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Review and prospect of geothermal energy application

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Abstract: *At present, the use of global carbon-based energy has caused various ecological problems, and there is an urgent need for a non-carbon-based clean energy that is rich in reserves and can provide stable energy. Geothermal energy is the most suitable among many new energy sources, but its development is subject to the level of economy and science and technology, and many countries have no clear development direction. The paper classifies the geothermal resources according to the different energy storage media, and expounds the basic situation of all kinds of geothermal energy, shallow geothermal, hydrothermal geothermal and hot dry rock are the main body of geothermal application. The main application methods of various geothermal resources are briefly described, including thermal energy utilization and electric energy utilization. Various power generation systems are reviewed in detail, and a new model of multistage utilization of geothermal resources is proposed. In the development of the geothermal industry, the potential problems are analyzed and corresponding solutions are proposed. Government policies should be fully tilted to help enterprises bear investment risks, and increase investment in preliminary survey, technology, equipment and talent reserve. Relevant enterprises and departments need control the cost of geothermal system construction in the early stage. Aim to alleviate the current energy pressure, the research and development group focuses on prioritizing key technologies for shallow geothermal and hydrothermal geothermal mining.*

Keywords: *Geothermal classification; geothermal application method; non-carbon-based energy; multistage utilization*

1. Introduction

With the emergence of problems such as global warming, environmental pollution and dwindling carbon-based energy reserves, it is urgent to carry out energy transformation and seek suitable alternative energy sources. Geothermal energy is a new type of energy buried below the surface for human exploitation and utilization. It has the characteristics of wide distribution, stable energy supply and large reserves, and is a high-quality alternative energy under the goal of energy conservation and emission reduction. Compared with carbon-based energy sources such as coal and oil, geothermal energy does not produce greenhouse gases and has a small impact on the environment when mined in the right way. Due to the different types of energy storage resources in different regions, geothermal development directions are different. For example, geothermal resources in China are mainly medium and low temperature geothermal, and the main utilization forms are shallow geothermal and hydrothermal geothermal, which leads to the maturity of the application system of medium and low temperature geothermal. In 2019, the total installed heat capacity of the world's geothermal direct utilization was 107,727 MWt. Among them, 49,079 MWt in Asia and 14,160 MWt in China. The level of science and technology, economic development, the demand for energy is not the same, many countries have not realized the impact of the non-renewable carbon-based energy on human beings after a hundred years, geothermal from discovery to use is a long process, advance preparation is conducive to smooth through the energy transition, has a positive effect on the development of the whole country. The utilization of geothermal energy is also facing many challenges. How to use it efficiently, green and safely is the focus of attention of many scholars. Due to different factors such as heat storage type, geological environment and scientific and technological level in different regions, the working conditions of each geothermal project are unique. The application conditions and methods of various geothermal resources have a far-reaching impact on the sustainable development of geothermal and the maximization of benefits.

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This paper makes a systematic review of geothermal energy, mainly expounds the classification of geothermal resources and mainstream application methods, and analyzes the potential problems in the future development of geothermal energy and gives corresponding solutions.

2. Geothermal Energy Classification

Geothermal resources can be divided into shallow geothermal energy, steam geothermal energy, hydrothermal geothermal energy and hot dry rock geothermal energy according to the different energy storage medium. According to the temperature of the energy storage area, it can be divided into low-temperature geothermal and medium-high temperature geothermal, as shown in Table 1. Different types of geothermal resources have differences in reserves, exploitation difficulties, input costs and application breadth.

Table 1: Classification of geothermal resources.

Type	Distribution depth	Energy storage medium	Approaches to application
Shallow geothermal	<200m	Soil or groundwater	Heating and watering
Steam geothermal	200m~3km	Underground steam	Steam electric power
Hydrothermal geothermal	2~3km	Underground water	Heating and power generation
Hot dry rock geothermal	>3km	Low permeability granite	Power generation

