China Geothermal Energy Development Report

(2018)

China Geological Survey, Ministry of Natural Resources

Department of New and Renewable Energy,
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Institutes of Science and Development,
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Editorial Board

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Preface

Geothermal energy is heat energy contained in the interior of the Earth and it is a clean, low carbon, widely distributed, largely reserved, safe and high quality renewable energy. In general, geothermal energy can be classified into three types-shallow, hydrothermal and hot dry rock. Geothermal energy development has characteristics of stable, recyclable and renewable, and can help reduce emission of carbon dioxide and improve environment. It plays an important role on clean energy development, and is expected to be a new direction for the energy structure adjustment. The *13th Five-Year Plan of Geothermal Development and Utilization* specifies, by 2020 utilization of geothermal energy will reach 70 million tons of standard coal equivalent annually, which will account for around 1.5% of primary energy consumption, and the share will increase by 1% compared to 2015. During the "13th Five-Year" period, the increment of geothermal energy utilization will account for one-third of the whole increment in non-fossil energy. Great promoting the development and utilization of geothermal energy and constructing the whole industry chain will not only improve the proportion of clean energy supply, but also boost high-quality development in spa, tourism, farming, cultivation and other industries.

Implement the important speech spirit of the General Secretary Xi Jinping-General strategy on promoting energy production and consumption revolution and promoting winter clean heating in North China, it has to carry forward the goals of the *13th Five-Year Plan of Geothermal Development and Utilization*, accelerate technical progresses in geothermal energy exploration and development, improve utilization level, solve issues such as space heating in winter and haze

treatment, and realize people's dream of cleaner energy utilization and better living "after got rich". In accordance with the spirit of the nineteenth conference of the Communist Party of China, grabbing the great opportunity to build a moderately prosperous society in all aspects, to promote the deep development of energy revolution, and to accelerate the great development of China's geothermal energy. The release of *China Geothermal Energy Development Report* is aiming at summarizing current development status, clarifying the development outline, specifying developing strategy and policies, and gathering power and consensus for the rapid development of geothermal energy in China.

Contents

1. Global Geothermal Energy Development Status

Geothermal resources on the planet are abundant, widely but unevenly distributed. They are mainly concentrated in four high-temperature geothermal belts. The development and utilization of geothermal energy has been increasing year by year, and its efficiency has been gradually improved. It is mainly used for direct utilization (space heating, cooling, industrial drying, health, tourism, cultivation, and so on.) and power generation. Technologies of geothermal development and utilization are being innovated constantly, which provides a strong support to the rational development and utilization of geothermal energy. The incentive policies of other countries help promote the sustainable development of their geothermal industry, which provides an important reference to China.

1.1 Abundant Global Geothermal Resources

The potential of the world's geothermal energy resources is great. According to reports from the International Energy Agency (IEA), the Chinese Academy of Sciences and the Chinese Academy of Engineering, the total amount of geothermal resources in the world is 1.25×10^{27}J (equivalent to 4.27×10^{7} billion tons of standard coal), among them geothermal resources between 0-5 km is 1.45×10^{26}J (equivalent to 4.95×10^{6} billion tons of standard coal).

The geothermal resources of middle-low temperature (25-150℃) are widely distributed, and the geothermal resources of high temperature (>150℃) is concentrated in the geothermal belts of the middle of the Atlantic Ridge, the Red Sea-East African Rift, the Pacific Rim and the

Mediterranean-Himalaya. Due to differences in geographical location and tectonic background, countries along the four high-temperature geothermal belts are rich in geothermal resources, including Iceland, Kenya, the United States, Japan, the Philippines, Indonesia, New Zealand, China, and Turkey. For example, the United States, which sits on the Pacific Rim geothermal belt, is rich in geothermal resources. In the US, the amounts of hydrothermal type and hot-dry-rock type geothermal resources at the depth between 0-10km are 9.6×10^{21}J and 1.4×10^{25} J respectively. Turkey, on the Mediterranean-Himalayan geothermal belt, has 3.96×10^{23} J of geothermal resources at a depth between 0-3km.

Currently, the drilled geothermal fields in the world are mainly distributed in high-temperature geothermal belts, such as the Krafla geothermal field of Iceland in the Mid-Atlantic Ridge geothermal belt, the Okalia geothermal field of Kenya in the Red Sea-East Africa Rift geothermal belt, the Geysers geothermal fields of America, the Cerro Prieto geothermal field of Mexico, the Tongonan geothermal field of the Philippines, the Kamojiang geothermal field of Indonesia, and the Wairakei geothermal field of New Zealand in the Pacific Rim geothermal belt, the Larderello geothermal field of Italy in the Mediterranean-Himalayan geothermal belt, and the Yangbajing geothermal field and Yangyi geothermal field in China, and so on.

1.2 The Annually Improved Capabilities of Geothermal Energy Development and Utilization in the World

1.2.1 Direct Utilization of Geothermal Energy

The number of countries developing shallow geothermal resources has increased year by year, from 26 in 2000 to 48 in 2015. By the end of 2015, the total installed capacity of heat pumps for the development of shallow geothermal energy had reached 50,000 MW, accounting for

around 71% of the total installed capacity of the world's geothermal energy. The number of heat pumps increased by 51% compared with 2010. By 2015 the number of installed heat pumps in the US was over 1.4 million, with an average annual growth rate of 100 thousands between 2010 and 2015. Sweden, Germany, France and Switzerland lead the development of shallow geothermal industry in Europe. Their installed capacity of ground source heat pumps accounts for 64% of the total in Europe.

