Hitotsubashi University
Institute of Innovation Research

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Yaichi Aoshima
Tomono Miki

IIR Working Paper WP#12-11

September 2012

Institute of Innovation Research
Hitotsubashi University

Tokyo, Japan
http://www.iir.hit-u.ac.jp

Possibilities of Geothermal Power Generation in Japan: Notes from an Iceland Field Study[1]

February 27, 2012

Institute of Innovation Research, Hitotsubashi University

Yaichi Aoshima

College of Business, Rikkyo University

Tomono Miki

[1] Much of the content of this report is based on a field survey in Iceland that was conducted from June 30 through July 1, 2011. When conducting the survey we received extensive support from Mr. Kristjan Bjarnar Olafsson of Orkuveita Reykjavikur (Reykjavik Energy) and Ms. Akiko Hasegawa at the Embassy of Japan in Iceland. We would like to express our deep appreciation for their assistance.

1. Introduction: Expectations Concerning Geothermal Resources in Japan

Former Japanese Prime Minister Hatoyama's declaration at the 2009 United Nations Climate Change Conference of Japan's intention to reduce greenhouse gases (GHG) by 25% by 2020 compared with 1990 is still a fresh memory. The speech was received with thunderous applause in the hall. Domestically, however, his remarks were also subjected to various criticisms as native words that disregarded the adverse effects on Japan's economy. Most of these opinions noted that unless Japan envisages purchasing a significant number of emissions rights when emissions are actually slashed by 25% by 2020 compared with 1990, there is no specific scenario laid out to realize this goal. It was provisionally calculated that just to reach the target of an 8% reduction compared with 1990 set out under former Liberal-Democratic Party Prime Minister Aso, Japan would have to construct nine new nuclear plants and boost plant operating rates from the 60% level up to 81% (Kaneko, 2010). So when the 25% reduction goal was laid out suddenly under these circumstances, it wasn't unreasonable for the proposal to be met with critical opinions.

To make matters worse, the Great East Japan Earthquake in March 2011 resulted in the accident at the Fukushima Daiichi Nuclear Power Station, and a situation now exists where even the continued use of existing facilities, let alone the construction of new nuclear plants, is being questioned. It will also be difficult for Japan to continue its energy policy of relying on nuclear power in the future given that former Prime Minister Naoto Kan also declared that Japan would seek to be a society without nuclear plants.

Along with being a major energy policy shift, the movement to break with nuclear power generation points to an even more serious issue for environmental policy. Japan probably can cover the immediate electricity shortage resulting from the shutdown of nuclear power plants by restarting cold thermal power plants. This will cause greenhouse gas (GHG) emissions to increase, however. Japan will be unable to maintain even the status quo, let alone achieve a reduction of 25%.

Japan currently seems to be confronted with three serious issues that are mutually contradicting in terms of its "energy policy (stable energy supply)," "environmental policy (reduction of greenhouse gases)" and "economic policy (long-term economic development)." Japan must do whatever it takes, however, to solve the complex simultaneous equations involving these issues, and find a balance over the long term among all three issues.

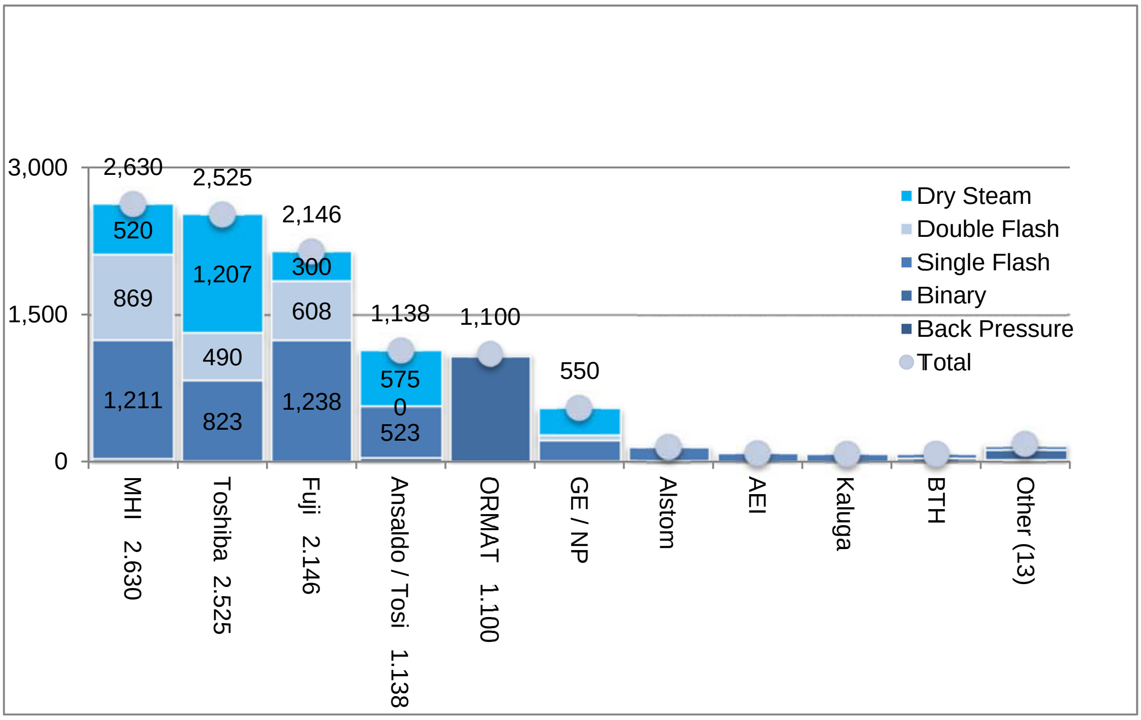
The key to that will be the early development of renewable energy. If it can cover its power supply needs using renewable energy with few CO_2 emissions, Japan might be able to solve its energy problem and environmental problem simultaneously. There remains the issue of cost, however. Under the present circumstances, the power generation costs of distributed renewable energies such as solar and wind power that have attracted so much attention are not at a level that can compete with nuclear or thermal power. According to the Economic White Paper for 2008, for photovoltaic power generation the cost per 1kWh was 46 yen, while the cost for wind power generation ranges from 10 to 14 yen. Because the per-kWh cost of coal-fired thermal power is from 5 to 6.5 yen and the cost of nuclear power is from 4.8 to 6.2 yen, from a cost standpoint there remains a significant gap[2]. Despite the fact the cost of wind power generation has declined considerably, such power is influenced by the weather and presents a problem in terms of unstable power supply. Therefore thermal power plants or some other alternative will have to be used to absorb the supply fluctuations. If electric power can be stored, that would help, but storage batteries are overly costly and their economic efficiency cannot be assured. The situation is the same with photovoltaic generation as well.

Judging from the perspectives of Japan's location advantage and power generation stability, geothermal power generation should be the one form of renewable energy that would attract the most attention. Among countries possessing geothermal resources, Japan ranks third in the world. Geothermal reserves (geothermal resources considered to be economically feasible to develop) are estimated to be 23.47 million kW (trial calculation by the National Institute of Advanced Industrial Science and Technology (AIST)). Because Japan has total electric power generation capacity of roughly 200 million kWh, of which about 60% is actually in operation, about 20% of total power generation capacity could be supplied by geothermal power if all of Japan's geothermal resources were developed for power generation. Even if that figure is unrealistic, if half of these geothermal resources were developed, it would certainly make a major contribution from the standpoint of replacing nuclear power plants. Moreover, geothermal power generation does not incur any expense for fuel, and the volume of CO_2 emissions also is extremely low.