2.1. Shallow Geothermal Energy

Shallow geothermal energy is mainly distributed in the earth's shallow 200m soil and groundwater contained in low temperature heat, reserves are extremely rich, the energy storage area temperature is often lower than 25 °C, can play a dual role in heating and cooling. Solar radiation heat transfer is the main source of its energy, and the global annual use of shallow geothermal energy is about 1.02×106 TJ, equivalent to the use of 64.4 million tons of oil [1]. This kind of geothermal energy use technology is not difficult, low risk, more suitable for countries where technology is still developing, but need to consider the early investment costs and later maintenance costs. In areas with perennial cold and low winter temperatures, this medium and low temperature energy can not only meet the demand for building heating, but also achieve the purpose of emission reduction. For example, since the establishment of mature shallow geothermal application systems in Beijing, Tianjin, Shenyang and other cities in China, CO_2 emissions have been reduced by 19.87×106 t [2]. The use of shallow geothermal in the world in 2014 was equivalent to a reduction of 149.1 billion tonnes of CO_2 emissions [3]. Such geothermal energy plays an increasingly important role in the increasing demand for heating area, and has the advantages of environmental protection, stability and high cost performance compared with coal and other heating methods.

2.2. Steam Geothermal Energy

Steam geothermal energy is a kind of high-quality high-temperature geothermal energy, its temperature is generally higher than 240 °C, the energy storage medium is high-temperature steam, the total proved resources only account for 0.5% of the total geothermal resources, the earth's internal molten magma and radioactive substances are its main energy sources. The composition of the energy storage medium in different regions is also different, and the proportion of water in the steam and whether it contains impurities are all problems that should be paid attention to before the utilization of such geothermal resources. First of all, the impurities contained in the steam will affect the use of geothermal forms, impurities need to be used in the use of a separator to remove impurities, and then through the pipeline to send steam into the turbine for power generation. When there is too much water in the steam, calcium and magnesium ions in the water are easy to form scales such as $CaCO_3$, $MgCO_3$ and $Ca(OH)_2$ at high temperature. These scales are adsorbed in the turbine, which is difficult to clean and reduces the service life of the steam geothermal system. Therefore, dehumidification should be carried out before being transported to the turbine [4]. Under reasonable mining methods, steam geothermal resources generally do not produce tail water during utilization, and the harm to the environment is very small, but the application of such geothermal resources in the world is still in the initial stage, and there are few application cases.

2.3. Hydrothermal Geothermal Energy

Hydrothermal geothermal energy storage medium for underground water and vapour, storage temperature range is relatively wide, mainly low temperature resources, high temperature as a supplement, shallow low temperature geothermal energy part also belongs to this kind of geothermal energy. Its mining potential and energy supply capacity are huge, and modern mining technology has matured, forming a commercial model. Taking China, the world's largest developing country, the total amount of hydrothermal geothermal resources is equivalent to 1.25 trillion tons of standard coal, and the annual recoverable amount is equivalent to 1.9 billion tons of standard coal, which is equivalent to 44% of China's national energy consumption in 2015 [5]. Hydrothermal geothermal resources are the main geothermal energy currently exploited and utilized in the world [6]. Medium and low warm water thermal resources are widely used in building heating, medical care and agricultural planting, and high-temperature resources are mainly used in industrial power generation, which fully improves the utilization efficiency of high-temperature hydrothermal geothermal.

2.4. Hot Dry Rock Geothermal

Hot dry rock geothermal energy is distributed 3~10 km below the surface, and the energy storage temperature is generally higher than 180 °C, which belongs to high temperature geothermal resources. Its energy storage medium is mainly low-permeability granite, and it does not contain or contain a small amount of groundwater. Granite is a crystalline rock, also called igneous rock, which is the main component of the Earth's crust. The cooled magma in the crust is the main body of granite, which contains quartz, feldspar and mica, and also contains U, Th, K and other radioactive elements [7], and the heat generated by the decay of these elements is also part of the heat source of hot dry rock [8]. Different from other types of rocks, the unit volume heat production rate of granite is the highest among all common rocks. The unit volume heat production rate of gneiss and schist is 2.4 $\mu W/m^3$ and 1.5 $\mu W/m^3$ respectively, while that of granite is 4.2~6.6 $\mu W/m^3$, which is significantly higher than that of other rocks. This is also one of the reasons why granite can be used as hot dry rock type geothermal energy storage rock [9]. With the current level of geothermal mining technology in the world, hot dry rock geothermal is the most promising new energy source for high-power power supply among all geothermal resources, and the world's proven reserves are about 5136 trillion tons of standard coal.