Utilization of hydrothermal energy presents favorable situation. By 2015, the installed capacity of hydrothermal energy space heating was 7,556MW, accounting for 10.7% of the installed capacity of global geothermal energy direct utilization. The annual geothermal energy utilization was 8.82×10^{16} J, which increased by 44% compared with 2010. Countries that are utilizing hydrothermal energy for space heating in a large scale include China, Turkey, Iceland, France and German etc..

1.2.2 Geothermal Power Generation

Geothermal power generation is an important way of geothermal utilization. By 2015, the installed capacity of hydrothermal power generation reached 12.6 thousand MW, which increased by 16% (1.7 thousand MW) compared with 2010. Among them, flashing geothermal power generation system accounted for 61.7%, dry steam geothermal power generation system accounted for 22.7%, binary geothermal power generation system accounted for 14.2%, and other types accounted for 1.4%.

At present, the development and utilization of the hot-dry-rock type geothermal energy is still in the experimental stage, and they have been done mainly in the US, France, Germany and other 5 countries. By 2017, the cumulative demonstration projects of enhanced geothermal system (EGS) reached 31, and the cumulative installed capacity was about 12.2 MW.

1.3 Experiences of Geothermal Energy Development in Typical Countries

Legislation first, straightens out the management system of geothermal energy. In order to support the development of geothermal energy industry, developed countries generally adopt legislation to establish the legal attribute of geothermal energy, clarify subjects of management responsibility and right, and straighten out the system and mechanism of government. For example, the *California Geothermal Act 1967* and *Federal Geothermal Steam Act 1970* of the United States clarified the legal attributes of geothermal energy and its ownership; a series of laws enacted by the government of Iceland, such as the *Study and Utilization Act of Underground Resources*, the *Natural Resources Protection Act* and the *Energy Act*, straighten out the management system of the exploitation and utilization of the geothermal energy and ensure a better development of the geothermal energy industry.

Policy incentives, promote the large-scale development and utilization of geothermal energy. The development of geothermal energy industry in developed countries has distinctive characteristics of government guidance and policy guidance. Iceland, the United States, Japan, Germany and other countries have introduced tax incentives including the production tax credits, and a certain proportion of financial subsidies for geothermal energy development and utilization projects. The *Geothermal Energy Research, Development and Demonstration Act* of the US and other legal provisions provide loan guarantees for renewable energy projects such as geothermal energy that meet local conditions. The introduction of supportive policies has played a significant role in promoting the orderly, healthy and rapid development of the geothermal energy industry in the corresponding countries. For instance, the installed capacity of geothermal power

generation in the United States ranks the first in the world for years, geothermal space heating in Iceland accounts for over 90%.

Scientific and technological innovation, promote the efficient exploration, development and utilization of geothermal energy. The typical countries of the world's geothermal energy development all pay attention to scientific and technological innovation. By increasing the investment of scientific research, setting up major research and development plans, and organizing joint research and development teams, these countries continue to promote geothermal energy exploration and development and utilization subversive technology to improve geothermal energy industry. In 2013, the European Union launched the *Horizon 2020* project and invested 83.6 million euros in 11 geothermal energy research projects to promote geothermal energy forward-looking technologies and key technologies. In 2015, the United States government provided 140 million US dollars to create the *FORGE* project, tackling a series of problems in the field of hydrothermal geothermal exploration, development and utilization, and enhanced geothermal system, which has greatly promoted the technological progress and industrial development of geothermal energy exploration and development.

International cooperation, assists geothermal development in developing countries. Developing countries also attach great importance to the development of geothermal energy industry. They develop and utilize domestic geothermal energy by attracting foreign advanced technology. Taking the Olkaria geothermal field in Kenya for example; Kenyan government has realized the development and utilization of 330°C hydrothermal geothermal energy with a depth of 2,200m through extensively attracting international cooperation and technical assistance from countries like China and Iceland, which laid a good foundation for the development of Kenya's geothermal energy.

2. China's Geothermal Energy Development Status

China is rich in geothermal resources. However, the ratio of explored and utilized geothermal energy is still low. Thus, the development of geothermal energy has great potential in China. In recent years, with the continuous innovation in exploration and development technologies, the equipment that is associated with developing and using geothermal energy is also improved rapidly. The utilization of shallow geothermal energy has increased remarkably, and the developing of hydrothermal resources continuously increases while the exploration of hot-dry-rock type geothermal energy has also started. The industry system of developing geothermal energy has been preliminarily formed. At the same time, the deeply-seated problems of inadequate and uncoordinated development need to be resolved urgently.

2.1 Great potential of China's geothermal resources

During the "12th Five-Year" period, the national survey and assessment of geothermal resources was conducted by China Geological Survey, the resource amount of shallow geothermal energy, hydrothermal energy and hot-dry-rock type geothermal energy were calculated. According to the evaluation results, the recoverable reserves of shallow geothermal resource in 336 cities equals to 0.7 billion tons of standard coals, which can meet the heating and cooling demand of 32 billion square meters. Among them, the Huanghuaihai Plain and the middle and lower plains of the Yangtze River are favorable areas for developing shallow geothermal energy.