What's more, from the standpoint of industrial policy there also exists the possibility of geothermal power generation becoming a promising market. The capacity at all geothermal power stations worldwide at the end of 2009 was 10,711MW. Although the growth of geothermal power generation slackened as a result of the global recession triggered by the collapse of Lehman Brothers, power generation capacity is predicted to expand in the future up to 18,500MW by 2015 (ABS Energy Research, 2010). Currently three Japanese companies (Mitsubishi Heavy Industries, Ltd., Fuji Electric Co., Ltd. and Toshiba Corporation) account for 7,300MW of installed generating capacity on a power generation basis, and have captured a global market share of about 70% in the turbines that are at the core of geothermal power generation facilities (see Figure 1).

[2] Although this trial calculation is not without problems, if nothing else it seems certain that under present conditions, solar and wind power remain expensive. According to a report released in August 2011 by the Institute of Energy Economics, Japan, nuclear power costs 7.2 yen/kWh and thermal power is 10.2 yen/kWh.

Figure 1: Global share of geothermal power generation turbines (Unit: MW)



Source: Reykjavik Energy materials

Because the market is small, the contribution to earnings at present is considered minor, but compared with photovoltaic generation and wind power generation it is a market sector where Japanese firms are highly competitive. As a stepping-stone toward the expansion of geothermal development in Japan, it could become a promising means of solving without contradiction the three problems of energy, environmental and economic concerns if the technology can be developed globally as an industry.

Unfortunately, however, no new geothermal power stations have been built in Japan for over ten years. The 18 geothermal power stations currently existing in Japan have a generation capacity of 535,000 kW, which corresponds to just 2% of the still untapped geothermal resources. How should geothermal resources be developed in Japan and how should the geothermal industry be developed as an environmental energy industry in the future, and how should Japanese firms use their competitiveness to create added value as part of this process?

The goal of this report is to lay out guidelines for the promotion of geothermal development in Japan by introducing the experience of Iceland, which has aggressively moved forward with geothermal development and relies on geothermal for over 60% of its primary energy and about 30% of its electric power supply.

2. Problems Confronting Geothermal Electric Power Development in Japan

Among countries possessing geothermal resources, Japan ranks third in the world after Indonesia and the United States. Geothermal resources are one of Japan's few domestic natural resources. Nevertheless, geothermal development in Japan is in a moribund state. Although construction of geothermal development and power plants was undertaken following the oil crises as Japan groped for energy alternatives to oil, and 18 facilities are currently operating, for the past ten years new construction has been halted. After geothermal energy was excluded from "new energy" in 1997, central government research and development assistance was sharply curtailed, and in 2003 R&D grants were discontinued. Why is no geothermal development being pursued in Japan? Before describing the experience of Iceland, let's first lay out the current situation in Japan.

The following three reasons are typically cited as reasons why geothermal power generation development in Japan is moribund.

(1) Lack of economic efficiency (particularly the amount of initial investment risk)
(2) Difficulty of coordination with nearby hot spring businesses
(3) Restrictions based on various regulations such as the Natural Parks Law

First is the problem of economic efficiency, a hurdle facing other renewable energy sources as well. According to the Geothermal Development Promotion Survey conducted by the New Energy and Industrial Technology Development Organization (NEDO) in 2002, geothermal power would cost 12.87 yen per 1kWh over 15 years and 11.03 yen over 30 years. Although far less expensive compared with solar power, which has attracted significantly more attention, the geothermal power generation cost varies substantially depending on location. Even in the NEDO survey, the cost had a range from 9 yen/kWh to 22 yen/kWh, which means generating stations that can undercut the cost of nuclear power and thermal power generation are limited in number.

According to estimates by the Institute of Energy Economics, Japan (IEEJ), however, new energy mainly including geothermal power generation has a cost of 8.9 yen/kWh, in contrast to 10.2 yen/kWh for thermal power and 7.2 yen/kWh for nuclear power, a result indicating that geothermal generation is less expensive than thermal power, which has been affected by the sharp jump in oil prices. From this it can be seen that although many existing geothermal power stations are aged, a situation caused by the fact capital cost recovery is advanced, these plants still ensure sufficient economic efficiency. That geothermal power generation's low economic efficiency is emphasized as an impediment to development despite this fact is believed to mainly reflect the degree of initial development risk and the investment risk.

To develop a geothermal power station, exploration surveys that take more than ten years are required. There is also the risk that geothermal resources will not be found as assumed even if the drilling of geothermal wells has in fact taken place. Because of such risk, borrowing from banks is out of the question, and projects must rely on equity financing. Even if a geothermal resource is developed, however, electric power supply has the strong nature of a public service, and unlike exploration for oil does not produce large returns. There is also the problem that the amount of capital investment has increased because of the sharp rise in prices for materials such as steel. Currently an investment outlay of nearly one million yen per 1kW is said to be required. As this indicates, geothermal development is "high risk, low-return." The difficulty of securing the capital necessary for initial development is thus a problem that constantly clouds geothermal power.

Another factor cited as a reason the development of geothermal power generation has lagged compared with other renewable energy is inadequate government support. As already noted, R&D assistance was curtailed sharply when geothermal energy was excluded from "new energy" in 1997, and in 2003 grants were discontinued. In addition, in the same year the flash steam system, which was the main technology used, was excluded from the eligible technologies under Japan's Renewable Portfolio Standard (only the binary system was eligible). In other words, even if Japanese power utilities purchased electricity generated by geothermal power stations, this would not fulfill the obligation imposed on them by the Renewable Portfolio Standard. Therefore unlike other renewable energy, geothermal electric power must compete on cost in the same arena as other alternatives such as coal-fired thermal power. Given such conditions, Japan Petroleum Exploration Co., Ltd., Japan Metals & Chemicals Co., Ltd. and DOWA Holdings, three geothermal power generation companies, had not alternative but to withdraw from the business (Adachi, 2009).

The second problem is the opposition from hot spring businesses nearby. Hot spring resorts frequently exist near locations that are suitable for geothermal power generation. Hot spring operators have strongly opposed geothermal development because of misgivings about a decline in the volume of discharge from the hot spring or disappearance of the hot spring as a result of the development of geothermal resources. The Kusatsu Hot Springs Cooperative, for example, has vigorously opposed even exploratory surveys[3]. Certainly in other countries there have also been cases where the hot springs water level has dropped and the hot spring itself has disappeared as a result of geothermal power generation development (Noda, 2009). Although such a problem has never actually occurred in Japan as of this time, the concerns of hot springs operators that have been managing their business for years isn't unreasonable, because the geothermal resources deep underground and hot springs at a shallower depth are not separated.