3. Geothermal Application Method

Different types of geothermal resources are suitable for different application methods, in the case of technology and economy, the selection of the most appropriate mining methods can avoid the waste of resources. There are two ways to use geothermal energy, one is to extract geothermal fluid or use heat exchange working medium to directly extract heat energy, mainly for heating. The other is the use of geothermal evaporation working medium into the turbine to generate electricity, the conversion of heat energy into electricity, has a very wide range of application ways. In order to reduce the proportion of carbon-based energy use, the parallel use of carbon-based energy, wind energy and solar energy has also become a new way of geothermal application.

3.1. Direct Utilization Method

For shallow low-temperature Geothermal energy resources, such as the above shallow geothermal resources and low-temperature hydrothermal geothermal resources, direct utilization of heat energy can be adopted. Geothermal heat pumps are mainly used for heat exchange, and the solar radiation stored in shallow geothermal energy can be replaced by low-temperature heat exchange working medium [10]. Or use a small amount of electricity to convert this low-grade energy into a high-grade heating source [11]. No matter how the surface temperature changes, the underground temperature changes very little, so this geothermal mining method can achieve uninterrupted mining without considering the thermal breakthrough [12]. This application method started relatively late and has only a hundred years of history. In 1912, Swiss scientists proposed the concept of heat pump extraction, and in 1946, the first shallow heat pump system was born in the United States. Since then, the world's ground source heat pump technology began to develop rapidly [13]. However, China's ground source heat pump system only

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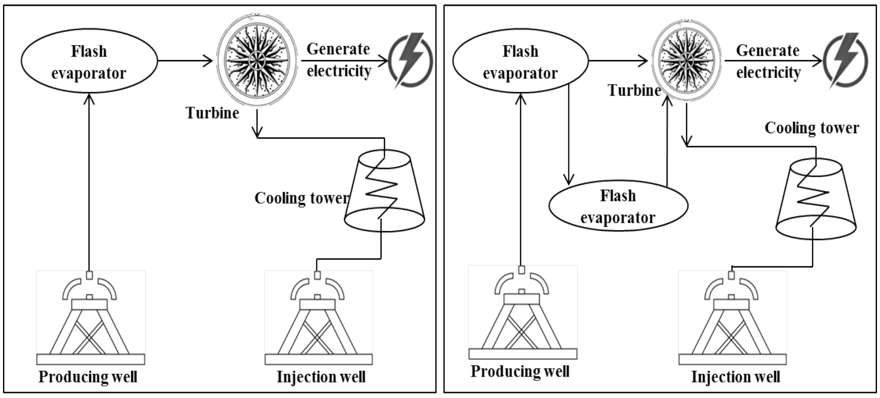
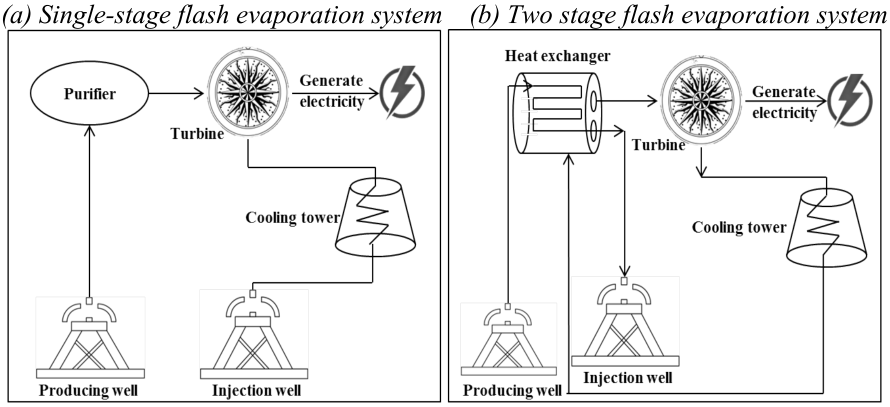
conducted pilot research in the early 21st century [14], and then promoted it to the whole country. In 2017, the heating (cooling) area reached 500 million m^2, ranking first in the world and making rapid progress. According to different heat source types, ground source heat pumps can be divided into soil type and hydrothermal type, which occupy 63% and 37% of the source heat pumps respectively [15]. Ground source heat pump can act as both heat source and cold source according to different seasons and places of use [16]. For example, in the cold areas of northern China, the advantage of soil-type ground source heat pump is that it provides heating in winter and obtains less heat in summer. Coupled with the problem of soil heat imbalance, additional supplementary heat treatment is required, which can effectively extend the service life of the system [17].

