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DEVELOPMENT OF GEOTHERMAL TECHNOLOGIES BETWEEN 1980 AND 2002 IN NEDO, JAPAN

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ABSTRACT

The program on R&D projects for geothermal development technologies was launched to secure geothermal energy as one of oil-alternative energies by NEDO in 1980 just after the second oil crisis. Under the program, various kinds of technologies such as exploration, drilling, well test and utilization of geothermal water were studied.

In the field of drilling and production technologies, heat-resistant durable bits in addition to effective drilling mud and cement slurry in high temperature circumstances were developed. PTSD detectors and fluids sampling devices were improved to adapt those instruments under high temperature circumstances at least below 400 °C. MWD (Measurement While Drilling) system was developed aiming at improving drilling efficiency and monitoring accuracy of well bottom information in real time. Basic studies on Hot Dry Rock power generation system (HDR) have been conducted for 18 years in the Hijiori experimental geothermal field, in the northern part of Japan. In the field test, as the final stage of the R&D on HDR, a 100 kW binary generation was successfully accomplished for 58 days with circulating water into the borehole during power generating. A Down Hole Pump (DHP), which was expected as a key technology for promoting a large-scale binary power plant in Japan in severe conditions with high temperature and high pressure, was experimentally developed as one of the R&D projects.

The projects have been conducted basically according to anticipated needs of geothermal resource developers in Japan, and the results were applied to each stage of resource development aiming at contributing to increase generation capacity in future. However, all R&D projects will be terminated at the end of this fiscal year (March 2003) due to change in policy based on its result evaluations taking fruitions of other new energy R&D projects into account. From the viewpoint of global environmental issues and long-term energy security, R&D projects on geothermal energy are expected to be resumed in the very near future.

1.0 INTRODUCTION

In 1974, after the steep rise of oil prices in 1973, the Sunshine Program Headquarter Office in MITI (Ministry of International Trade and Industry) was established to promote the research and development of technologies for renewable energies such as solar, wind, and geothermal energies. The R&D programs were at first conducted by the Sunshine Office, and later taken over by NEDO (New Energy Development Organization; reorganized as New Energy and Industrial Technology Development Organization in 1988) after its establishment in 1980 under the supervision of the Sunshine Office (the New Sunshine Program Headquarter Office since 1994). The budget for each program was transferred to the research enterprises by NEDO, aiming to increase the output of electricity generation. The R&D projects under the programs were launched to develop not only survey, drilling and collection technologies for conventional geothermal power plants but also those for unused resources. NEDO's programs have supported geothermal development directly or indirectly, and numerous geothermal technical engineers have been trained through these programs. It is no doubt that they have contributed greatly to increasing electrical power output and stabilizing the electrical output of geothermal power plants at present and in the future.

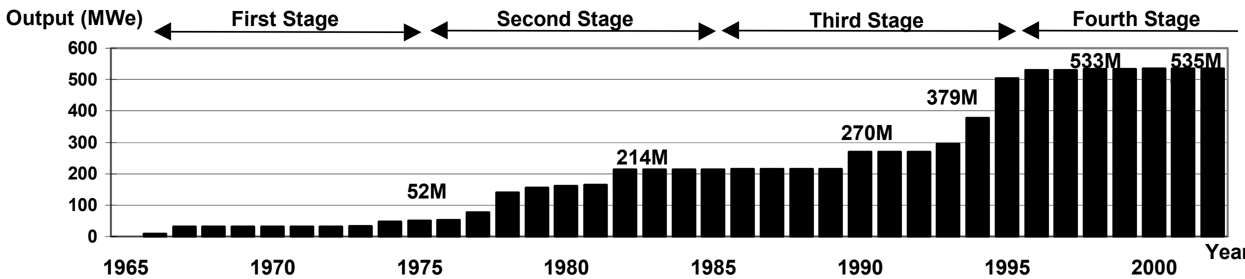

Figure 1. Total authorized rated output in Japan.

Figure 1 shows the installed capacity of the geothermal power plants in Japan. The installed capacity increased from 1988 to 1998, but no additional capacity has been added for the last five years though the total installed geothermal generation capacity in Japan was 535 MWe, ranked sixth in the world (Japan Geothermal Energy Association, 2001). The stagnation of the geothermal power generation is recognized as one of the obstacles for continued support of the geothermal R&D by the government.