The third problem hindering geothermal development is regulations under the Natural Parks Law. Of Japan's 23.47 million kW of geothermal resource reserves, 19.22 million kW or 81.9% of

[3] "Geothermal Power Station to Undertake no New Construction for Over 10 Years, Coexist with Local Region by Supporting 'Eco-hot Springs'" *BPnet*, May 10, 2001

the total amount is found within national park special protection zones and national park special zones (Muraoka, 2008). Only 4.25 million kW, or 18.1% of the total, exists in zones that are not subject to national park restrictions on development. Of this, 530,000kW has already been developed. In other words, there is little hope for any significant growth in geothermal power generation as long as restrictions on development in Japan's national parks are not eased.

Incidentally, in 1972 consent was given under the names of bureau directors at both the Environment Agency and the Ministry of International Trade and Industry to limit geothermal electric power development in national parks to six locations and to not undertake any new development. In 1974, notification was given that approvals would be limited to surface surveys by the Agency of Industrial Science and Technology (AIST), and in 1994 a notification was put out under the name of a section chief of the Environment Agency to enable local governments and businesses to separately conduct studies concerning development in the ordinary zones of national parks while giving consideration to protection of the visual environment.

Following concerns about electricity shortages due to the Fukushima nuclear power plant accident, however, the Ministry of the Environment is assessing the technological progress in controlled drilling, which would involve sinking wells diagonally from outside of national parks, and has begun studying the deregulation of geothermal power generation in national parks[4].

The reasons Japan has not moved ahead with development of the vast geothermal resources at its disposal have been marshaled from the three points discussed above. Yet these circumstances apply more or less to Iceland as well. The problems concerning economic efficiency must be similar to those in Japan. For Iceland in particular, which depends entirely on foreign companies including Japanese firms for its power plant equipment, there are drawbacks as well.

Certainly the standoff with hot springs businesses might be a problem unique to Japan. In Iceland, however, for many of the pools that people use every day, all of the hot water is pumped from underground. As explained below, rather than being at odds, in Iceland power generation and hot water utilization have a supplementary relationship with each other. The problem that many of the geothermal resources are under national parks, while different in degree, also similarly exists in Iceland. And in Iceland as well, various regulations have been put on geothermal resource development from the viewpoint of environmental protection.

In contrast with Japan, however, geothermal electric power development has advanced rapidly in Iceland since the latter half of the 1990s. Geothermal power station capacity in Iceland already exceeds the capacity in Japan, and is approaching 30% of the country's entire power generation capacity. Making a simple comparison between Japan and Iceland isn't possible, given the two countries' vast differences in population and topographic features, but there might be much that

[4] "Toward Expanded Use of Geothermal Power Generation and Deregulation of Development… Government Policy," *The Yomiuri Shimbun*, October 12, 2011

Japan can learn from Iceland's experience in overcoming the issues involved in geothermal resource development.

3. History of Geothermal Development in Iceland

3.1 Iceland's geothermal resources[5]

Like Japan, Iceland is an island nation where earthquakes occur. In Japan's case, it is well-known that earthquakes occur as the result of four plates jostling one another. Two of these plates – the North American Plate and the Eurasian Plate – appear in Iceland. Iceland sits above a hot spot (the mid-Atlantic ridge), and the two plates are moving away from each other by an average of 2cm per year. This is the reason Iceland is shaken frequently by quakes.

Iceland has more than 200 active volcanoes that are strung out along the hot spot. The region where the active volcanoes exist is called a "high temperature field" because it spews out steam with a temperature of about 200°C even at a depth of 1,000 meters underground. Around the perimeter of this zone extends a broad area called a "low temperature field" where the temperature even 1,000 meters below ground is no more than 150°C. The first Europeans who immigrated to Iceland around 870 A.D. and saw this steam boiling up in various locations mistook it for "smoke." Hence they named the place where they settled "Reykjavik," meaning "Smoky Bay."

3.2 Direct use and indirect use of geothermal resources

Geothermal resource use can be broadly separated into direct use and indirect use. "Direct use" refers to water at a temperature of 90°C or less that is pumped from the earth and used directly for home indoor heating or used for commercial purposes such as hot spring spas and plant cultivation. "Indirect use," on the other hand, indicates water at medium or high temperatures from 150°C to about 350°C or steam that is pumped out from underground and used for power generation. There also are numerous so-called cogeneration systems that separate the high-temperature brine and steam taken out of the earth into steam and water, and use the former for power generation and the latter for direct applications such as heating. In Iceland, the cogeneration mode has been adopted for the three power plants at the Nesjavellir, Svartsengi and Hellisheidi power stations as described below.

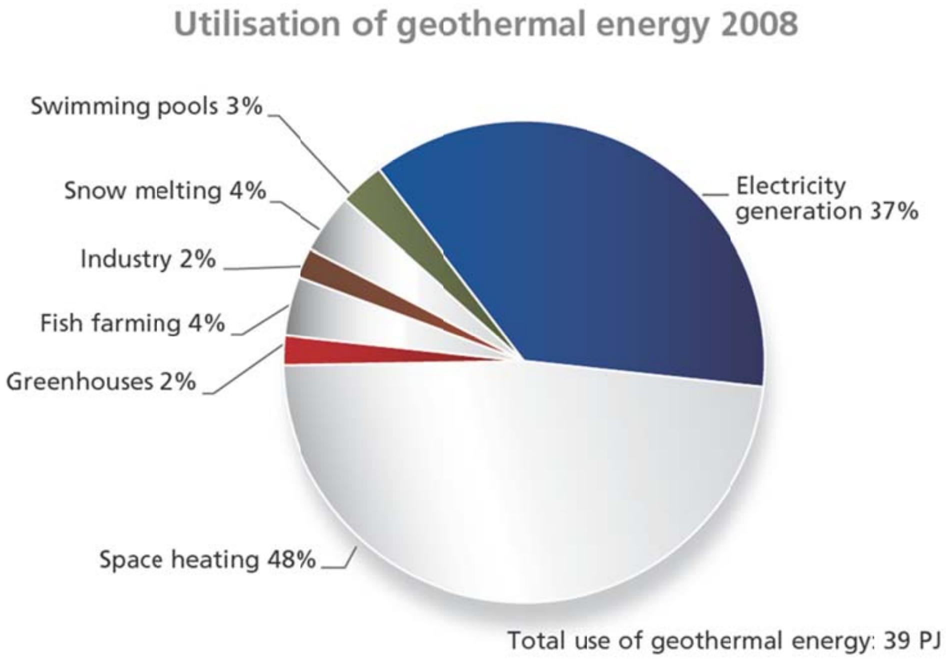
When examined globally, as of the end of 2009 direct-use production capacity was 50,700MW, more than four times the power generation capacity of 10,711MW. Direct use in Iceland is about twice the amount of indirect use.

As will be described below, Iceland has a long history of geothermal power use, where it has

[5] Taken from Orkustofun (2010) "Geothermal Development and Research in Iceland," and Reykjavik Energy materials.

been used chiefly for heating homes. Fully 66% of Iceland's primary energy use is covered by geothermal power, with the greater part of this being for direct use. Of the 39PJ (petajoules) of geothermal power used in 2008, 63% was for direct use and the remaining 37% was for indirect use for power generation. Among direct uses, the largest category of use is heating applications, which has risen to 48% of all geothermal power use (See Figure 2). Geothermal power use in Iceland can be said to have begun with direct use centered on heating applications, and expanded into use for power generation afterwards.