3.2. Heat to Electricity Utilization Method

For high temperature geothermal resources, whether hydrothermal or hot dry rock, it is the most efficient to convert thermal energy into electric energy for storage and utilization. The conversion system mainly includes flash evaporation power generation system, dry steam system and working medium system. The specific working process is shown in Figure 1.



(a) Single-stage flash evaporation system (b) Two stage flash evaporation system



(c) Dry steam system (d) Working medium system

Figure 1: Schematic diagram of working principle of geothermal power generation system.

3.2.1. Single-stage Flash Evaporation System

Flash evaporation electric system is divided into single-stage flash evaporation electric system and two-stage flash evaporation electric system. Single-stage flash is the extraction of high pressure and high temperature geothermal water for pressure reduction treatment, the boiling point of geothermal water will be reduced with the reduction of pressure, and then converted into high temperature steam through the turbine to do work, the specific working principle is shown in Figure 1 (a). On the basis of single-stage flash evaporation, the geothermal water after work is reduced pressure flash again, and secondary power generation is carried out by steam turbine. The thermal efficiency of second-stage flash evaporation can reach 25%, which is more efficient than single-stage flash evaporation [4]. The specific working principle is shown in Figure 1 (b). The advantages of the flash evaporation electric system are simple structure and easy to implement, but the disadvantages are low geothermal utilization efficiency, high concentration of halogen elements in the tail water after power generation, and serious scaling of turbine blades.

3.2.2. Dry Steam System

Dry steam power generation system is the use of dry steam to drive steam turbine work, of which "dry steam" refers to the complete gasification of geothermal water, which contains some impurities, need to use a purifier to separate solid particles from gaseous water before use, the specific working principle is shown in Figure 1 (c). Compared with the flash evaporation system, the power generation system has less impact on the environment, does not produce brine, and the turbine failure rate is low, but the number of high-quality dry steam geothermal fields in China is small, and the United States, Japan and other countries are the main users of the system.

3.2.3. Working Medium System

The working medium power generation system uses the heat exchange working medium to indirectly extract geothermal energy without direct contact with geothermal water. According to the different types of heat exchange, it can be divided into Kalina power generation system and organic Rankine cycle (ORC) power generation system. The heat transfer working medium of Kalina power generation system adopts ammonia mixture, which is a dynamic working medium, and its boiling point is related to the concentration of ammonia water. At the initial stage of heat transfer, the temperature of ammonia mixture is low and the boiling point is high. With the progress of heat transfer, the temperature of ammonia mixture rises, and the evaporated ammonia gas enters the turbine through the pipeline to drive the blades to rotate and generate electricity. As the ammonia gas continues to evaporate, the concentration of the ammonia mixture decreases, and the boiling point decreases. Although the temperature of geothermal water in the pipeline is also reduced after heat transfer, ammonia gas can still continue to evaporate into the steam turbine to do work. The heat transfer working medium of ORC power generation system uses organic compounds, and the power generation process is similar to that of Kalina power generation system. The system heats low-boiling organic working medium. Then, organic steam enters to drive the blade to do work and generate power. The specific working principle of the working medium power generation system is shown in Figure 1 (d).

3.3. Coupling Application Method

The coupled application method usually inputs one or more energy sources to produce multiple energy outputs, and its purpose is to further enhance the utilization value of geothermal energy and reduce the cost of energy production. At the same time, the use of certain coupled systems can also reduce environmental impact and enhance the sustainability of energy use.

