maintains a temperature of around 20°C, but normally it is discharged and is not reused. It is not an exaggeration to say that potential thermal energy from hot springs is being wasted.

Based on this situation, the Japan Environmental Sanitation Center organized the "Research Group on Global Warming Countermeasures for Hot Springs." This group began studying the technological feasibility of effective utilization of hot spring heat while carefully considering promoting hot spring utilization.

Source: Akio Okumura・Yasuo Kawabe・Takahiro Ohno(2010): Current Status on Utilization of Heat Sources through Hot Springs and their Effective Use, Bulletin of JESC No.37. pp.92-100
http://www.jesc.or.jp/Portals/0/center/library/shoho/H21shoho6.pdf

Ministry of Environment(2018：2017 materials of promotion seminar, Effective use of hot spring heat
https://www.env.go.jp/nature/onsen/spa/spa_utilizing.html

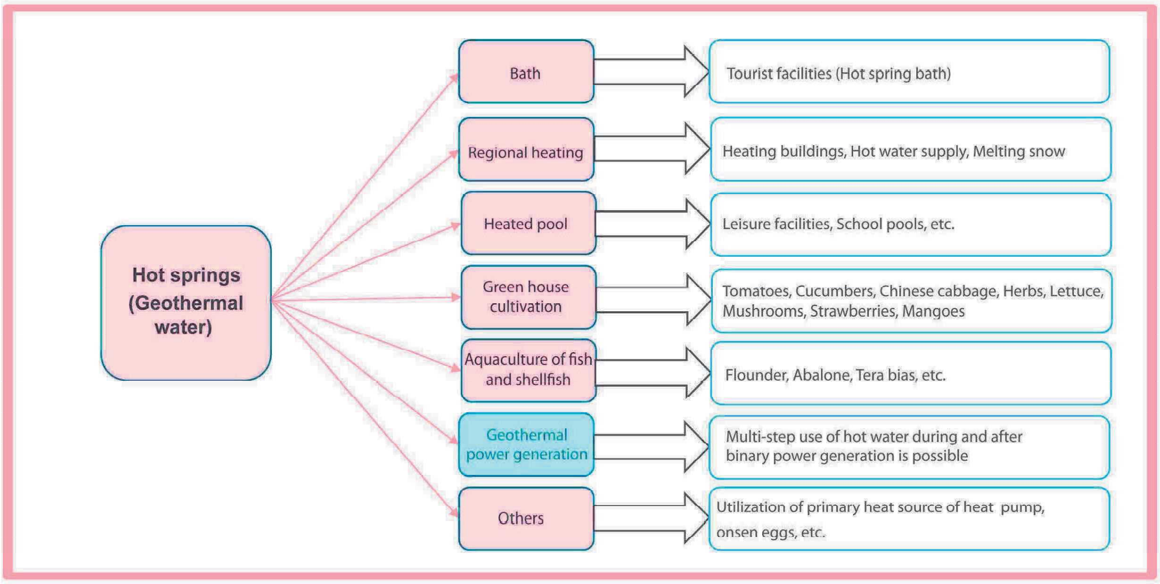


Figure 2-6 Various Hot Spring Uses

Source: Hiroshi Shinomiya (2018): Enrich region by utilizing geothermal resource ~ Treasure mountain project starting ~2017 seminar for effective utilization of thermal fever, material -3
https://www.env.go.jp/nature/onsen/spa/spa_utilizing.html

2.2.2 Heat utilization of hot springs by temperature

Various measures, as shown below, are being taken to promote the use of hot spring heat, depending on the temperature zone of the hot springs. (Hokkaido Economic Affairs Department Industry Promotion Bureau, 2017). Heat usage images are shown below.
① Binary power generation can be expected if the temperature is higher than 70°C. However, for binary power generation, it is important to have a flow rate of hot springs of 200L/min or more and cooling water of 330L /min or more at 30°C or less.
② The heat of a hot spring can be utilized directly with a heat exchanger. When the temperature of the hot spring is above 45°C, it can be used after releasing and cooling the heat through a heat exchanger because the temperature is too high for bathing.
③ Even low-temperature heat, such as from discharged hot water, can be used for preheating a hot water supply, resulting in curbed fuel consumption.
④ Discharged hot water can be used as a heat source for a heat pump. However, because the initial cost is high, it may be used as an alternative source as long as the heat source from accommodation

facilities whose operation rate and fuel consumption are high. However, it must be noted that when the flow rate is low, it cannot be used, so the scale may be reduced. The temperature range required varies depending on the purpose and the conditions of use, for example, it is sufficient to ensure a Geothermal/hot temperature at which the soil does not freeze when cultivating leafy vegetables for agricultural use.

【References】

Hokkaido Economic Affairs Department Industrial Promotion Bureau (2017): Geothermal/hot spring thermal problem-solving guide book
http://www.pref.hokkaido.lg.jp/kz/kke/kadai-gaido.pdf

2.2.3 Direct utilization of geothermal heat in Japan and in the world

The proportion of direct use of geothermal heat in Japan and in the world is shown in **Figure 2-7** and **Figure 2-8** as the proportion of the installed capacity by thermal unit (MW_t).

In Japan, uses for bathing and pools account for the majority, but on a worldwide scale, uses for bathing and pools is at 45%. This shows that geothermal resources are used for a greater variety of purposes outside of Japan. It is necessary to expand further direct use of geothermal heat in Japan.

【Unit of generation capacity and installed capacity of heat output】

Worldwide, a unit of installed capacity of a geothermal power plant is written as "MW_e (megawatt electrical): Watt Electrical is the unit of power output."
Installed capacity of direct use of geothermal heat is written as "MW_t or MW_{th} (megawatt thermal): Watt thermal is a unit of heat output."
In Japan, it is rare to distinguish between these. Installed capacity (power generation capacity) of a geothermal power plant is written in units of "W." Therefore, this case collection follows the Japanese notation.
The unit of equipment capacity for direct utilization of geothermal energy is "MW_t" (t is a half-width subscript). Note that 10,000 kW is 10 MW.