The recoverable reserve of hydrothermal resource is equivalent to

1.865 billion tons of standard coals (under the condition of rejection), among which the medium-to-low temperature geothermal resource accounts for 95%. The medium-to-low temperature geothermal resources are distributed not only in plain areas (basins) such as the North China basin, Songliao basin, Subei basin, Jianghan basin, and Ordos basin, but also in hilly areas, such as the southeastern coast, Jiaodong Peninsula, and Liaodong Peninsula. The medium-to-low temperature geothermal energy is mainly used for heating, drying, tourism, cultivating and so on. The high temperature geothermal resources are mainly distributed in south of Tibet, west of Yunnan, west of Sichuan, and Taiwan Province. Annual recoverable reserves of the high temperature geothermal resources in Southwest China are equivalent to 18 million tons of standard coals, and the potential of power generation capacity reaches 7,120MWe. The cascade utilization of high temperature geothermal resource in Southwest China can meet power needs and heating demands of 50% population of western Sichuan and some minority in southern Tibet.

According to a preliminary estimation, the resource amount of hot dry rock within the depth of 3km to 10km in mainland China is about 2.5×10^{25}J (equivalent to 856 trillion tons of stand coals), among which, the resource of hot dry rock within 3km to 5.5km is about 3.1×10^{24}J (equivalent to 106 trillion tons of stand coals). Considering the difficulty in exploring and utilization of hot-dry-rock type geothermal energy, the hot-dry-rock type geothermal energy that buried between 3km to 5.5km are the priority research areas in the next 15 to 30 years.

2.2 China's geothermal energy industry system has been constructed

China is one of the earliest countries that develop geothermal energy and the utilization of hot spring can date back to pre-chin period. In the

1950s, China began to utilize hot spring in large scale, building 160 different thermal spring sanitariums successively. At the beginning of 1970s, China's geothermal energy was utilized in many different ways: bathing, space heating, power generation, and so on. Since the beginning of the 21st century, impelled by policies guidance and market demands, the development and utilization of geothermal energy has developed rapidly.

Shallow geothermal energy grows rapidly. The development and utilization of shallow geothermal energy began at the end of the 19th century and at the year of 2000; the hearting/cooling area of ground source heat pump was merely 100,000 square meters. As people pay more attention to energy saving and climate change, the development and utilization of shallow geothermal energy grows rapidly. The heating/cooling area of ground source heat pump was 7.67 million square meters in 2004 and since 2010, the heating/cooling area of shallow geothermal energy grows at the rate of 28%. By the end of 2017, the installed capacity of China's heat pumps had reached 20,000MWe, ranking the first in the world and the development and utilization of shallow geothermal energy reduce the burning of 19 million tons of standard coals and meet the heating and cooling demand of 0.5 billion square meters, mainly in the city district of Beijing, Tianjin, Hebei, Liaoning, Shandong, Hubei, Jiangsu, Shanghai, and so on. Among them, the heating/cooling area of shallow geothermal energy ranks first in the Beijing-Tianjin-Hebei region.

Hydrothermal energy grows continuously. During the past ten years, the average annual increase rate of hydrothermal energy was 10%, and the amount hydrothermal energy utilization ranked the first in the world for many years. Geothermal energy is primarily used for space heating, then used for bathing, cultivating, and so on. In the year of

1990, hydrothermal energy heating area was merely 19 million square meters, and increased to 11 million square meters in 2000, and at the end of 2015 the number had reached 102 million square meters. Among them, geothermal energy heating area in Tianjin was 21 million square meters, ranking the first in China cities and accounting for 6 percent of total hydrothermal energy heating area. In Xiongxian county of Hebei province, the hydrothermal heating area was 4.5 million square meters, which had satisfied more than 95% heating demand of whole urban area. The developing of geothermal energy in Xiongxian county made it become the first no-smoking town in China and the "Xiongxian Model" was proposed to develop hydrothermal geothermal energy in scale. According to incomplete statistics, by the end of 2017, the hydrothermal heating area in China had exceeded 150 million square meters; among them, Shandong, Hebei and Henan province grow well. China's geothermal energy power generation began at 1970s. The first middle-to-low temperature geothermal power station was established on December 1970 in Dengwo Village of Fengshun County, Guangdong province and successfully generated power. On September of 1977, the first high temperature geothermal power station-Yangbajing power station was successfully constructed with 1MWe installed capacity, which made China became the 8th country to own geothermal energy power generation technology. In 1991, the installed capacity of Yangbajing geothermal power generation of Tibet reached 25.18MWe, and the generated electricity accounting 40-60 percent of total electricity in Lhasa city at that time. By the end of 2017, the installed capacity of geothermal energy power generation in China was 27.28MWe, ranking 18th in the world.

The development and utilization of hot-dry-rock type geothermal energy is still at the early stage. The development and utilization of

hot-dry-rock type geothermal energy is the future of geothermal energy. After 20 to 40 years of research, countries like US, German, France and Japan have made significant accomplishments and accumulated valuable experience in the exploitation of hot-dry-rock type geothermal energy, reservoir reconstruction, and power test. Comparably, China's researches on the hot-dry-rock type geothermal energy were relatively late. It began from the National High-tech Research and Development Program (863 Program) which conducted by the Ministry of Science and Technology. Since 2013, China Geological Survey and Qinghai Province have been collaboratively propelling the exploitation of hot-dry-rock type geothermal energy in key areas in Qinghai province. In 2017, 236℃ hot dry rock was drilled at the depth of 3,705m in Gonghe Basin of Qinghai Province and this was the first time to find such high temperature hot-dry-rock type geothermal energy in contemporary non-volcanic activity regions. Through deep research, in the future, the development and utilization technologies for hot-dry-rock type geothermal energy will make great breakthrough to promote the rapid development of China's geothermal energy power generation and cascade utilization industries.