The duration of geothermal energy storage area in heat transfer state is limited. Current studies have shown that excessive input flow of heat exchange working medium and low injection temperature are not conducive to thermal recovery of energy storage area and shorten the service life of the system [18-19]. In order to ensure the long-term operation of the geothermal system and maintain the geothermal grade does not decline, it is necessary to carry out intermittent heat recovery, leave a certain recovery time for the energy storage area, or use artificial heat recharge to speed up its heat recovery. However, in order to output power and electricity to meet building needs, other energy sources can be used in parallel with geothermal energy to generate electricity. The coupling of solar energy and geothermal energy for power generation has great advantages. In addition to photovoltaic power generation, residual thermal energy is used to heat the heat exchange working medium in the geothermal power generation system and jointly drive the turbine, which can not only reduce the cost but also increase the turbine power [20]. The geothermal heat-natural gas coupling power generation system comprehensively utilizes the underground heat energy and the cold energy of natural gas. In the process of regulating the pressure of natural gas, the pressure drop will lead to the occurrence of non-condensing gas at the port of the transportation pipe, thus hindering the transportation of natural gas. The traditional measure is to preheat the pipeline, but the geothermal residual temperature can be used to heat the natural gas pipeline in the coupled system. The cold energy rich in natural gas can be used to cool the heat exchange working medium in the geothermal power generation system [21]. In addition, the geothermal system can also work in parallel with the hydrogen production system. Compared with the single geothermal power generation system and the power purchase hydrogen production system, the coupled system can reduce the load loss and obtain better economic and environmental benefits.

3.4. New Model of Multistage Utilization of Geothermal Energy

According to different geothermal types, a single application method cannot achieve efficient utilization, and the use of different systems in series can greatly improve energy utilization efficiency

[22]. Based on this background, the author proposes a new geothermal application model. After the high-temperature geothermal fluid is produced, the heat energy is converted into electricity by a flash evaporation system, and then the depressurized and cooled geothermal fluid is sent to the organic Rankine circulation system for power generation. Finally, the low-temperature fluid is transported to the building groups through the pipeline network for heating or other ways. This new model of multistage utilization of geothermal energy is shown in Figure 2.

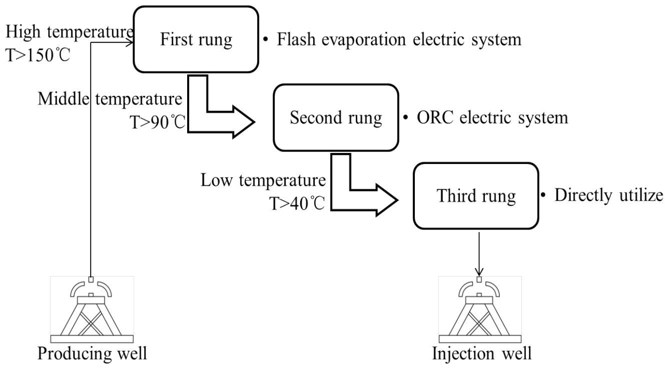


Figure 2: Schematic diagram of geothermal multistage utilization model.

4. Potential Problems and Solutions

4.1. Policies

The proportion of energy utilization, the rate of technological development and the number of companies involved are all closely related to a country's energy policy. Led by developed countries, various geothermal energy development and utilization policies have been formulated in order to develop geothermal energy more rationally. In the United States, in addition to national energy policies, states have enacted 24 state-level acts related to geothermal resource development [23]. The European Union has established a geothermal law specifically for member states, including Austria, France and Italy. In addition, other countries with geothermal development potential, such as China, are working to develop supportive policies related to geothermal heating and ground source heat pumps. Although countries are increasing the development of geothermal energy and efforts to formulate relevant policies, there is no universal set of international standards for the use of geothermal energy technology.

4.2. Technological Difficulty

Geothermal fluids need to go through two processes of injection and production in geothermal systems, and injection technology is very important. First of all, deep extraction and shallow injection may lead to shallow groundwater pollution and reduce the quality of used water. Secondly, tailwater recharge can also maintain the stress stability of the energy storage area and solve the pressure of tailwater discharge. But the immaturity of injection technology will bring the following problems. It is difficult to select the injection well location. Meanwhile, the injection pressure is too large, which is easy to cause surface expansion and the risk of inducing earthquakes.

4.3. Economic Benefits

Compared with other energy sources, the initial investment cost of geothermal energy development and utilization is higher and the investment recovery cycle is longer. At the same time, if the quality and reserve size of geothermal resources cannot be fully grasped before exploitation, then geothermal investment is extremely risky. Therefore, it is necessary to carry out reasonable economic analysis in each stage of geothermal development, reduce the uncertainty of geothermal development, and ensure the maximization of economic benefits of operating enterprises. Figure 3 shows the six stages of the geothermal energy development and utilization process, and to achieve the economy of geothermal energy development and utilization, the cost of each stage needs to be strictly controlled.