【Reference】

NEDO (2008): Geothermal Energy・Barometer 2007 (EU), NEDO Overseas Report, NO.1021
https://www.nedo.go.jp/content/100105395.pdf

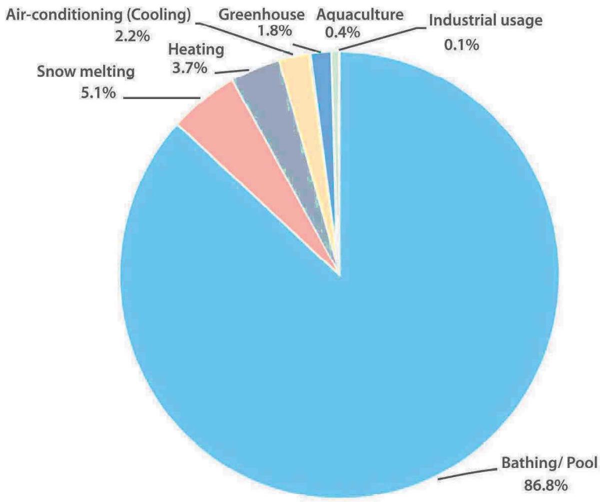


Figure 2-7 Direct Utilization of Geothermal Power in Japan
[Percentage of installed capacity as calorie; based on Japan's heat utilization data (total 2,086 MW_t) published in IGC's GEOTHERMAL POWER DATABASE (data on heat pump excluded)]

Source: IGC: GEOTHERMAL POWER DATABASE (As of February 2019)

https://www.geothermal-energy.org/explore/our-databases/geothermal-power-database/#direct-uses-by-purpose

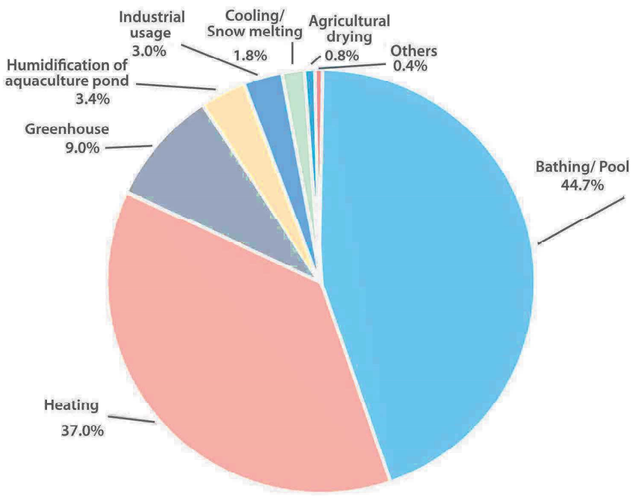


Figure 2-8 Direct Utilization of Geothermal Power in the World

[Percentage of installed capacity as calorie; based on 2015 world heat utilization data of Lund and Boyd (2015) (total 20,431 MW_t) (heat pump excluded)]

Source: John W. Lund and Tonya L. Boyd (2015): Direct Utilization of Geothermal Energy 2015 Worldwide Review, Proceedings World Geothermal Congress 2015

2.3 Use as geothermal power generation

2.3.1 Distribution of geothermal resources

This graph shows the geothermal resource volume per listed country. The United States, with the world's largest geothermal area (The Geyser geothermal area), ranked first (30 million kW); Indonesia, consisting of many volcanic islands, ranked second (27.79 million kW). Japan is the third (23.47 million kW) and is considered one of the world's leading geothermal resource countries (**Table 2-3**). As shown in **Figure 2-9**, geothermal resources have a strong correlation with the number of active volcanoes present. The geothermal power generation capacity in each country is shown in **Figure 2-10**. Large-scale geothermal power generation facilities are installed in the Pacific Rim Volcanic Zone.

Table 2-3 Geothermal Resource and the Installed Capacity in Major Countries

Country	Geothermal Resource (10,000kW)	Installed Capacity (10,000kW)
USA	3,000	372
Indonesia	2,779	186
Japan	2,347	55
Kenya	700	68
Philippines	600	193
Mexico	600	92
Iceland	580	71
New Zealand	365	98
Italy	327	92

【Geothermal resource amounts posted by Ministry of Economy, Trade and Industry, Agency for Natural Resources and Energy (2018): Overseas geothermal power generation capacity is extracted from the 2017 data of BP (2018): Japanese geothermal power generation capacity is the latest value as of February 2019 recalculated based on 2017 data of Thermal Power Nuclear Power Technical Association (2018) in accord with the information as of February 2019 by (Tohoku Electric Power Co., 2017; Japan Heavy Industries, Ltd., 2019) 】

Source: Ministry of Economy, Trade, and Industry, Agency for Natural Resources and Energy (2018): 2017 Annual Report on Energy (Energy White Paper 2018)
http://www.enecho.meti.go.jp/about/whitepaper/2018pdf/

Source: BP(2018：BP Statistical Revier of World Energy, 67th edition, Renewable energy - geothermal
https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2018-renewable-energy.pdf

Source: Thermal Nuclear Power Technologies Association (2018): Current status and trends of geothermal power generation 2017

Source: Tohoku Electric Power Co. (2017): Regarding the start of operation by changing the rated output of Yanaizu Nishiyama Geothermal Power plant, August 28, 2017
https://www.tohoku-epco.co.jp/news/normal/1195420_1049.html

Source: Japan Heavy Industries Ltd. (2019): Geothermal power plant started full-scale operation in Matsuo Hachimantai area of Iwate Prefecture, January 29, 2019
http://www.jmc.co.jp/岩手県松尾八幡平地域で地熱発電所が運転開始.html