The equipment for developing and utilizing geothermal energy improves rapidly. A set of key equipment that used for geophysical exploration, drilling, heat pumps, heat exchange are greatly improved. In the aspect of geophysical exploration, China has equipped with world-leading 2D/3D seismic, time-frequency electromagnetic methods (TFEM), magnetotelluric sounding, gravity and magnetic and other equipment. In the aspect of drilling, China has successfully developed rig available for 10km and oil rig for more than 8km. The technology for full-hole coring can reach as deep as 7,018m. All of these rigs can be used for geothermal energy drilling. The SongKe No.2 Well, a scientific drilling well launched by Chinese government, was completed in 2018.

The water-based mud can resistant temperature as high as 242℃, the PDM drilling equipment can resistant temperature as high as 180℃ while turbine tools that instead drilling equipment can resistant temperature as high as 240℃. In the aspect of heat pumps, currently, China has become a major producer and consumer of ground source heat pumps. As the improvement of production ability, domestic equipment has occupied most of the heat pump market. In recent years, with the issuing of national financial policies and other stimulated policies, ground source heat pump system and hydrothermal energy heating system developed drastically, and also promote the rapid development of associated new materials, high-end equipment, scientific researches and related services.

2.3 Continuous technical innovation for geothermal energy exploration, development and utilization in China

The technology system for geothermal energy exploitation continuously improved. Since 1970s, China has made significant achievements in geology, geophysics, geochemistry, drilling, and so on.

The first one is geological study on geothermal system. China has made great progress in geothermal flow distribution, origin of geothermal energy, distribution pattern, geothermal resources evaluation, and so on. Currently, China is positively investigating the origin of deep geothermal energy, three dimensional geological model of geothermal field, fine description of the structure of heat reservoirs, the evaluation of resource amounts under the condition of rejection. All of these studies will provide theoretical guidance for the exploration and development of geothermal energy.

The second one is the study on geophysical methods. A variety of comprehensive geophysical prospecting techniques, from gravity, magnetoelectric survey to detailed seismic prospecting, have

been preliminarily formed. In recent years, with the technology of comprehensive interpretation of seismic data and fine descriptive technology for 3D seismic geological model, the accuracy and efficiency of target selection and borehole location for hydrothermal energy and hot-dry-rock type geothermal energy has been greatly improved.

The third one is the study on geochemistry. China has gradually built a technology system for geochemistry exploitation. After several decades' development, based on isotope and chemical characteristics of gas, water and rock, Chinese institutes have basically employed/created a set of geochemical methods which can be used in judging abnormal area of geothermal energy, evaluating heat reservoirs' temperature, inferring the origins of geothermal water, predicting scaling and eroding, and so on.

Fourthly, there is a great improvement in geothermal energy drilling. Since the end of 1990s, China has attempted to combine technology of oil drilling and completion with developing of geothermal energy which greatly improved the efficiency of drilling and shorten the period of drilling. China has successfully completed many high-temperature drilling projects (above 300℃) in Yangbajing of Tibet, Kenya, Turkey and some other regions.

The technologies for geothermal energy utilization improved steadily. With the development of heat pump technology, China has the ability to recreate large-scale heat pump system, high temperature heat pump system, multifunctional heat pump system which are feasible in China's markets. Major technologies and facilities have been basically localized.

Tail water reinjection technology has improved. The technology of tail water uni-layered reinjection in confined space in karstic reservoirs is relatively mature. After numerous scientifically experiments, the technology of economic reinjection in sand reservoirs has made

significant progress, however, to promote it to a large scale still need more experiments and researches.

The cascade utilization of geothermal energy has been positively studied in China and some demonstration projects have been constructed in Beijing-Tianjin-Hebei region and southeastern coastal areas where developing geothermal energy for power generation, space heating, and so on.

2.4 The management system and policies of China's geothermal energy industry are constantly improving.

The regulatory framework is basically established. In 1986, *Mineral Resources Law of the People's Republic of China* stipulates that mineral resources belong to the state. Exploration and exploitation of mineral resources must be approved to obtain the right of exploration and mining. Mining mineral resources must pay taxes on mineral resources and compensation fee for mineral resources in accordance with the relevant provisions of the state. *Rules for the Implementation of Mineral Resources Law of the People's Republic of China* clearly defines geothermal energy as mineral resources. In 1988, *Water Law of the People's Republic of China* stipulates that water resources include groundwater; the implementation measures of *Water Law of the People's Republic of China* promulgated by the people's governments of provinces, autonomous regions and municipalities stipulate that water intake should get the permit from regulation departments for taking water directly from the ground, and water resources fees shall be paid. Since then, to solve the problems arising in the management of geothermal energy resources, Legislative Affairs Office of the State Council issued *Reply Letter on the Attributes and Applicable Laws of Geothermal Water* to Legal Bureau of the People's Government of Tianjin in 1995; State Commission Office

of Public Sectors Reform issued *Notice on the Division of Responsibility for the Management of Mineral Water and Geothermal Water* in 1998; Legislative Affairs Office of the State Council issued *Reply Letter to Ministry of Land and Resources about Letter on Further Clarifying the Division of Responsibilities for the Management of Mineral Water and Geothermal Water* in 2003, which further defines the legal basis and related matters of the management of geothermal resources. In 2009, the newly revised *Renewable Energy Law of People's Republic of China* incorporated geothermal energy into renewable energy. The formation of these laws have basically established the legal basis for the exploration, development and utilization of geothermal energy, and laid the institutional foundation for the orderly development of geothermal energy.