In 2001, the central government was reformed and MITI was reorganized into METI (Ministry of Economy, Trade and Industry). METI decided to terminate NEDO's Geothermal R&D programs at the end of fiscal year 2002. The decision was partly because of the difficulty in increasing the number of geothermal power plants in Japan and because of the diminution of the significance of geothermal technology development. This paper reviews the R&D programs for the geothermal energy in NEDO and describes the major results of the projects. NEDO's projects for geothermal development technologies are shown in Table 1.

2.0 OUTLINE OF NEDO’S R&D PROJECTS FOR GEOTHERMAL TECHNOLOGIES

2.1 R&D Projects on Surveys and Exploration Technologies

Sengan – Kurikoma Regional Survey (FY 1980 – 1988)

To study basic geothermal exploration technologies including resource assessment and the necessity to develop new exploration techniques, regional surveys were carried out in the Sengan and the Kurikoma geothermal areas called as the Known Geothermal Resource Areas (KGRA) in Japan. Various kinds of exploration methods were experimentally applied and exploratory wells were drilled based on the results of those newly applied techniques. Through this project, a standard geothermal exploration methodology was proposed.

Development of Sophisticated MT Equipment (FY 1984 – 1988)

To meet the requirement to obtain high-resolution data in noisy area like in Japan, MT equipment and measurement system were developed by introducing the idea of MT remote reference technique. A portable and real time multiple point measurement system was developed. After the system was applied in KGRA to verify its effectiveness, MT survey was taken in the standard geothermal methodologies, especially to “Geothermal Development Promotion Survey (GDPS)” by NEDO.

Fracture-Type Geothermal Reservoir Exploration Study (FY 1988 – 1996)

The development of exploration technologies to delineate fracture distribution related to geothermal resource was carried out. For its delineation, seismic, electromagnetic and micro earthquake techniques were studied to obtain high-resolution data to analyze detailed subsurface structure. In relation with the project, Vertical Seismic Profiling (VSP) method and Seismic tomography method are applied to geothermal fields. "Array-CSMT system" and "Micro-Earthquake data Processing and Analysis System (MEAPAS)" were likewise developed.

Table 1. NEDO's geothermal technologies R&D projects.

● Surveys and Exploration Technologies	
Sengan-Kurikoma Regional Surveys	FY 1980 - 1988
Development of Sophisticated MT Equipment	FY 1984 - 1988
Fracture-type Geothermal Reservoir Explanation Study	FY 1988 - 1996
Deep-Seated Geothermal Resource Survey	FY 1992 - 2000
Development of Technology for Reservoir Mass and Heat Flow Characterization	FY 1997 - 2002
● Drilling and Production Technologies	
Countermeasures against Lost Circulation in Geothermal Well Drilling	FY 1986 - 1990
Research on Hydrological Mechanism Change Caused by Reinjection of Geothermal Brine	FY 1982 - 1989
Study on Optimum Production Technology of Geothermal Fluids	FY 1985 - 1988
Technologies to Increase Recovery Rate of Thermal Energy from Geothermal Brine	FY 1989 - 1994
Development of MWD (Measurement While Drilling) System	FY 1991 - 2001
Development of Drilling and Production Technology for Deep-seated Geothermal Resources	FY 1992 - 2001
● Hot Water Utilization Technologies	
Development of Total Flow Power Plant (Two-phase Flow Rotary Expander)	FY 1980 - 1982
Development of Basic Techniques for Binary Cycle Power Plants	FY 1980 - 1986
Reinjection Technology of Low-Temperature Geothermal Water	FY 1981 - 1986
Technologies for Preventing Deposition of Calcite Carbonate Scale	FY 1984 - 1985
Hydrogen Sulfide Removal Technology	FY 1980 - 1985
Development of a Downhole Pump	FY 1983 - 1992
10MWe Class Experimental Binary Cycle Power Plant	FY 1985 - 1988
● Hot Dry Rock Power Generation	
Hot Dry Rock Power Generation System	FY 1985 - 2002
● Non-Volcanic Geothermal Water	
Study on Deep Geothermal Water Supply System by Exploitation of Non-volcanic Geothermal Formations	FY 1980 - 1985

Deep-Seated Geothermal Resource Survey (FY 1992 – 2000)

To clarify the conditions of deep geothermal reservoir, an exploratory well of 4000 m deep, WD-1, was drilled in the Kakkonda KGRA in the northern part of Japan. Various geoscientific studies were carried out to select the drilling target for WD-1, and the characteristics of deep geothermal fluids were studied including its potential utilization for power generation. The highest recovered temperature was measured to be about 500^{o}C at the bottom using temperature-melting tablets composed of metal-based compounds. It is probably the highest recorded temperature in geothermal wells in the world. A drilling technology called “Top-Drive Drilling System” was adopted with a technology of drilling mud cooling system, and this combined system was verified to be efficient for deep drilling in very high temperature formation. Followed by this project, the technology was applied at the Unzen Volcano Research Project in drilling a deep exploratory well near the crater. A methodology from surface exploration to the assessment of deep-seated geothermal resource experimented in the project was expected to be effective also when applied to other geothermal fields.