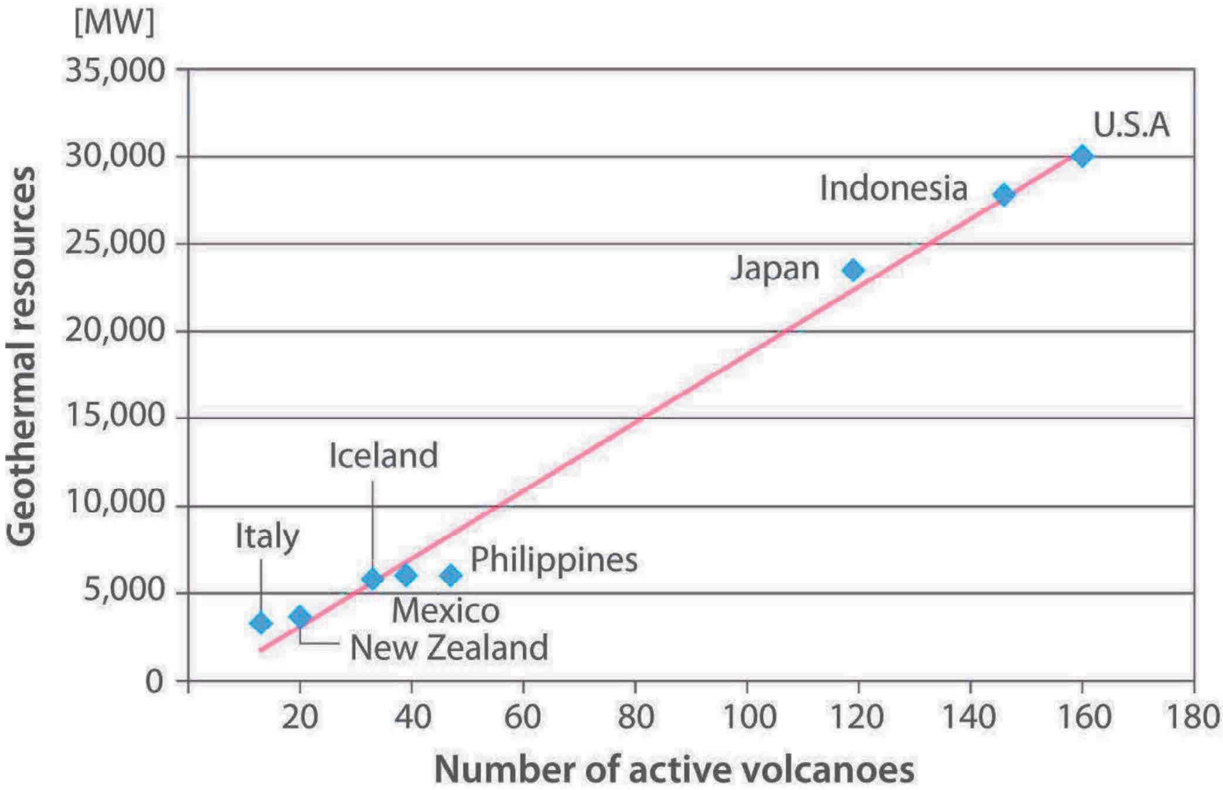
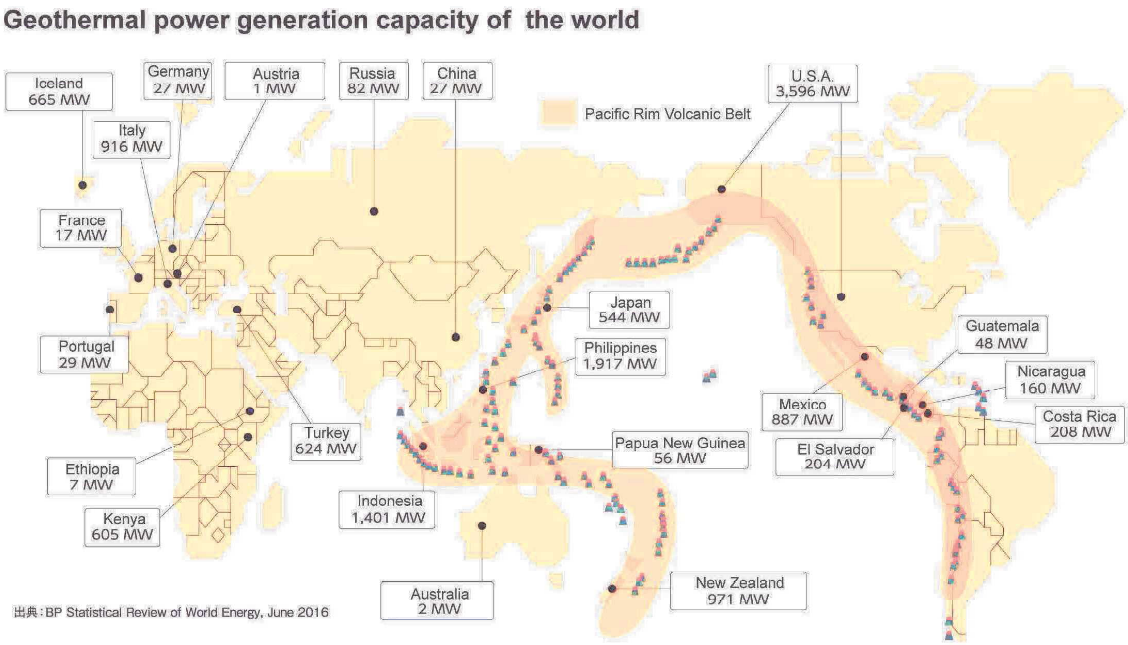


Figure 2-9 Worldwide Geothermal Resources in Correlation to Active Volcanoes

Source: NEDO (2014): Renewable Energy Technology White Paper, Second Edition, Chapter 7 Geothermal Power Generation
https://www.nedo.go.jp/content/100544822.pdf



[JOGMEC (2018) fixed geothermal power plant capacity data. Overseas-changes to the 2017 data of the BP (2018). Japan-the latest value as of February 2019 shown in Table 2-3.]