The management system has been preliminarily formed. China has basically established the management system for geothermal resources, including exploration license, mining license, drilling approval, drilling construction supervision, open sale of mining rights, record employment unit, management of compensation fee pay for mineral resources, mining right price management, source protection, science and technology project management and many other systems. They have preferably maintained the order of exploration, development and utilization of geothermal energy. Beijing, Tianjin, Chongqing, Yunnan, Hebei, Inner Mongolia and other provinces (autonomous regions, municipalities) have promulgated local regulations or regulations in succession. Ji'nan in Shandong, Nantong in Jiangsu, Weinan in Shaanxi and Baoding in Hebei and other cities have also promulgated and implemented the standardized documents for the management of geothermal energy resources. Beijing-Tianjin-Hebei region and other places have developed a series systems for geothermal energy

development and utilization review, geological environmental impact assessment, geothermal tail water reinjection protection, annual index verification, annual development unit inspection, and so on. To a certain extent, they have standardized the rational development, utilization and protection of local geothermal resources.

Policies and measures have been improving in succession. In January 2013, National Energy Administration, Ministry of Finance, Ministry of Land and Resources, and Ministry of Housing and Urban-Rural Development jointly issued *Guidance on the development and utilization of geothermal energy*. In January 2017, National Development and Reform Commission, National Energy Administration, and Ministry of Land and Resources jointly issued *The 13th Five-Year Plan for the development of Geothermal Energy* in China. In December 2017, National Development and Reform Commission, Ministry of Land and Resources, Ministry of Environmental Protection, Ministry of Housing and Urban-Rural Development, Ministry of Water Resources and National Energy Administration jointly issued *Notice on Accelerating the Development and Utilization of Shallow Geothermal Energy to Promote the Replacement of Coal Burning in Northern Heating Areas*. In December 2017, National Development and Reform Commission, National Energy Administration, Ministry of Finance, Ministry of Environmental Protection, Ministry of Housing and Urban-Rural Development, State-owned Assets Supervision and Administration Commission of the State Council, General Administration of Quality Supervision, Inspection and Quarantine, China Banking Regulatory Commission, China Securities Regulatory Commission, and Logistics Support Department of Military Commission's issued *Winter Clean Heating Planning in the North Region (2017-2021)*. The introduction of these policies has strongly supported the rapid development of geothermal energy industry.

2.5 The problems of inadequate and uncoordinated still exist in China's geothermal industry

Firstly, more work should be done regarding the exploration and evaluation of geothermal energy resources and scientific research. The national geothermal resources evaluation had been carried twice in China, however, only a few geothermal fields have been systematically explored and the research foundation is relatively weak. The evaluation results on resources of each province and each basin are less accurate, and there is a significant gap when compared with developed countries. At present, the number of heat flow data in China is only 1,230, while United States has more than 17,000 heat flow data. In the field of dry hot rocks exploration and development, the United States has been studied hot-dry-rock type geothermal energy for more than 40 years, and achieved many research results. Germany, France, Britain, Japan and Australia have also carried out fruitful work. However, China just started.

Secondly, the policies are not sufficient in the early stage of geothermal energy industry development. Recently, the central and local governments have introduced some financial and price policies to accelerate the development and utilization of shallow geothermal energy and promote clean heating in the northern areas. However, policies are not quite perfect and the implementations of the policies are not in place and insufficient. First of all, the laws and regulations related to geothermal energy are in poor operability. At present, the laws and regulations on financial and tax support for geothermal energy are lack of implementation terms and rules, and there are no unified and clear standards for incentive policies, such as preferential tax rate and subsidy, and the policies are "difficult to carry out". The standard of resource tax is relatively low, which cannot reflect the real cost to social and the

advantages of developing geothermal energy. Next, there is insufficient preferential treatment for the development and utilization of geothermal energy. According to the additional policy requirements of renewable energy electricity price, the electricity price subsidy policy is given to the commercial operation projects of geothermal energy power generation. But, there are no enough preferential policies for specific development and utilization at the moment. There are still shortcomings in the existing geothermal energy preferential policies, which are mainly reflected in the lacking of policies for land utilization, equipment manufacture and product consumption. Finally, subsidy models are unscientific and support methods need to be improved. The form of subsidy only adopts the way of pre-subsidy and production-linked subsidy, and the results are greatly reduced. Direct subsidy is the main way, but still has the problem of lacking market-based methods and the period is long.

