing new energy utilization and conversion equipments with more potential for development, whether electric vehicles or hydrogen fuel cells, are still far away from the current equipment of dominant energy in terms of function and economical efficiency, especially in the energy storage, a revolutionary breakthrough is urgently needed. It will take a long time for hydrogen

fuel-cell vehicles to surpass the piston engine vehicles in the overall performance. For electric vehicles, the problems of efficiency, duration, flexibility, and cost wait to be solved. If the key to the energy transformation in the past is the improvement of efficiency, the energy revolution in the future will, to a great extent, depend on the breakthroughs and changes in energy storage equipment.

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