Development of Technology for Reservoir Mass and Heat Flow Characterization (FY 1997 – 2002)

The project objectives are to develop technologies that can contribute to the stabilization of power output of geothermal power stations and that can look for secondary prospective areas in the vicinity of power stations based on the results. The project consisted of two phases. In the 1st phase from FY1997 to FY2001, the fundamentals of geoscientific technologies were studied and discussed. In the 2nd phase in FY2002 which was originally planned for FY2002 to FY2004 but terminated because of the reason mentioned previously, the technologies were practically applied to several KGRA in Japan to verify the applicability for the project objectives.

The studied technologies for the project are mainly divided into three categories as follows: (1) Selection of optimum reservoir monitoring technologies including gravity, electrical, electromagnetic, and seismic methods; (2) Development of highly sophisticated reservoir modeling and numerical simulation software; and (3) Improvement of reservoir modeling software with functional capabilities by adding hydrologic, geological and geochemical factors. The changes of Microgravity, SP, and resistivity by means of MT, and AE distribution were selected and studied as the most optimum reservoir monitoring technologies. The reservoir simulator (Pritchett, 1995) on the basis of UNIX-based STAR was reprocessed to the software of PC platform type. In parallel, several postprocessors were developed, which translate numerical simulation results into surficial geophysical and geochemical survey functions such as changes of microgravity, SP, resistivity, and discharged chemical components. For improvement of reservoir models, a pressure transient test system programmed by computer was developed to supply accurate hydrological properties related to geothermal reservoirs, and modeling software was also developed to supply geological data into the model.

The integrated results composed of description of case studies in several KGRA with technical guidance are scheduled to be transferred from NEDO to AIST and private sectors with the expectation that the research and development of this project will be continued and enhanced.

2.2 R&D Projects on Drilling and Production Technologies

Countermeasures against Lost Circulation in Geothermal Well Drilling (FY 1986 – 1990)

Circulation losses except in production zones are desired to be avoided because the cost for countermeasures to shut off the phenomena seriously affects the total drilling cost. If the cost for lost circulation countermeasures can be reduced by some effective means, it will largely contribute to the reduction of construction cost and power generation cost. To meet this purpose, detection for the technologies and analysis at circulation losses were studied. In parallel, countermeasures against lost circulations were studied by integrating technologies consisting of computerized mud control system and various plugging material tests.

Research on Hydrological Mechanism Change Caused by Reinjection of Geothermal Brine (FY 1982 – 1989)

Production and reinjection of geothermal brine cause changes in temperature and pressure of geothermal reservoirs. In order to maintain stable steam production for a long term, monitoring of geothermal reservoirs and optimum measures to geothermal reservoir changes are essential for stable operation of power plants. In the project, the hydrological structures for various types of geothermal reservoirs were studied by analyzing physical and chemical data related to the geothermal reservoir. In addition, several fundamental tests such as rock sample test in autoclave, brine transmission test with experimental lines, and practical injection test were carried out to study the behavior of supersaturated silicic acid in case of rapid temperature drop and the silica scaling mechanism from polymerization process of silicic acid in geothermal brine. As a result, the reduction of reinjection was defined to occur when low temperature geothermal brine is reinjected rather than brine higher than 100^{o}C.

Study on Optimum Production Technology of Geothermal Fluids (FY 1985 – 1988)

The most optimum production technologies to utilize geothermal brine effectively were studied including the Binary Cycle System.

Technologies to Increase Recovery Rate of Thermal Energy from Geothermal Brine (FY 1989 – 1994)

Hydraulic fracturing technology to increase the production rate was tested, and related fundamental technologies were studied.