Figure 2-10 Geothermal Power Generation Capacity of Countries around the World

Source: JOGMEC (2018): Geothermal Heat, Energy living in harmony with local nature, brochure http://geothermal.jogmec.go.jp/report/file/jogmec_geothermal.pdf

Source: BP (2018): BP Statistical Revier of World Energy, 67th edition, Renewable energy - geothermal https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2018-renewable-energy.pdf

The amount of potential geothermal resources in Japan is estimated to be 23.47 million kW as output (**Table 2-3**). This is based on the results of the estimation conducted by Muraoka et al (2008) of the National Institute of Advanced Industrial Science and Technology. By using GIS, they conducted a nationwide assessment of the geothermal resources with a temperature of 150°C or higher and estimated that the total amount was 23.47 million kW. The evaluation result is shown separately under a special protection zone of the national parks, special areas, and others in **Figure 2-4.**

According to the results of this evaluation, 81.9% of the hydrothermal resources above 150°C are within the designated protected area of a National Park/Special Area. Only 18.1% of these areas do not have development restrictions. Developmental regulations within natural parks act as a barrier to geothermal development.

Table 2-4 Relationship between Hot Water Resources of 150°C and the Distribution of National Parks

Classification of calculated areas	Amount of natural resources (10,000kW×30years)	Share nationwide (%)
Total national parks	1,922	81.9
Special protection zone	780	33.2
Special areas	1,142	48.7
Others	425	18.1
Total	**2,347**	**100.0**

Source: Hirobumi Muraoka・Keiichi Sakaguchi・Susumu Sasaki (2008): Evaluation of hot spring system resources in Japan 2008, Abstracts of academic lecture of FY2008 Geothermal Society of Japan, B01
https://www.jstage.jst.go.jp/article/grsj1979/30/Supplement/30_Supplement_B01/_pdf
Source: Yusaku Yano (2008): Development possibility of geothermal power generation, H20.12.1 Study group on geothermal power generation (1st), reference 5 (data cooperation: Hirofumi Muraoka) Group on Geothermal Power Generation (1st), Reference 5 (Materials Cooperation: Hirofumi Muraoka)
http://warp.da.ndl.go.jp/info:ndljp/pid/286890/www.meti.go.jp/committee/materials2/downloadfiles/g81201a05j.pdf

2.3.2 What is geothermal power generation?

The Earth's interior is composed of four layers: inner core, outer core, mantle, crust. The temperature of the center is estimated to be over 5,000ºC. When the rock melts at the top of the mantle, magma occurs, which breaks the crust, and when they reach the surface of the earth, they cause eruptions, forming a volcano. There are magma reservoirs from several kilometers to 20 kilometers underground in the volcanic belt. Their temperatures reach as high as 1000°C. Geothermal power generation is a method of generating electricity using this heat.

In order to generate geothermal power, a geothermal reservoir which holds steam and hot water above 150°C and is under high pressure must exist deep underground at around 2000 meters.

Three elements, ① water (precipitation), ② heat (magma), and ③ container (cap rock), are required to form the geothermal reservoir. By excavating the well (production well) in the formed geothermal reservoir layer, steam and hot water are collected to generate electricity. (See **Figure 2-11**)

The remaining hot water, after power generation, is returned to the geothermal reservoir through the reinjection well, which makes power generation sustainable.

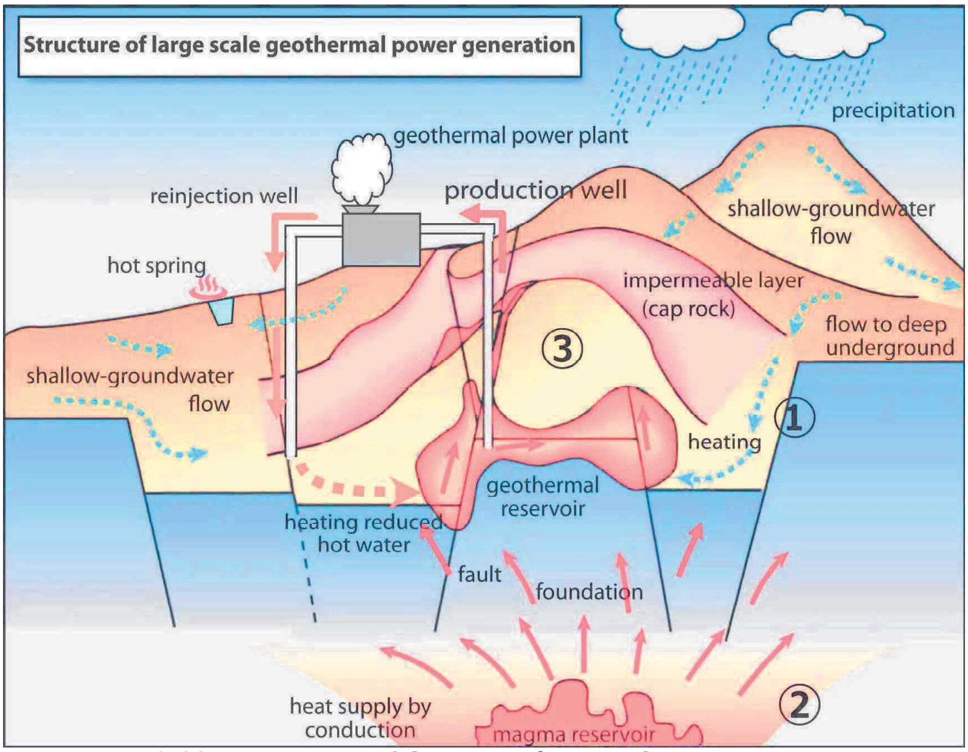


Figure 2-11 Mechanism of Geothermal Power Generation

Source: Agency for Natural Resources and Energy (2017) : On the current state of geothermal resource development Resource and Fuel Subcommittee, Total Resources and Energy Research Committee (22nd), Material - 4 June 2017
http://www.meti.go.jp/committee/sougouenergy/shigen_nenryo/022_haifu.html

Geothermal power generation is relatively clean in terms of CO2 emissions as compared to electricity generated by fossil fuels. Geothermal power is an effective clean energy source aiding in the prevention of global warming. Moreover, it has higher stability compared to other natural energies (sunlight, wind power, etc). Because hot water mixed with steam is returned to the ground, it does not harm the environment.