Figure 2: Geothermal power use in Iceland



Source: Orkustfnun (National Energy Authority) HP http://www.nea.is/geothermal/direct-utilization/

3.3 Direct use: Development of the district heating system

The people of Iceland have long used geothermal power directly for needs such as bathing and washing laundry. Geothermal heat was used for greenhouses for the first time in 1924, and came into use for heated swimming pools and space heating at around the same time. Heating needs are especially large in a country as cold as Iceland. While peat, coal and oil had traditionally been used as a fuel for heating, the systematic use of geothermal for district heating began in 1930.

In 1930, a mechanism was built by which geothermal water from the Thvottalaugar district was delivered to two elementary schools, a swimming pool, a hospital and the homes of 60 families within the Reykjavik area. To carry the geothermal water a 3km pipeline was laid. In 1943 a new

18km pipeline from Rykir was constructed, and heating service in the Reykjavik area was introduced. By the end of 1945, 2,850 households among Reykjavik's population of 44,000 were able to use district heating.

Spurred by the oil crises in 1973 and 1979, Iceland implemented a major energy policy shift, sharply reducing the use of oil and moving toward the utilization of its existing domestic hydropower and geothermal energy resources. In conjunction with this shift, it also greatly expanded geothermal heating applications, and from 1970 to 1982 significantly reduced the percent of heating provided by oil from 53 to 7%. Many pipelines ranging from 10 to 20km in length also were constructed to carry the geothermal heat to towns and villages. Today 92% of Iceland's population is using geothermal heat for heating applications. The percentage of heating supplied by oil is a mere 1%.

3.4 Indirect use: Construction of power plants and development of the aluminum industry

Although the first geothermal power station in Iceland was built in 1969, the construction of power plants on a practicable scale has progressed since the second half of the 1990s. As the result of construction carried out since the second half of the 1990s to expand the power generation plants at the Nesjavellir, Reykjanes and Hellisheidi power stations, in 2008 power generation capacity was 575MW and the total amount of electricity generated annually was 4,038GWh, accounting for 24.5% of Iceland's entire power supply (the remainder is provided by hydro-power). This figure nearly rivals geothermal power generation capacity in Japan. Furthermore, in 2008, two new 45MW turbines were installed at the Hellisheidi Power Station, which increased capacity to 663MW and boosted the annual supply of electric power to 4,600GWh from 2009.

Iceland's power-generation business and the aluminum refining industry have a deep relationship. Iceland has a background of using its abundantly existing natural energy (hydro-power and geothermal) to strategically develop the aluminum industry, which consumes a tremendous amount of electricity. Traditionally heavily dependent on fishing, Iceland has achieved industrial diversification through its development of the aluminum industry, and today the population working in the aluminum industry outnumbers the population involved in fishing.

Although aluminum smelters had been constructed since the latter half of the 1960s, they were affected by the deterioration of the global market and in the 1980s Iceland was unable to achieve its anticipated industrial development. Therefore Iceland established the Energy Strategy Agent in 1988 and decided to strategically develop power consuming (power-intensive) industries that would use renewable energy. Based on this change, the Energy Strategy Agent secured four large-scale investment projects totaling 800 million dollars after 1995 and the aluminum industry expanded. As a result, the volume of aluminum produced rose from 210,000 tons in 2000 to 770,000 tons in 2008.

Currently there are three large aluminum refining plants in Iceland. The biggest smelter, located in eastern Iceland and owned by Alcoa, Inc., has a production capacity of 346,000 tons (2008). A smelter with production capacity of 180,000 tons (2008) located in southwest Iceland is owned by Century Aluminum Company, a U.S. firm[6]. The Canadian entity Alcan, which built the original aluminum smelter in Iceland, has its plant on the outskirts of Reykjavik, the capital. That facility's annual production capacity is 180,000 tons (2008). Annual production capacity including output from smelters other than these three plants is being expanded each year, and aluminum production in Iceland is forecast to reach one million tons in 2011. This constitutes about 3% of global aluminum production and puts Iceland among the world's top ten producers. The electric power consumed by Iceland's entire aluminum industry is currently 5,500GWh, all of which is covered by hydro-power and geothermal power generation.

4. Iceland's Geothermal Power Plants

After the first geothermal power plant was constructed at Bjarnarflag in 1969, a total of seven geothermal power stations had been established in Iceland by 2006 (see Figure 3). As of 2011, Iceland had total geothermal power generation capacity of 662MW, sufficient to handle more than one-quarter of the country's electric power production.

The Bjarnarflag power plant is located in northern Iceland and currently has 3.5MW of power generation capacity[7]. Over the following years the Svartsengi, Krafla, Nesjavellir, Husavik and Rekjanes power plants were constructed, and the newest power plant, the Hellisheidi geothermal power station, began operating in 2006 and was enlarged in subsequent years up to 2011. A summary of each power plant that is presently operating is shown in Figure 4[8].

As can be understood from Figure 3, the Nesjavellir Geothermal Power Station and Hellisheidi Power Station are owned by Reykjavik Energy, while the Svartsengi Power Station and Reykjanes Power Station are owned by HS Orka. The Bjarnarflag Power Station and Krafla Power Station are owned by Landsvirkjun, the state-owned power company. Reykjavik Energy and HS Orka are electricity companies that focus on geothermal power generation. Landsvirkjun, on the other hand, is involved primarily in hydroelectric power, and supplies power for the aluminum industry. Overviews of the Nesjavellir Geothermal Power Station, Hellisheidi Power Station and Svartsengi Power

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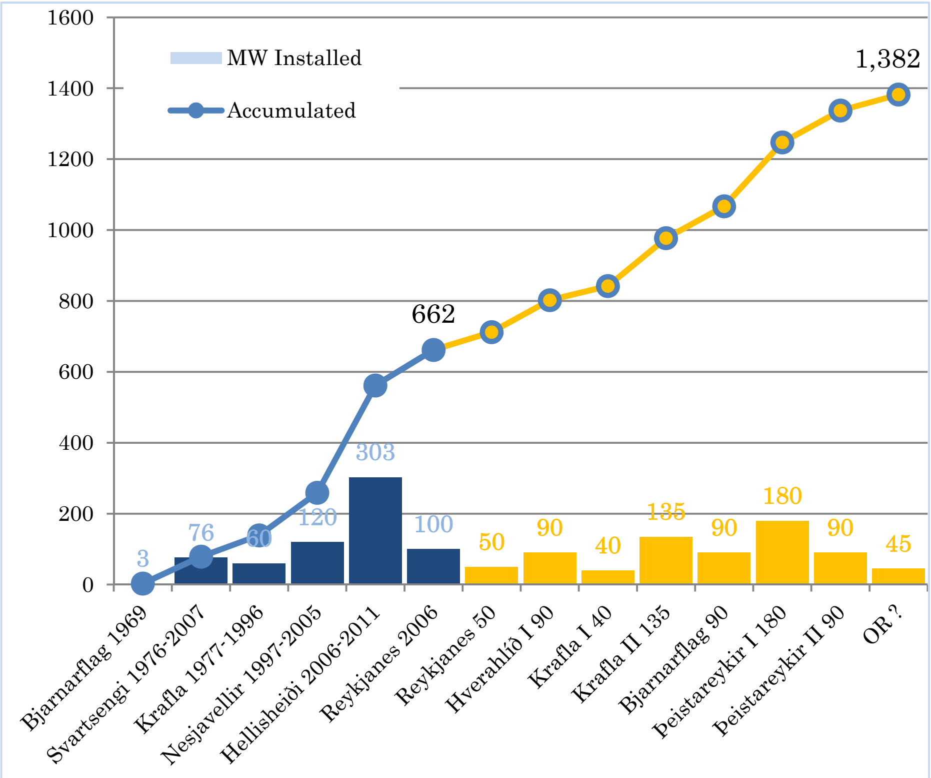
6 See the Ministry of Fisheries and Agriculture website.
http://www.fisheries.is/economy/Structure/Manufacture-sector/