Development of MWD (Measurement While Drilling) System (FY 1991 – 2001)

In case of drilling into deep formation such as igneous rocks and the Tertiary basement where temperature is very high, many obstacles associated with drilling are anticipated like large circulation loss, equipment damage, sloughing, and sticking. If directional drilling is adopted, more obstacles can be anticipated because drilling technologies became more complex rather than in vertical well drilling. To reduce those hazards, the real time monitoring on the bottom-hole information is required, and the system is called MWD. The MWD system development was launched in 1991 to measure drilling direction, inclination, tool-face, bottom temperature, bottom pressure, etc. during drilling, which allows engineers to monitor various required information to reduce risks at the surface in real time. The first prototype sonde was manufactured and improved in 1998. Several field tests were performed using the sonde and essential technologies were developed.

Development of Drilling and Production Technology for Deep-seated Geothermal Resources (FY 1992 – 2001)

If deep-seated geothermal reservoirs can be expected below existing present reservoirs, a considerable amount of geothermal energy for power generation will be extracted. However, present drilling and production technologies are required to overcome anticipated obstacles due to very high pressures and temperatures in deeper formation.

The project was divided into two categories: one is the development of drilling technology in deeper formation and the other is the development of production technology in very high temperature circumstances. In the former category, heat-resistant durable bit, effective drilling mud and cement slurry, and a downhole motor were developed. In the latter category, technologies of PTSD logging, PTC monitoring, tracer monitoring, scale monitoring, and production management were adopted and improved. In the course of the project, geophysical, geochemical, reservoir dynamic condition monitoring technologies, and anti-scale measures were also studied.

2.3 R&D Projects on Hot Water Utilization Technologies

Development of Total Flow Power Plant (Two-phase Flow Rotary Expander) (FY 1980 – 1982)

In order to promote effective utilization of two-phase flow geothermal fluids, a two-phase flow rotary expander, which can generate electricity using both steam and hot water, was studied. The fundamental studies regarding elementary technologies such as internal seal, steam feeding design, and the expansion rate due to two-phase flow were implemented. A 300 kW-class two-phase flow rotary expander was fabricated and tested, and the results were analyzed for future commercial use.

Reinjection Technology of Low-Temperature Geothermal Water (FY 1981 – 1986)

When hot water is reinjected after being used in a binary cycle power generation, silica scale occurs and clogs in the formation, resulting in the deterioration of reinjection capacity of wells. The objective of the project was to analyze the process of reinjection well deterioration induced by reinjecting low-temperature geothermal water and to obtain optimum reinjecting conditions among factors of pH, silica concentration and reinjecting temperature.

Technologies for Preventing Deposition of Calcium Carbonate Scale (FY 1984 – 1985)

A new type of caliper to measure the hole-size and an experimental apparatus which can observe the changes of scale deposits with factors of temperature and pressure were designed and fabricated. In addition, scale inhibitors were tested to analyze the mechanism of scale deposition inhibition. Physical and chemical properties of producing steam and hot water were analyzed, and the relationship between these properties and scale deposition was studied.

Hydrogen Sulfide Removal Technology (FY 1980 – 1985)

The objective of the project was to develop equipment to reduce hydrogen sulfide emissions from power plants.

Development of Downhole Pump (FY 1983 – 1992)

A submersible type downhole pump (DHP) to lift up the fluids from subsurface to the wellhead was expected as an essential technology, especially in the operation of binary cycle power plants. The first experimental pump was manufactured in 1985 and some field tests were carried out in 1986 to confirm its availability to binary power cycle plant. As for the second experimental pump, the pumping rate and heat-resistance were improved. The required pump rate for the operation of a 10 MWe binary plant was achieved when the improvement of the third pump was completed. Two motors in tandem were adopted and they were successfully operated for about 1,000 hours at the temperature of 200^{o}C.

10 MWe Class Experimental Binary Cycle Power Plant (FY 1985 – 2000)

In order to utilize geothermal fluids of moderate temperature ranging from 150-200^{o}C, an experimental binary cycle power plant using a downhole pump had been tested in Sugawara KGRA in Kyushu.

2.4 R&D Projects on Hot Dry Rock Power Generation

Hot Dry Rock Power Generation System (FY 1985 – 2002)

The objectives of R&D on the hot dry rock (HDR) project at Hijiori in the northern part of Japan are to establish technologies of drilling, well logging, hydraulic fracturing, fracture mapping, reservoir assessment, and power generation. Fundamental technologies were developed in the project and some of them were transferred to the conventional geothermal power generation.