【Reference】

The Agency for Natural Resources and Energy (2018): The merit of geothermal power generation
http://www.enecho.meti.go.jp/category/resources_and_fuel/geothermal/explanation/development/merit/clean/

Figure 2-12 shows the life-cycle of CO2 emissions by type of power supply. Geothermal power generation, like nuclear power generation and small and medium hydropower generation, has very low CO2 emissions.

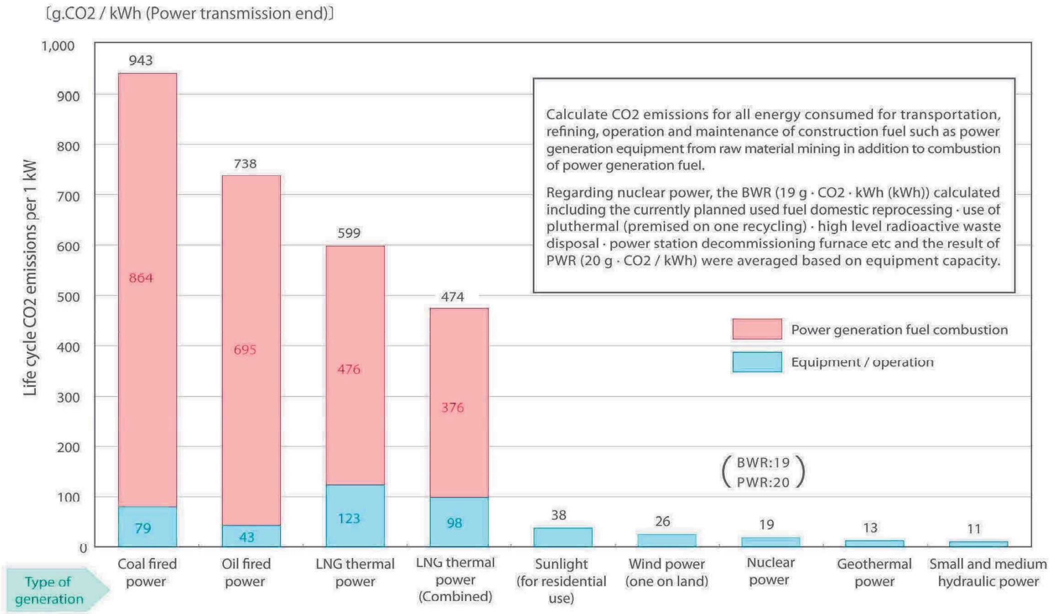


Figure 2-12 Life-cycle CO2 Emissions by Each Power Supply

Source: Japan Atomic Energy Culture Foundation (2018): Drawings of "Nuclear Energy" https://www.ene100.jp/zumen_cat/chap

2.3.3 Geothermal power generation systems

There are two types of systems for geothermal power generation that have already been put into practical use: the widely used flash steam system and the relatively new binary cycle system.

(1) Flash steam system

In the flash steam system, steam and hot water with temperatures between 200 to 350 °C in the geothermal reservoir flow upwards, through a well. The steam is then separated by a steam-water separator and used to rotate a turbine to generate electricity.

The hot water separated by the power steam-water separator is then injected back into the ground through a reinjection well. Most Japanese geothermal power plants use a single flash steam generation system (**Figure 2-13**).

There are also other systems, for example, the double flash steam system and the dry system. The double flash system separates hot water, which is then led to the flasher (low-pressure steam/water separator) and is separated into hot water and steam again. The steam is then sent to the turbine together with the primary steam. The hot water is then sent to a reduction well. Alternatively, the dry steam system draws from underground resources of steam. The steam is piped directly from underground wells to the power plant, where it is directed into a turbine. It does not require a steam/water separator and is used to power turbines.

In Japan, Hatchobaru Power Plant (Kyushu Electric Power Co., Ltd.) and Mori Power Plant (Hokkaido Electric Power Company) use the double flash system, and the Matsukawa Geothermal Power plant (Tohoku Hydroelectric Geothermal) uses the dry steam type.

(2) Binary cycle system

In the binary cycle system, generally, using medium-to-high-temperature hot water or steam of 80°C to 150°C as a heat source, a working fluid, that has a low boiling point, is heated and evaporated; consequently, the turbine is rotated and generates electricity. Working fluids with a boiling point of 100°C or lower such as pentane (boiling point 36.07°C), hydrocarbons, substitute Freon, or ammonia (boiling point -33.34°C) are used. After use, these working fluids are then liquified by a condenser and used repeatedly. This method is called a binary cycle system because hot water and working fluid with a low boiling point, together, generate electricity using two independent thermal circulation cycles (**Figure 2-14**). This system makes it possible to utilize low-temperature hot water and steam which cannot be used in flash steam power system.