7 http://www.mannvit.com/GeothermalEnergy/GeothermalPowerPlants/GeothermalProject-Hellisheidi/

8 The Husavik power plant is a binary type (Kalina Cycle) power plant and is not described in Figures 3 and 4 because it currently is not operating. Wasabi Energy of Australia acquired the plant in 2011, which it plans to refurbish it with the goal of commencing operations.
http://www.wasabienergy.com/Downloads/News/Husavik%20Announcement%2010%20Jan%202011.pdf#search='Husavik%20geothermal'

Station, the three main geothermal power plants in Iceland that play a key role as cogeneration facilities for power generation and district heating, are introduced in the following section.

Figure 3: Electric power generation in Iceland using geothermal power (1969-)



Note: Facilities in blue are as of 2010. Figures in yellow show planned future additions.

Source: Reykjavik Energy materials

Figure 4: Summary of Iceland’s geothermal power plants

Power plant	2010 generating capacity (MW)	Year built	Owner	Main turbine manufacturer
Bjarnarflag	3	1969	Landsvirkjun	
Svartsengi	76	1976	HS Orka	Fuji Electric Co., Ltd.
Krafla	60	1977	Landsvirkjun	Mitsubishi Heavy Industries, Ltd.
Nesjavellir	120	1997	Reykjavik Energy	Mitsubishi Heavy Industries, Ltd.
Hellisheiði	303	2006	Reykjavik Energy	Mitsubishi Heavy Industries, Ltd./Toshiba Corporation
Reykjanes	100	2006	HS Orka	Fuji Electric Co., Ltd.

Source: Taken from Reykjavik Energy materials and other sources

4.1 Nesjavellir Geothermal Plant

The Nesjavellir Geothermal Plant is located on the Lake Thingvallavatn levee adjacent to Thingvellir National Park, a high temperature zone in the northern part of the Hengill volcano and a UNESCO World Heritage site. Outfitted with four 30MW turbines manufactured by Mitsubishi Heavy Industries, Ltd., it has a total power generation capacity of 120MW. The plant has 26 boreholes and a maximum steam well depth of 2,000m. Because it is located near a national park, the plant was constructed with emphasis on the building and landscape design.

The Nesjavellir Geothermal Plant is a cogeneration facility, and in addition to electric power it supplies hot water for district heating in Reykjavik. The plant was initially developed as a base to supply hot water to Reykjavik. Although heating and service water within Reykjavik were being covered using low-temperature geothermal sources, the geothermal resources at Nesjavellir about 30km east of Reykjavik were newly developed because the water level was projected to decline as the result of growing demand. Supply of hot water to the city began in 1990. A power plant designed to use the well field for hot water was subsequently constructed, and power supply from geothermal power generation was started in 1999.

A total of 300MW of energy is created for heating. The geothermal brine and steam gushing from the boreholes is divided into hot water and steam, and the steam is used to spin the turbines and produce electricity. The separated hot water and the heat and low-pressure steam remaining after turning the turbines are sent through a heat exchanger and used to heat low-temperature groundwater. The water heated to 82°C is then transported to Reykjavik through a 27km pipeline.

The first plans to utilize the geothermal heat at Nesjavellir were made in 1947. Several test boreholes were later drilled to evaluate the feasibility of power plant development and assess the chemical syntheses of the steam, and specific search surveys were continued from 1965 through 1986. Construction of the geothermal power station was finally begun in 1987; the first stage was commissioned in May 1990, and the last turbine was brought on line in 2005.

4.2 Hellisheidi Geothermal Plant

The Hellisheidi Geothermal Plant is the newest geothermal power station in Iceland. It is situated in the Hellisheidi wilderness at a location to the south of the Hengill volcano[9]. The plant is equipped with six 45MW turbines manufactured by Mitsubishi Heavy Industries, Ltd. and one 33MW turbine from Toshiba Corporation, giving it a total power generation capacity of 303MW. There are 50 boreholes, each to a depth of 2,000m. Like the Nesjavellir generating plant, it produces hot water for district heating, which corresponds to energy of 400MW. Like the Nesjavellir Geothermal Plant, it was also designed with emphasis on the landscape.

Many research boreholes were drilled when the power plant was constructed. Boreholes for research were made on Klvidarholl hill in 1985 and on Olkelduhals ridge in 1994. The data obtained from both boreholes, however, was not sufficient to build a power plant. Consequently two boreholes were made in Hellisheidi heath in 2001, and three more were drilled in 2002, and the data obtained from these holes finally provided the grounds for building the power plant, enabling the work to go forward.

The Hellisheidi power plant was constructed from the beginning as a cogeneration facility. The first two 45MW turbines, made by Mitsubishi Heavy Industries, Ltd., were introduced in 2006, and electricity generation began with a capacity of 90MW. This was followed by a 30MW low-pressure turbine made by Toshiba Corporation, which was brought on line in 2007. Two more 45MW turbines from Mitsubishi were added in 2008, boosting power generation capacity to 210MW. Furthermore, the supply of hot water was initiated with the construction of a geothermal facility (130MW) for heating in 2010, and in 2011, two more 45MW turbines manufactured by Mitsubishi began generating electricity.

4.3 Svartsengi Geothermal Power Plant

The Svartsengi Geothermal Power Plant is a generating station owned by HS Orka hf. It was the first geothermal power station in Iceland to achieve energy supply for power generation and district heating.

Development of Svartsengi was carried out in six phases. In Phase I (1978-1979), two 1MW turbines made by GE were commissioned and began generating power in 1978, mainly for district heating. In Phase II (1979-1980), the facilities for district heating were expanded. Power generation capacity was then gradually increased by introducing a 6MW turbine from Fuji Electric Co., Ltd. in Phase III (1980), and an 8.4MW binary facility manufactured by Ormat in Phase IV (1989). With the

[9] Three volcano systems exist in the vicinity of Hengill; at least three volcano explosions have been confirmed to have occurred in the past 11,000 years. The most recent explosion occurred in 2000.

commissioning of a 30MW turbine from Fuji in Phase V (1999-2000), both power generation capacity and district heating capacity were substantially increased. Most recently in Phase V (2006-2008), further capacity expansion was achieved when another 30MW turbine manufactured by Fuji was introduced. As a result, as of 2011 the plant has a total electric power generating capacity of 75MW and creates 150MW of energy to supply warm water for district heating.