The project was categorized into two phases. The first phase was to create artificial reservoirs at the depth of 1800 m and circulation test was conducted three times. The recovery rate and the extracted heat were measured to confirm the effectiveness of HDR. The second phase was aimed at creating larger fractures and higher temperature reservoir at the depth around 2200 m by hydraulic fracturing. Beginning at the end of November 2000, a long-term circulation test was conducted to evaluate the feasibility of HDR power generation project. In June 2002, a power generation test with a 100 kW binary cycle plant was conducted for 58 days. The results of these tests were reported by Kawasaki et al. (2002).

2.5 Study on Non-Volcanic Geothermal Water

Study on Deep Geothermal Water Supply System by Exploitation of Non-Volcanic Geothermal Formation (FY 1980 – 1985)

The non-volcanic geothermal waters seated in deep alluvium formation have not been developed yet. The system for district heating to urban areas by utilizing these waters will be useful for energy saving.

3.0 R&D PROGRAMS FOR GEOTHERMAL TECHNOLOGY IN NEDO AND GEOTHERMAL DEVELOPMENT TECHNOLOGY HISTORY IN JAPAN

3.1 The First Stage; Mid-1960s to Mid-1970s

The first geothermal power generation (9.5 MWe) with a vapor-dominated geothermal reservoir was started in the Matsukawa geothermal field, and the second (11 MWe) with a water-dominated reservoir was started in the Otake geothermal field. Technologies to assess geothermal resource potential were not established yet and many issues to be solved technically remained. The total installed capacity in 1975 was 51.5 MWe.

3.2 The Second Stage; Mid-1970s to Mid-1980s

Geothermal developers aimed to construct large-scale power plants of 50 MWe as a standard, such as Hatchobaru (1st unit), Kakkonda (1st unit), and Mori, based on their own technical experiences attained during the preceding stage. After the second oil crisis, MITI founded NEDO in 1980 and launched the national geothermal resource development projects called "Geothermal Development Promotion Survey (GDPS)". In parallel with GDPS, R&D projects were also started such as "10 MWe Binary Cycle Power Generation Plant" and "Hot Dry Rock Power Generation Plant". To promote GDPS projects, the results of R&D projects were required to be utilized, and GDPS and R&D projects were closely connected with each other. Total installed capacity in 1985 reached 213.7 MWe.