【Reference】

NEDO (2014): White paper on renewable energy technology, second edition, chapter 7-Geothermal power generation
http://www.nedo.go.jp/content/100544822.pdf

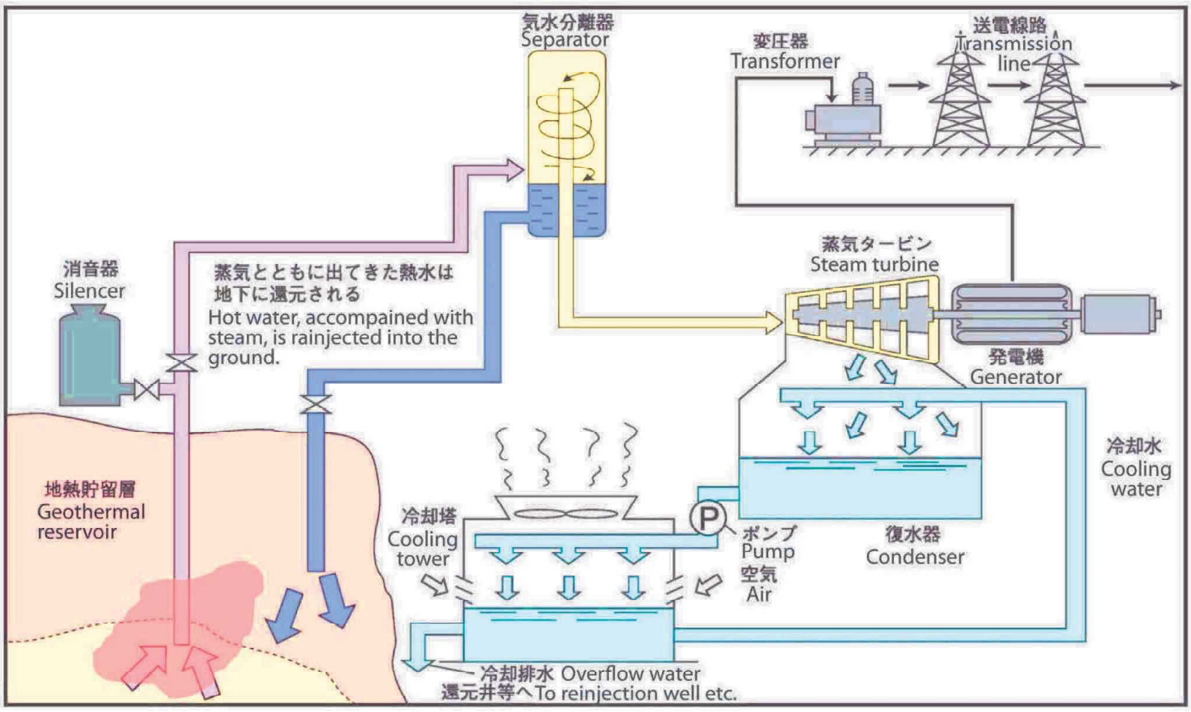


Figure 2-13 Conceptual Diagram of a Single Flash Power Generation System

Source: NEDO (2014): White paper on renewable energy technology, second edition, chapter 7-Geothermal power generation
http://www.nedo.go.jp/content/100544822.pdf

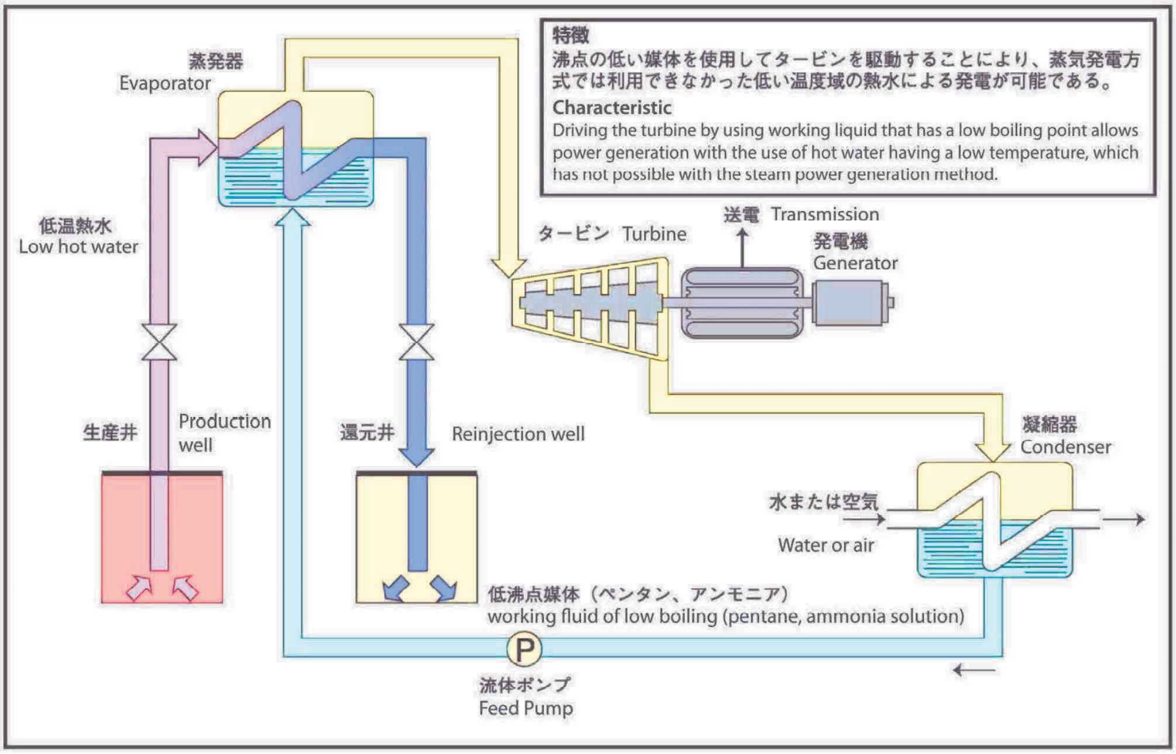


Figure 2-14 Conceptual Diagram of Binary Cycle Power Generation System

Source: NEDO (2014): White paper on renewable energy technology, second edition, chapter 7-Geothermal power generation
http://www.nedo.go.jp/content/100544822.pdf

2.3.4 History of geothermal power generation

Geothermal power generation in Japan began in 1919 when Lieutenant General Yoshihisa Yamauchi succeeded in fumarolic drilling in Beppu, Oita Prefecture. Mr. Heiji Tachikawa, director of the research center of Tokyo Denki Co., Ltd., then took over the project and succeeded in Japan's first geothermal power generation (output 1.12 kW) in 1925. Following Director Tachikawa's work, no major development was seen until the end of World War II.