Thirdly, the problem of uncoordinated still exists in geothermal energy industry. Mainly shows in: The first one, the accuracy of geothermal exploration and evaluation lags behind the speed of development and utilization. The exploration base of geothermal energy is weak, low precision, as well as lack systematic exploration. In the field of the preferable areas election and development scale determination there are some blindness, which not only increases the risk of project investment, but also leads to extensive, inefficient development and bring more environmental problems. The second one, technological innovation and geothermal energy development and utilization are not in harmony. The key technologies and equipment of geothermal energy exploration, hydrothermal energy injection, dry hot rocks development and utilization, medium-to-low temperature geothermal energy efficient power generation need to be innovated urgently to realize develop geothermal energy in large scale. Next, geothermal energy development

projects are not coordinated with the overall planning of city. Although there are more than 10 provinces published geothermal energy planning and relevant documents, which greatly promoted the development of geothermal energy industry in China, these plans are not compatible, and there are no links between different levels of planning. The current development and utilization planning of geothermal energy is not integrated into the local and urban development plans. It leads to the lack of operability of planning in practice. It is also difficult to achieve the goals of *The 13th Five-Year Plan for the development of geothermal energy* in China. Last but not the least, government regulation is not compatible with sustainable development and utilization of geothermal energy. The multi-management and less of regulation capability of government are not compatible with the rapid development of geothermal energy. The existing problems include less of relevant standards and technical specifications, supervision missing and offside. Through shallow geothermal energy and hydrothermal energy has been developed for years, dynamic monitoring system has not been constructed, which seriously hinders the healthy and sustainable development of geothermal energy industry.

Fourthly, the geothermal energy resource management system is not coordinated. In China's current legal system, "geothermal" is controlled by three laws, but the relevant regulations have not accurately understood the basic properties of geothermal energy. Thus, the applicability and operability of the laws need to be solved urgently. *The Mineral Resources Law of People's Republic of China* stipulates that "geothermal" belongs to the minerals. Since "geothermal" is renewable, the management mode of non-renewable mineral resources can't meet the needs of large-scale exploration and exploitation of geothermal energy. *The Water Law of People's Republic of China* stipulates that

"underground hot water" belongs to water resources. Since the utilization of geothermal energy does not consume water, employing the way of managing water resources to manage geothermal restricts the rational development of geothermal energy is not correct. Although *The Renewable Energy Law of People's Republic of China* emphasizes that geothermal energy is renewable energy, it is only in principle and it lacks the management means and measures like it given to wind energy and solar energy.

3. Suggestions on China's Geothermal Energy Development

China has abundant geothermal resources, vast market demand, and good development tendency. It is a sunrise industry with great potential. The development of geothermal energy industry will be of great significance for China to adjust its energy structure and prevent environmental pollution. In terms of economic benefits, the rapid progress of geothermal energy industry will take a more important position in China's economic growth and economic structural transformation and upgrading. The high-quality development of geothermal energy industry will not only promote employment increase, but also facilitate a comprehensive development of both upstream and downstream industries, such as equipment manufacturing, geological exploration, construction, modern agriculture and leisure tourism.

3.1 The China's overall guideline for geothermal energy development

3.1.1 Guiding ideology

The geothermal energy industry development guidance can be regarded as an in-depth implementation of The Thought on Socialism with Chinese Characteristics for a New Era and The Spirit the 19th National Congress of the Communist Party of China, both of which call for a decisive victory in building a moderately prosperous society in all respects, including ecosystem. High-quality development of geothermal energy industry will play an important part role in promoting ecological civilization and energy revolution, building a green energy system, and realizing people's yearning for clean energy and a better life. Guided by

"Lucid waters and lush mountains are invaluable assets", the geothermal energy industry is committing to optimizing energy structure, preventing and controlling air pollution, coping with climate change, and developing green industry. Based on national conditions and geothermal energy resources endowment, the geothermal energy industry is actively integrating into the coordinated development of Beijing-Tianjin-Hebei, the development of the Yangtze River economic belt and the construction of the "Belt and Road", embracing modernization, the world and the future. Efforts will be made to comprehensively plan the high-quality development of the geothermal energy industry chain, optimize the overall planning and layout of the industry. The industry will be dedicated to enhancing the vitality of the micro-subjects in the market, focusing on comprehensive geothermal energy resources survey and evaluation, building a scientific development and utilization technology support system. Also, the industry will focus on promoting deep integration with other energy industries, building a technologically advanced, environmentally friendly, and economically viable geothermal energy industry cluster, accelerating the healthy and sustainable development of the industry, and helping to build a beautiful China.

3.1.2 Basic principles

(1)The principle of adaptation to local conditions. The core task is to help prevent air pollution. In the central and eastern China where the ecological environment is relatively severe, such as Beijing, Tianjin, and Hebei, geothermal energy will be used, on a priority basis, for heating/cooling. This measure will help replace the traditional coal-fired boilers, address pollution caused by non-centralized coal burning in rural areas, and help promote clean winter heating in northern region. In the western China, geothermal energy will be used in power generation in an orderly manner, providing clean energy for the development of the

western region. In hot-summer and cold-winter areas of China, shallow geothermal energy will be used to meet the need of heating and cooling and help the green development of the Yangtze River economic belt. We will also strengthen cooperation in the field of geothermal energy with countries participating in the "Belt and Road" initiative and other countries to cope with climate change together.