While cogeneration utilizing geothermal heat and groundwater for power generation and district heating is a feature shared with the other two power plants described above, the Svartsengi Power Station is characterized by it further expansions of the scope of cogeneration. One is a resort facility called "Blue Lagoon." A spa that uses seawater warmed by geothermal heat, the Blue Lagoon is visited by 400,000 people every year, making it Iceland's number one sightseeing spot. Its beginning traces back to 1981, when people noticed by chance that the constituents in the heated water in a small hot water pond (lagoon) created next to the Svartsengi Geothermal Power Plant are good for the skin, and in 1987 the location was opened as a public spa. The facility was newly opened as "Blue Lagoon" in 1999. The Blue Lagoon covers an area of 5,000 square meters and is spring-fed with six million liters of seawater warmed by geothermal heat per hour. It is calculated that all of the seawater is renewed in approximately 40 hours. Located on two continental plates, the Blue Lagoon has become a location visited not only by the local population but also by many tourists. Moreover, because the spa uses geothermal seawater and cosmetics are based on silica and algae, beauty products have been developed and are being sold. Ethanol is also being produced, and various uses for geothermal resource are being pursued.

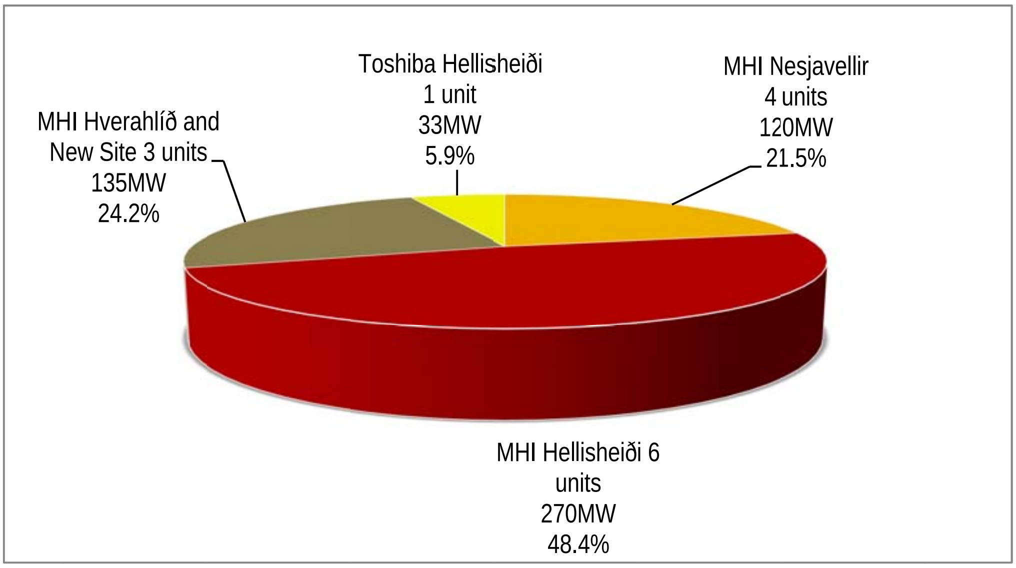
5. Geothermal Power Generation Systems and the Role of Japanese Firms in Iceland

Geothermal power generation systems are divided into three basic technologies: (1) dry steam, (2) flash steam and (3) binary. Dry steam, the oldest geothermal power generation technology, is a technology to directly extract the steam from a geothermal reservoir and generating electricity by using the steam to turn a power generation turbine. In contrast to this technique, flash technology – currently the most widespread technology – is a technology to extract high-pressure hot water and steam heated to 182°C or more from a geothermal reservoir using pumps, and using the steam that has been separated from the hot water by a steam separator to turn a power generation turbine. The third technology is a binary power plant, which is a system to transfer heat from the hot water drawn up from the geothermal reservoir to a separate medium that has a low boiling point, such as pentane (36°C boiling point), causing the medium to expand into a gaseous vapor that is then used like ordinary steam to drive the power generation turbine. This system is used for wells having comparatively low temperature. With a binary system, the water (primary medium) drawn up from the reservoir does not come into direct contact with the power generation machinery, and is returned to the reservoir after its heat has been exchanged. Therefore one characteristic of such systems is that they eliminate the concern that the water level in the reservoir will decline. Incidentally, of these three systems, the binary system is the only technology that is acceptable at this time under Japan's Renewable Portfolio Standard. One issue for geothermal development in Japan is addressing the worry of hot spring resort operators that geothermal power use will lower the underground water level; this is not a concern if a binary cycle system is utilized.

Of the world's total geothermal power generation capacity at the end of 2009, which exceeded 10,000MW, dry steam systems accounted for 2,878MW, flash systems accounted for 6,483MW and binary systems accounted for 1,178MW. Three Japanese firms – Mitsubishi Heavy Industries, Toshiba and Fuji Electric – have shown themselves to be highly competitive in this market, delivering 2,007MW (share exceeds 70%) for dry steam systems and 5,240MW (share exceeds 80%) for flash systems (including single flash and double flash). Up until now, however, Japanese companies have not handled binary systems[10], and as of 2010 Ormat Technologies, Inc., a U.S. firm, has nearly 100% share of this market.

With the exception of certain facilities, all of the main geothermal power stations in Iceland use flash systems, and power generation turbines manufactured by Japanese firms have been adopted for nearly all of these plants. For example, of the 14 turbines Reykjavik Energy has at all at its power plants, including those that are in planning, 13 were manufactured by Mitsubishi Heavy Industries, Ltd. and the other unit was made by Toshiba Corporation (Figure 5).

Figure 5: Reykjavik Energy's geothermal turbines (including planned)



[10] In May 2010 Fuji Electric announced it will commercialize a 2MW binary system. http://www.fujielectric.co.jp/about/news/10051001/

Source: Reykjavik Energy materials

6. Players Involved in Geothermal Resource Development in Iceland

6.1 Resource Exploration: ISOR (Iceland GeoSurvey)

The establishment of a geothermal power station broadly involves three phases: (1) exploration, (2) drilling and (3) plant construction. In the exploration phase, the objective is to confirm and assess the existence of geothermal resources. Because of the large cost involved to actually drill, it is necessary to identify beforehand and as accurately as possible the locations where geothermal resources exist.

Detailed maps showing the locations where potential geothermal resources exist, including information on tectonics and lithology, are drawn based on the accumulation of geological surveys made over many years. When the outlines of candidate sites for geothermal resource development are shown on a map and a candidate site is identified, specific measurements concerning a variety of physical characteristics and chemical attributes are taken and the geothermal resource conditions (depth, temperature, etc.) understood. Thus the status of the geothermal reservoir, which exists deep underground and cannot be observed directly, is extrapolated to the extent possible.

Following the search from the earth's surface, exploration wells are drilled. The purpose is to more accurately grasp the conditions underground by drilling a few wells prior to commencement of full-scale geothermal well drilling. Compared with the past, it has even become possible to understand underground conditions from information obtained from the earth's surface, based on extensive geothermal resource development experience. Nevertheless, without actually drilling, accurate well sites and conditions cannot be fully understood.