Postwar Japan needed a stable supply of electric power and promoted the construction of hydropower and large-scale thermal power plants. At that time, the focus was on conducting investigative research and development for practical uses of geothermal power. These efforts finally bore fruit when, in 1966, the Matsukawa geothermal power plant in Iwate Prefecture, a vapor-dominated type plant, started operation as the first full-scale geothermal power plant in Japan. In 1967, the Otake power plant, in Oita prefecture, using the Hot Water excellence system started operations. The success of these two power plants has greatly advanced geothermal development.

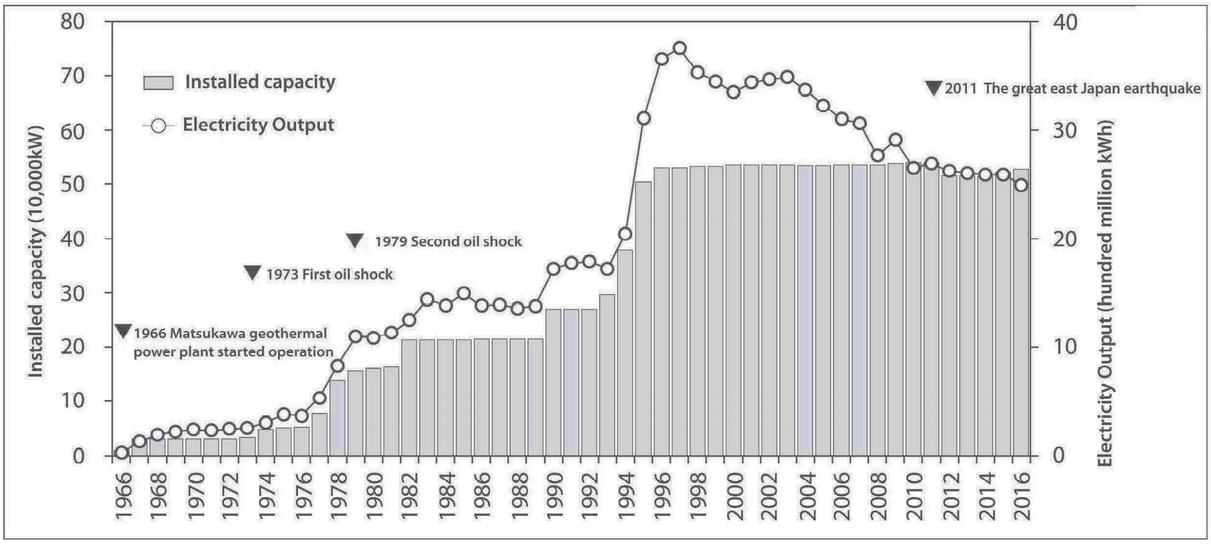
In the 1970s, triggered by two oil shocks, Japanese geothermal development was greatly advanced as the geothermal portion of the Sunshine Project that was initiated in 1974 as an alternative energy policy. In the Tohoku and Kyushu regions, the construction of power plants continued one after another, and in 1996 the installed geothermal power generation reached 500,000 kW. Japan has become one of the leaders in geothermal power generation technology.

In the 1990s, due to the stabilization of oil prices and the conversion of the energy policy in Japan, the development of the geothermal power generation leveled off. The concerns of the cost of power generation, the laws regulating natural parks and the need for harmonious coexistence with hot spring operators all affected further development of geothermal power plants. In 2002, the national technology development budget terminated. Therefore, since 2006, only the Hatchobaru power plant was constructed. However, due to the serious energy crisis caused by the Great East Japan Earthquake, in 2011, the Fixed Price Purchase System (FIT) was introduced. As a result, expectations toward geothermal power generation have increased. It is recognized as a stable power supply based on a renewable energy source.

【Reference】

Source: JOGME HOME＞Geothermal heat, general information＞History of geothermal power generation＞History to date
http://geothermal.jogmec.go.jp/information/history/history.html

Figure 2-15 shows geothermal power generation capacity and generated power. Since 1996, the capacity of power generation facilities has remained flat, but the generated electric energy has decreased due to aging facilities that have weakened power generation efficiency and declined due to scale adhesion.



{Created from Thermal Power Nuclear Power Technology Association (2018)}

Figure 2-15: Secular Change of Installed Capacity and Electricity Output

Source: Thermal Nuclear Power Technology Association (2018): Current situation and trend of geothermal power generation, 2017

2.3.5 The amount of available geothermal heat and potential for introduction by region

Figure 2-16 shows the distribution of the available geothermal heat based on the power supply by area (Source: EX Research Institute Ltd. et al., 2011). **Figure 2-17** shows the conditions of the distribution of potential geothermal heat introduction.