(2)The principle of step by step. Based on China's geothermal energy resources endowment and market needs, in the near- and midterm future, heating and cooling will be the main usage of geothermal energy, while power generation will be secondary. During this period, a green industry chain will be built. Geothermal heating will be taken as a stepping stone, which will help to increase policy support, accelerate the efficient development and utilization of geothermal energy, and enhance the awareness and recognition of geothermal energy industry in all sectors of society. Meanwhile, we will pay close attention to tackling key problems of the EGS, laying the foundation for large-scale geothermal power generation in the future. Demonstration projects for early and pilot implementation of Green industry based on geothermal energy will be gradually promoted to the whole country. After 2035, with the gradual maturity of exploration and development technology and the continuous improvement of the market system, efforts will be made to cultivate geothermal energy into a driving force for green development, and play an important role in optimizing and adjusting China's energy structure.

(3)The principle of adhering to high quality development. We will move faster to advance the change of geothermal energy industry development pattern from a single, extensive, inefficient one to a diversified, intensive, efficient modern one. Precise exploration and cascade utilization of geothermal energy will be widely used in order to improve resource utilization efficiency and improve geothermal project

profit. In addition, we will push forward with the "Geothermal Plus" and speed up deep integration and coordinated development of multiple clean energy sources based on local circumstances. We will strengthen our capability for making technological innovations, work toward accelerating geothermal energy industry transformation and upgrading, and speed up talent cultivation. These measures will enable us to achieve a well-performing and sustainable development of the geothermal energy industry.

3.2 Suggestions on promoting the high-quality development of geothermal energy in China

3.2.1 To carry out the high quality geothermal resources evaluation through China as soon as possible is an urgent issue by far.

Some actions need to be taken to facilitate the development of China's geothermal resources evaluation, such as increasing financial investment, encouraging active participation of all kinds of social capital, and carrying out investigations and evaluations of national geothermal resources. Focusing on North China, Songliao, Jianghan, Ordos, Subei and other basins (plains), China should accelerate the ascertaining of geological conditions, reservoir characteristics, quality and quantity of both hydrothermal type and hot-dry-rock type geothermal areas (fields), and evaluate the technical and economic conditions for its development. Besides above mentioned suggestions, China should also speed up the exploration and development of deep geothermal resources, and prepare for the large-scale and commercialized development of hot-dry-rock type geothermal energy.

China should not only establish the system of data collection, sharing and service for the government-led whole industrial chain in geothermal energy exploration, development and utilization, but also form the

national data platform for geothermal energy development and utilization which includes basic data of geothermal resources, dynamic and efficiency monitoring data of geothermal development and utilization, and industrial network information management system, aiming at proving supports for geothermal energy investigation and evaluation and scientific development and utilization.

3.2.2 Key techniques for the development and utilization of geothermal energy should be tackled fast.

The central finance and local finance should set up the major specialized funds for geothermal resources survey and for scientific and technological innovation, increase the investment in the research and development of key technologies for geothermal energy exploration and development, and strengthen the research and development of special equipment and special technology for geothermal energy.

The first is to develop comprehensive geophysical and geochemical technique that can directly detect the underground temperature field, so as to realize three-dimensional fine characterization of the underground temperature field. The second is to strengthen the research and development of directional drilling technology and equipment at high temperature, to break through the key technical bottlenecks of high temperature and low cost drilling, and to achieve the upgrading of core equipment. The third is to tackle technical problems in the economical recharge technology of sandstone reservoir, to improve the well completion technology of recharge wells, and to optimize the layout of the production and recharge system. The fourth is to make technical breakthroughs in hot dry rock exploration and development, and to break through the key technologies of reservoir construction, reconstruction and efficient heat exchange. The fifth is to explore a multistep, comprehensive, and efficient model of utilizing technology system and

business mode, and to tackle key technologies in power generation, heating, cooling, commercial application, and other related areas.

3.2.3 High-quality demonstration areas for geothermal energy development in a leading and exploratory way should be cultivated.

The first is to establish a demonstration area for efficient development and utilization of geothermal energy in Xiong'an New Area. To make the "Xiong'an Model" of geothermal energy utilization into a global model in accordance with the goal and requirement of the "Xiong'an Quality" in the planning and construction of Xiong'an New Area. In terms of planning concept, geothermal planning will be carried out first instead of the previous geothermal development following urban agglomeration. For the source of energy supply, the original hydrothermal-focused type will be reformed as the geothermal, hydrothermal and hot dry rock integrated type. For the way of energy supply, the single heating supply will be replaced by multiple supplies of electricity, heating and cooling supplies. The way of energy consumption will be transformed from single geothermal consumption into multi-energy consumption. The energy-consumption cycle will be changed from one heating season to four seasons. The industrial chain will be transformed from the single energy industry into an integrated industrial cluster of upper, middle and lower streams of geothermal energy.

The second is to establish a demonstration area for shallow geothermal energy utilization in Beijing's subsidiary administrative center. With the coordinated planning and construction of underground and up-ground space, build a distributed and complementary large-scale energy station system for shallow geothermal energy development and utilization, form a demonstration area of cluster utilization, meet the needs of heating and cooling of large building aggregates of Beijing's subsidiary administrative center, and assist the construction of green low carbon city.

The third is to establish a pilot site for hot-dry rock exploration and development in the Gonghe Basin. Facing the future development needs for geothermal energy and aiming at the technology frontier of hot dry rock, we will carry out pilot tests to tackle difficulties in strategic science and technology in the Gonghe basin of Qinghai, vigorously promote the development of theory, technology, engineering and equipment for the exploration and development of dry-hot-rock type geothermal resources, and strive to achieve a major breakthrough in the exploration and development of the hot-dry-rock type geothermal resources as soon as possible.