During the search phase for Iceland's geothermal resources, ISOR (Iceland GeoSurvey) has played a key role. Iceland's electric power market was deregulated in 2003 by amendment of its laws. The power generation market was entrusted to free competition, while electric power transmission and supply were placed under government control. The role of the NEA (National Energy Authority) in management and oversight of the deregulated market was enlarged, and the GeoScientific Division, which was the NEA's research arm, was spun off and established as an independent entity renamed ISOR. Until becoming independent in 2003, the GeoScientific Division had supported the Icelandic government and Iceland's power utilities, mainly through geological surveys, for 60 years.

Although the spun-off and independent ISOR is state-owned, financially it operates as an independent entity. According to its annual report for 2010, operating revenues in that year were 866 million kronor (about 577 million yen) and the net loss was 94.4 million kronor (about 63 million yen). The organization's main business is services such as geothermal exploration and surveys, drilling consultancy, geothermal well testing and evaluation, and environmental impact assessment. While traditionally its customers were the government and Iceland's electric power companies, in recent years ISOR has expanded its operations overseas, and its revenues as of 2010 have been broadened to include foreign activities within the scope of its business.

6.2 Exploration: Iceland Drilling Ltd.

Iceland Drilling Ltd. is the biggest firm sinking geothermal wells in Iceland. Established in 1986 as a firm owned jointly by the state and the city of Reykjavik, Iceland Drilling traces its roots back to 1945 when it predecessor, State Drilling Contractors (a government agency), was founded. To achieve more diversified ownership, in 1992 the Iceland Drilling shares owned by the government and city were also offered up to ordinary investors.

As a firm specialized in geothermal well drilling, Iceland Drilling handles activities ranging from the exploration phase to full-scale drilling. It is developing its services not only in Iceland but overseas as well. The company also owns Helka Energy GmbH, a wholly-owned subsidiary in Germany, and is developing its business internationally as Helka Energy.

6.3 Plant construction: Engineering firms

Engineering firms are in charge of geothermal field development and geothermal power plant construction. Iceland has a number of engineering firms, including small and medium-sized companies; two engineering firms related to geothermal power station construction are Mannvit Engineering and Verkis.

Mannvit, the largest engineering firm in Iceland, was created through the merger of three engineering companies that were all founded in the 1960s. In 2010, the company employed 400 employees and had operating revenues of six billion ISK (about four billion yen) and net earnings of 570 million ISK (370 million yen). The company also provides services in other countries. Verkis was established in 2008 through the merger of five engineering and consulting firms. VST, one of the pre-merger entities, had a history going back to 1932.

Both companies, through the firms that were their predecessors, were involved in the first stage of thermal resource development in Iceland. Both provide wide-ranging services, from geothermal resource exploration to drilling, plant construction and plant management. While most of the plant facilities installed during geothermal power plant construction in Iceland are purchased from foreign companies, including Japanese and German firms, engineering services are being provided by these domestic entities.

6.4 Electric power companies

The companies that actually make the investments in geothermal resource development and use geothermal resources as a business are the power utilities. The costs related to development are either financed internally, or through the use of financing schemes that include domestic and overseas investors. As discussed earlier, the three power utilities that own geothermal power stations in Iceland are Reykjavik Energy, HS-Orka and Landsvirkjun. The power-generation business and power transmission business in Iceland are separate; the power transmission business takes the form of a monopoly managed by a single state-run company, while the three power utilities operate the power-generation businesses.

Reykjavik Energy is a public utility corporation (the government owns nearly 100% of its shares) formed in 1999 by the merger of Reykjavik Electricity and Reykjavik District Heating. Both companies had long histories; Reykjavik Electricity began operating in 1921, while Reykjavik District Heating was founded in 1930. The former supplied electric power, and the latter supplied heating systems. Today Reykjavik Energy supplies electricity to 56% of Iceland’s entire population, and supplies hot water and chilled water to 61% and 41% of the population, respectively.

HS Orka was made independent in 2008 after it was separated from Hitaveita Sudurnesja hf, which was established in 1974. Discussion of geothermal development in the Sudurnes district began in 1953. NEA examined the feasibility of geothermal development in Svartsengi for years, and Hitaveita Sudurnesja hf was subsequently established in 1974 to construct a district heating/power generating system. The supply of hot water was started in 1976, and power generation began from 1978. HS Orka is a firm that specializes in the production of geothermal power based on this experience. Initially, most of HS Orka’s shares were held by public institutions, but in 2009 Magma Energy of Sweden acquired a 41% stake, and Geysir Green Energy of Iceland purchased 57.4% of the shares. In 2010 the company became a de facto subsidiary of Magma Energy, which now owns 98.1% of the shares.

Landsvirkjun is a state-run power utility that generates 73% of the electricity used in Iceland. In contrast to Reykjavik Energy, whose main customers are ordinary families, Landvirkjun’s principal business is supplying power for industries that use large amounts of electricity at sites such as aluminum smelters. About 80% of the company’s sales are to industries with concentrated electric power needs. Landvirkjun has grown together with the global aluminum companies Alcan and Alcoa, which have constructed smelter plants in Iceland. Most of Landvirkjun’s power generating capacity is hydro power, and the company has only two geothermal power stations, at Krafla and Bjarnarflag.

7. Overcoming Geothermal Development Issues

As described earlier, three reasons why the development of geothermal power generation has not progressed very far in Japan have been identified: (1) economic efficiency (initial investment risk), (2) the opposition of hot springs operators and (3) Natural Parks Law regulations. Other than the opposition from hot springs operators these issues, while different in degree, are found in Iceland as well. In Iceland, however, power generation capacity has been increased rapidly in recent years despite these geothermal resource development issues. Why has that been possible?

7.1 Economic efficiency: Diversified resource use

Although there are no detailed data concerning power generations costs, with regard to the economic efficiency of geothermal power generation we can surmise the cost to some degree based on rates. Figure 6 shows the electricity rates of Reykjavik Energy and HS Orka for electricity sold to homes. Because the power generation, power transmission and electric power supply businesses were separated in Iceland in 2003, the electricity rates customers pay are shown divided into the amounts for power generation, power transmission and power supply. Looking at the power generation portion, we can see that both Reykjavik Energy and HS Orka charge about three yen/kWh. This is end selling price, so the power generation cost is assumed to be lower than this. Considering that the cost of nuclear power and thermal power generation in Japan is from 7 to about 10 yen, we can see that a considerably low cost has been achieved. This is very inexpensive even when compared with the power generation cost for geothermal power generation of about nine yen found in Japan (IEEJ, 2011).

Figure 6: Household electricity rates for geothermal power in Iceland (price/kWh)

	Supply rate	Transmission rate	Electric bill	Energy tax	Electric bill including 25.5% sales tax (on power generation only)	Electric bill including 25.5% sales tax (on power generation, transmission and supply)
Reykjavik Energy	3.53 (2.29 yen)	1.27 (0.83 yen)	4.74 (3.01 yen)	0.12 (0.08 yen)	6.07 (3.94 yen)	12.12 (7.88 yen)
HS Orka	—	—	4.59 (2.98 yen)	0.12 (0.08 yen)	5.91 (3.84 yen)	—

Notes: Because HS Orka is only in the power generation business, charges for electric power supply and transmission are not included in its rate. Figures in parentheses are the value in yen calculated at 1ISK=0.65 yen.