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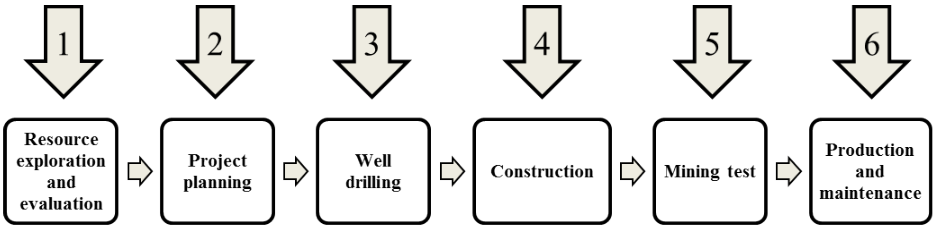

Figure 3: Whole process of geothermal energy development.

4.4. Inadequate Preparation for Geothermal Resource Application

First, most countries in the world are unclear about their geothermal reserves, basic geothermal exploration is backward, and there is no specific government docking agency. The lag of exploration is not conducive to the formulation of geothermal exploitation planning, resulting in an increasingly prominent contradiction between supply and demand in the geothermal market, which affects the sustainable development of the geothermal industry. Second, the utilization of geothermal energy in most countries is too simple and extensive, and the method of multistage utilization is not adopted, and the tailwater is discharged at will, resulting in the decrease of water level. These methods not only cause the waste of resources, but also shorten the service life of the geothermal system, increase the pressure of urban sewage treatment, lack of advanced application model and evaluation system. Third, geothermal systems lack a fast, accurate and comprehensive monitoring network. The energy storage area temperature, pressure, water level and other data can't be timely feedback. It is not conducive to the efficient use of geothermal energy and scientific research. Fourth, geothermal exploration and mining equipment are almost all initially applied to the oil field, with the increase of mining depth, can't meet the development of geothermal industry, the existing equipment can't operate under high temperature conditions. Technical barriers such as drilling, cementing, recharge and anti-corrosion are also restricting the rapid development of geothermal. In China, for example, geothermal development and utilization will be included in junior college education only in 2021. Chengdu University of Technology is the first university to offer geothermal energy major. Up to now, only dozens of universities in China have offered geothermal related undergraduate majors. Only masters or PhDS in new energy or mining will study the application of geothermal energy. As a result, the geothermal industry lacks a workforce in all dimensions, especially in application and research and development. Increasing capital investment in universities and paying attention to talent training can maintain the vitality of geothermal industry.

4.5. Solutions

Aiming at the problems in Section 4.1, countries should fully learn from the exploitation experience of other countries and establish standards for the use of geothermal exploitation technology in combination with their own geothermal resources.

Aiming at the problems in Section 4.2, it is an effective way to solve this problem as soon as possible to set up an injection technology research and development project and make use of the strength of university research teams.

Aiming at the problems in Section 4.3, relevant technical personnel of enterprises need to undergo professional training, and the establishment of special regulatory agencies by the government can effectively control costs.

Aiming at the problems in Section 4.4, a special exploration team should be set up, a reasonable application plan should be prepared, a visual monitoring system should be built, and attention should be paid to the cultivation of geothermal professionals, encouraging universities to add geothermal majors and providing financial support.

5. Conclusions and Prospect

(1) Shallow and hydrothermal geothermal energy are the pivotal resources that can be used at present, and vigorously develop ground source heat pump technology to reduce the proportion of carbon-based energy. The hot dry rock geothermal resources are rich in reserves, which can be used as the main energy supply in the future by exploration and design in advance and optimization of mining

methods.

(2) Geothermal application system should not be limited to single use, for different temperatures of geothermal resources, can be used in the way of multi-stage utilization. For example, the high-temperature geothermal fluid first carries out flash evaporation electricity, cools down and then passes into the working medium power generation system, and finally provides heating for buildings.

(3) As a non-carbon-based energy source, geothermal energy occupies an important position in the future energy structure. The national policy should be tilted toward the industry, encourage the scientific utilization of geothermal energy, increase the investment in scientific research of universities, promote cooperation between schools and enterprises. Let scientific research results be put into the field.

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