The forth is to build a demonstration town featured in geothermal energy. Taking the Xiaoyangkou of Jiangsu Rudong as a demonstration area, to build a town based on geothermal energy and featured in the cascade and high efficient development and utilization of clean energy. Following the comprehensive and high efficient utilization concept, it will form a clean energy industry cluster for heating, cooling, electricity generation, bath therapy, hot spring leisure, old-age service, efficient modern fishery, agriculture, flower drying and so on. It will provide a demonstration for the acceleration and development of green industry system supported by clean energy.

Apart from the construction of pilot sites over the country, at the same time, we should set up the trial and error mechanism of further reform and opening up as soon as possible, fully mobilize the enthusiasm of all parties to participate in the reform and innovation, explore the pilot boldly, practice the new concept of development, sum up the experience in time, and then popularize it in the whole country after the conditions are basically mature.

3.2.4 Preferential policies should be introduced to support the high-quality development of geothermal energy.

At the early stage of geothermal energy industrial development,

support policies of finance, tax and finance for wind power, photovoltaic and other renewable energy can be referenced, so as to give great support to the exploration and utilization of hydrothermal and hot dry rock type geothermal energy. The geothermal development and utilization should be included into the subsidy range of the renewable energy fund, and should be issued with green certificate quotas in accordance with the green certificate system of renewable energy. Relevant preferential policies of value-added tax, property tax and urban land use tax should be implemented for enterprises of hydrothermal and hot dry rock energy development and utilization as well as other related equipment and materials manufacturing enterprises. Financial subsidy policies for geothermal energy to replace fossil energy for heating, cooling and power generation should be studied and formulated, based on the amount of heating (cooling) and electricity as the unit.

Carrying out pilot promotions of the franchise right. In order to attract social forces and financial capital to participate in geothermal exploration and evaluation, and to promote the scale development and standard development of geothermal energy industry, pilot promotions of the franchise right for geothermal development will be carried out. Enterprises participating in the exploration of basic public welfare geothermal energy and integrating the survey and evaluation data into the national geothermal energy data management platform will be granted the priority of obtaining the franchise qualification of geothermal resources (mining rights).

3.2.5 The management and monitoring system of geothermal energy should be established and improved.

The first is to make a proper special planning for geothermal energy. The special planning of geothermal energy utilization will be included in the national spatial planning system, and the overall objectives and

basic ideas of the geothermal energy development and utilization will be clearly defined. The geothermal energy heating (cooling) will be included in the special planning of local infrastructure construction, so as to realize the scientific layout and efficient development of geothermal energy development.

The second is to improve the management system of geothermal energy. In accordance with the principle of "One department is responsible for one thing", the management measures for geothermal energy development and utilization will be formulated in line with the *renewable energy law of the People's Republic of China* as soon as possible. The boundaries and standards for utilizing water resources, geothermal resources, and for both water and heat intakes will be clearly defined. The market access regulations of geothermal energy exploration and development, the bid, auction, listing and selling of mining rights, and third party services will be perfected. The reinjection system of geothermal tail water will be perfected, effective implementations will be made, and the geothermal resources and environmental protections will be strengthened. The strengthened supervision, standardized market order, and increased penalties for illegal enterprises will be targeted. Finally, a statistical report system for geothermal energy exploration, development and utilization will be established.

The third is to establish an evaluation system for geothermal energy development and utilization. In areas of the northern region and the Yangtze River economic belt that meet the requirements, transform their energy system into comprehensive application demonstration projects (areas). The utilization of geothermal energy should be included in the assessment system of regional ecological civilization construction, and act as an additional part of the assessment system for energy conservation and emission reduction.

Closing Remarks

The rapid development of clean energy has become one of today's hot topics. Facing international upsurge in the development and utilization of geothermal energy and the huge domestic demand for clean energy, the development and utilization of geothermal energy in China has achieved a rapid growth with the joint efforts of "Government, Industry, University and Institutes". China has made great progress in the exploration, development and utilization technology, and has ranked as one of the top countries in the world with rich resources and high degrees of geothermal energy development and utilization.

With the vigorous promotion of the *Clean Winter Heating Planning for the Northern Region (2017-2021)* and the orderly launching of the "Coal to Geothermal Energy", the construction of demonstration areas for geothermal energy development and utilization, represented by Beijing's subsidiary administrative center, Xiong'an New Area and Jiangsu's Rudong Xiaoyangkou, as well as the implementation of deep geothermal exploration in areas of the Beijing-Tianjin-Hebei region and demonstration projects of hot dry rock utilization in Qinghai Gonghe Basin, will promote and lead China's geothermal energy exploration and development to the fast lane It will become an important force to cope with climate change, and serve to win the blue sky defense battle and to optimize the energy structure. Meanwhile it will make great contributions to the green development and the ecological civilization construction.

The introduction of *China geothermal energy development report* aims to build an exchange and communication platform to promote the great transformation of China's energy and to explore the healthy and rapid development of geothermal energy industry. We look forward

to the release of the *China geothermal energy development report of 2018* to further stimulate the community to explore the reform path of the geothermal industry, to condense consensus, and to cooperate with the development of geothermal energy utilization. Here, we sincerely thank all relevant departments, research institutes, industry associations, enterprises, international institutions and many experts for their strong support and assistance.