Source: Taken from HS Orka and Reykjavik Energy websites

Why can these firms generate electricity at such low cost? We cannot provide a detailed analysis in this paper concerning this point, but one factor is believed to be that geothermal resources are put to multiple uses including the provision of heating and hot water[11].

As mentioned previously, Iceland's geothermal resources were originally developed for district heating. Power plants were constructed later at the developed geothermal fields. To the extent the same field is shared, it appears possible to lower the costs.

Contrast this with the situation at the Hatchobaru Geothermal Power Station, for example, the biggest geothermal power station in Japan, where Kyushu Electric Power Co., Inc. uses geothermal heat only to generate electricity and, except for heating the interior of the power plant itself, does not sell the hot water externally. Yet because Hatchobaru can achieve a power generation cost of 7-8 yen/kWh, among renewable energy sources the plant could probably become extremely economically efficient if it were to also use the geothermal heat for indoor heating applications.

Even if such strong potential economic efficiency is recognized, however, there is still a problem in terms of financing because of the high development risk. This point is the same in Japan and Iceland. In Iceland, however, the major electric power firms like Reykjavik Energy that have strong hallmarks of government entities are aggressively undertaking self-financing and pushing ahead with geothermal power development. Despite the risk, a firm that has been granted a monopolistic position probably can absorb the development risk to some extent.

7.2 Coexistence with the environment and local area

Although the restrictions in Japan are greater, the current situation in which many geothermal resources lie under national parks is the same in both Japan and Iceland. Regulations have been placed on geothermal resource development in Iceland as well, based on the Nature Conservation Act (environmental protection law). Plants are constantly monitored so they do not affect the ecosystems in national parks, and harmony with the landscape and power plant design are emphasized in power plant construction.

In Iceland firms are lucky that resource exploration and plant construction are not stifled by opposition from hot spring resorts like in Japan. Heated swimming pools everywhere in Iceland, and

[11] However, compared with Japan Iceland also has an advantage in terms of power plant construction costs. In contrast to Iceland, where the required investment amount per MW is said to be 2.5-3.0 million dollars (from 200 million to 240 million yen), in a trial calculation made in 1996 the amount in Japan was 660 million yen, and in a calculation prepared in 2008 was 510 million yen (Adachi, 2009). While the two sets of figures are not directly comparable because the trial calculations for Japan also include running costs, this is a significant difference even if the running cost is assumed to account for 1/3 of the total cost.

the fact that people are able to enjoy the pools every day seems to have heightened awareness of the benefits of geothermal development. Geothermal development and hot water use are two sides of the same coin. The status of hot water and steam use is monitored continuously, however, and moderate use of natural resources is borne in mind. Hot water is pumped and used from wells within the city of Reykjavik, for example, but changes in the underground water level are monitored continuously and the pumping rate controlled. For development of the Nesjavellir geothermal field as well, the fact that hot water pumped up to meet the increase in hot water and heating demand within the city would cause the water level to fall and draw in hot water from a location 30km away was considered.

7.3 Development authorization and handling of rights

When developing a geothermal resource, one more issue in relation to districts and the environment is development rights. Entities wanting to develop a geothermal resource in Iceland (typically a power utility) must obtain a license from the NEA. Licenses are either an “exploration license” or a “utilization license.”

Both licenses are provided in accordance with the Act on Survey and Utilization of Ground Resources, and the Electricity Act. Moreover, to exploration for or use resources, approval must also simultaneously be obtained in accordance with the provisions of the Nature Conservation Act and Planning and Building Act.

The NEA can grant exploration licenses to entities that want to undertake resource exploration, whether on publicly owned land or in a privately owned area. In the case of privately owned land, the party that receives the license is not necessarily the landowner. Although resources belong to landowners, resource utilization licenses are not granted just to land owners, and landowners also do not have priority to receive a resource utilization license. The fact landowners and development rights holders are separated is a special characteristic of Iceland.

Usually the entity that receives an exploration license and conducts an exploration will then obtain a resource utilization license and proceed with resource use, but the party that has received a license must obtain mutual agreement with the landowner concerning the resource use (including compensation) within 60 days from the day when the license was received. If a mutual agreement is not obtained, the license is revoked.

When mutual agreement is not obtained it is also possible to pursue mediation based on the judgment of a specialist. In other words, both parties will be urged to reach a consensus based on a compensation amount judged by the specialist to be appropriate. Therefore landowners cannot in fact continue to refuse resource utilization by other parties.

8. Conclusion: Feasibility of Geothermal Development in Japan and Issues

Viewed from the perspective of the creation of a renewable energy industry that solves the environmental problem, energy problem and financial problem, geothermal power generation looks very promising. Among countries possessing geothermal resources, Japan ranks third in the world. If half of those reserves (geothermal resources considered to be economically feasible to develop) were developed, they would be able to cover about 10% of Japan's total power demand. Not only does geothermal power generation not incur any expense for fuel, the volume of CO_2 emissions also is extremely low. Judging from the case history of Iceland, potentially high economic efficiency can be expected at a minimum. Considering how highly competitive Japanese firms are in turbines, development could also be expected to stimulate industrial development in Japan.

Notwithstanding such benefits, the development of geothermal resources in Japan has been extremely slow. It is an area that has been disregarded in policy for a long time. Despite receiving greater attention in the wake of the Great East Japan Earthquake, the hurdles remain high. Therefore the goal of this paper has been to identify some guidelines for Japan's geothermal development by analyzing the case history of Iceland as a geothermal development pioneer. In addition, although sufficient analysis has not yet been completed, some hints were obtained as well.

The first is that multiple uses of geothermal resources, through utilization that includes direct use of hot water and district heating, appears to be the key to boosting the economic efficiency of geothermal power generation. For Japan as well, the effectiveness of the use of geothermal heat for district heating in cold areas such as the Tohoku region is believed to be high. There is a possibility the environment and energy problems can be solved while maintaining high economic efficiency if heating and power generation are developed as a set.

The second hint is the importance of continuously maintaining concern for the environment. One reason people in hot spring resorts oppose construction of geothermal power stations is their worry that the hot spring water level will fall. To eliminate such concern, monitoring the status of the underground resource continually, and keeping moderate resource use in mind, appears to be necessary. Consideration of the landscape also is vital. In Iceland, considerable care is taken with power plant design. Unlike in the case of a normal power plant, the value placed on designs that do not disrupt natural park landscapes and harmonize with surroundings appears to be considerable.

The third hint is that the problem of investment risk appears to be solvable to some extent if a large monopolistic firm (power utility) addresses the issue seriously. Moreover, in the case of hot spring development, a scheme in which the spring's source is not developed by the party owning the resource at its own risk, and the risk is borne individually by the land owners, developers and investors and the parties cooperating, might be necessary. Development might move forward if appropriate investment schemes can be formulated, because the potential economic efficiency is high. Of course, geothermal development is likely to be accelerated by the full-volume feed-in tariff purchase system set to begin this year if a high price of 20 yen/kWh or more is set. One critical factor, however, will be to have a scenario for development as an industry without having to rely indefinitely on taxes (public financing burden).

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