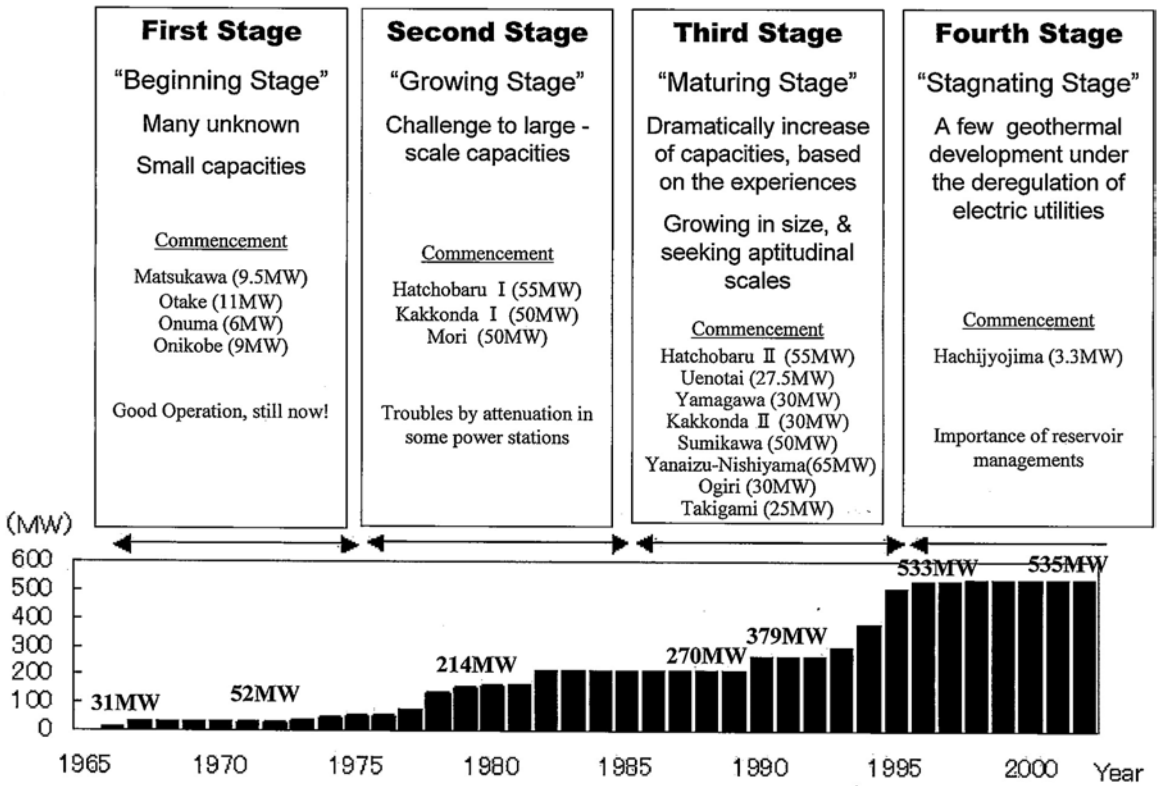

Figure 2. History of geothermal development in Japan.

3.3 The Third Stage; Mid-1980s to Mid-1990s

The 20 to 30 MWe scale power plants were constructed instead of constructing 50 MWe power plants because there were many issues associated with developing large scale plants. Sophisticated technologies such as delineation of reservoir extent, drilling techniques to reach the target accurately and integrated reservoir assessment were required. To monitor accurate drilling track, the "MWD system development" project was launched by introducing existing MWD system used in petroleum fields in which the reservoir temperature is not as high as that of geothermal. The project objective is to improve the existing system which can be used even in high temperature conditions. In addition to this project, the "R&D on Deep-seated geothermal" project was conducted to establish technologies related to greater depth drilling and fluids production.

In 1996, the output of installed geothermal power plants reached 530 MWe. The third stage was regarded as the matured period of geothermal development in Japan.

3.4 The Fourth Stage; Mid-1990s to the Present

In some geothermal power plants, due to production rate reduction of steam and hot water, the power outputs have not been generated up to the designed outputs. Technologies to monitor and maintain the reservoirs were required to recover the outputs and to look for subsequent exploitable zones where steam and hot water are still abundant. To meet these requirements, NEDO launched the project titled "Development of Technology for Reservoir Mass and Heat Flow Characterization" in 1997, to contribute to the stabilization of power plant operation by providing useful technologies such as optimum reservoir monitoring, reservoir assessment based on a model integrated by hydrological, geological and geochemical information, and numerical simulation.

After the total installed capacity of geothermal plants became 530 MWe, the geothermal resource development has stagnated. The only two small additional geothermal power plants are Hachijo-jima (3.3 MWe) in 1999 and Kokonoe Hotel (2 MWe) in 2000. The geothermal development plan in Oguni (20 MWe) was suspended due to objections of local habitants.

Because the states of electricity market and related regulations have changed since the beginning of 1990s in Japan like other countries in the world, even in geothermal power, the generating cost has been required to compete with that of other conventional cheap power sources. In addition, geothermal energy categorized as “Renewable Energy” is not included in the group of “New Energy” in Japan, which means that the geothermal energy would not be secured unlike other new energies. Then, future geothermal power plants are not any longer attractive as one of power resources in Japan; or rather it may become uncompetitive energy resource without any incentives. In these circumstances, the R&D budget for geothermal energy development will be suspended by the government from FY2003 and the geothermal energy development in Japan will be in the grip of the most severe situations since it started in 1960s.

4.0 CONCLUDING REMARKS

The research and development of technologies for geothermal energy was initiated in 1974 just after the second oil crisis in 1973. The Japanese government wished to establish energy independence to be less dependent upon imported fossil fuels by means of increasing the share of renewable and oil-alternative energies. The total current generation output by geothermal energy is 535 MWe. The development of the latter part of 535 MWe has been achieved through the support of the government together with the efforts of private geothermal developing companies. More than a quarter century has passed since the Sunshine Project was started, and the present energy supply conditions in the world are quite different from that as anticipated in 1974. Deregulation of electric utilities has been implemented to lower the market price of electricity.

Geothermal energy is considered to be costly compared with other energies of fossil fuel origins. Because of these economical and social disadvantages in Japan at present, the geothermal companies are reluctant to launch next geothermal power development. As far as no increase of geothermal power is expected, no financial support will be provided by the government especially for R&D projects. A new RPS in Japan becomes effective next FY2003, and Japan will start to develop new energies together with renewable energies to meet obligations for CO_2 reduction based on the Kyoto protocol. After some unknown difficulties and disadvantages of new energies would be realized from now on, the utilization of geothermal energy would be reviewed and maybe revived in the very near future as the sole and abundant indigenous energy still reserved in Japan, not only for power generation but also for multipurpose utilization.

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