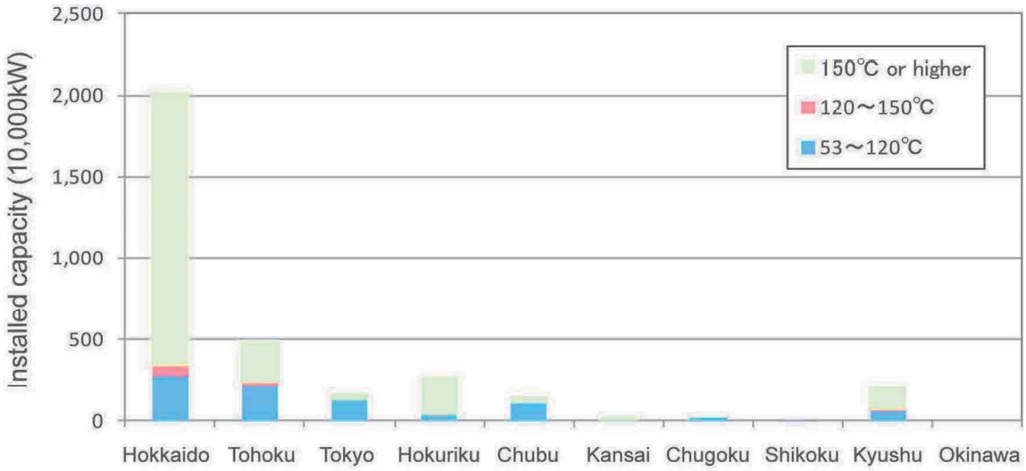
Apart from the amount of available geothermal heat, the natural conditions and social conditions (such as regional classification based on the Natural Parks Act) in individual areas have been taken into consideration.

The amount of available geothermal heat, according to each geographic power supply area, with a temperature of 150°C or more is concentrated in the Hokkaido area, accounting for 71% of the total, followed by the Tohoku area at 11%, the Hokuriku area at 9% and the Kyushu area at 6%. Supply areas with temperatures of 120°C to 150°C show similar distribution conditions.

Available geothermal heat with temperatures of 53~120°C is distributed over a relatively wide geographic range, from 32% in Hokkaido, 25% in Tohoku, 15% in Tokyo and 13% in Chubu. The distribution map for the introduction of potential hydrothermal resource development (53°C ~ 120°C) is shown in **Figure 2-18.**

【Reference】

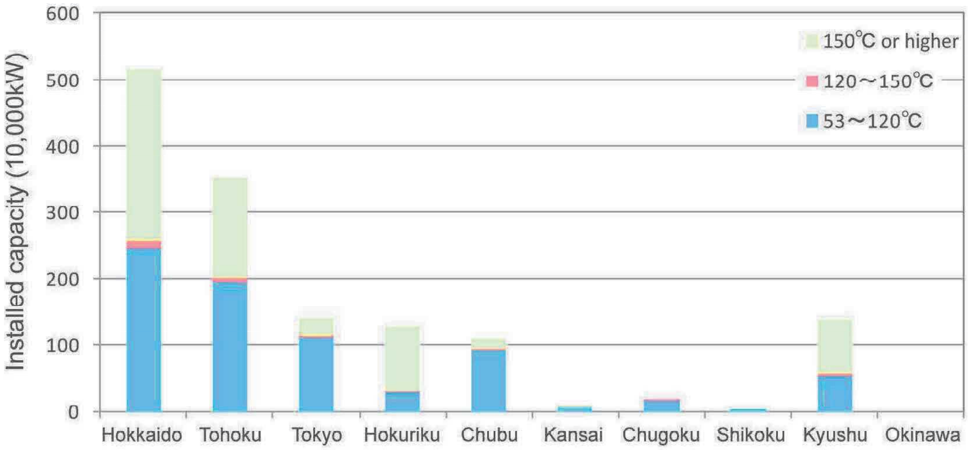
EX Research Institute Co., Ltd. · Asia Aeronautical Corporation Co., Ltd. · Pacific Consultants Co., Ltd. · ITOCHU Techno-Solutions Co., Ltd. (2011): FY 2010 Potential for introducing Renewable Energy Investigation Report, 2010 Ministry of Environment commissioned project, pp.213-225 https://www.env.go.jp/earth/report/h23-03/chpt6.pdf



Temperature	Nationwide	Hokkaido	Tohoku	Tokyo	Hokuriku	Chubu	Kansai	Chugoku	Shikoku	Kyushu	Okinawa
150℃ or higher	2,357	1,674	252	39	220	37	2	0	0	134	0
120～150℃	108	70	16	2	7	3	0	0	0	9	0
53～120℃	849	272	216	128	37	107	8	17	4	60	0
Total	3,314	2,016	484	169	264	147	10	17	4	203	0

Figure 2-16 Distribution of Geothermal Viability by Area

Source: EX Research Institute Co., Ltd. •Asia Aeronautical Corporation Co., Ltd. · Pacific Consultants Co., Ltd. · ITOCHU Techno-Solutions Co., Ltd. (2011): FY 2010 Potential for introducing Renewable Energy Investigation Report, 2010 Ministry of Environment commissioned project, pp.213-225
https://www.env.go.jp/earth/report/h23-03/chpt6.pdf



Temperature	Nationwide	Hokkaido	Tohoku	Tokyo	Hokuriku	Chubu	Kansai	Chugoku	Shikoku	Kyushu	Okinawa
150℃ or higher	636	261	150	28	99	16	0	0	0	82	0
120～150℃	33	12	9	2	3	1	0	0	0	5	0
53～120℃	751	245	194	113	28	93	8	15	4	52	0
Total	1, 419	518	353	142	129	110	8	15	4	140	0

Figure 2-17 Distribution of Potential for the Introduction of Geothermal Power Generation by Area Based on Natural and Social Conditions

Source: EX Research Institute Co., Ltd. • Asia Aeronautical Corporation Co., Ltd. • Pacific Consultants Co., Ltd. • ITOCHU Techno-Solutions Co., Ltd. (2011): FY 2010 Potential for introducing Renewable Energy Investigation Report, 2010 Ministry of Environment commissioned project, pp.213-225
https://www.env.go.jp/earth/report/h23-03/chpt6.pdf

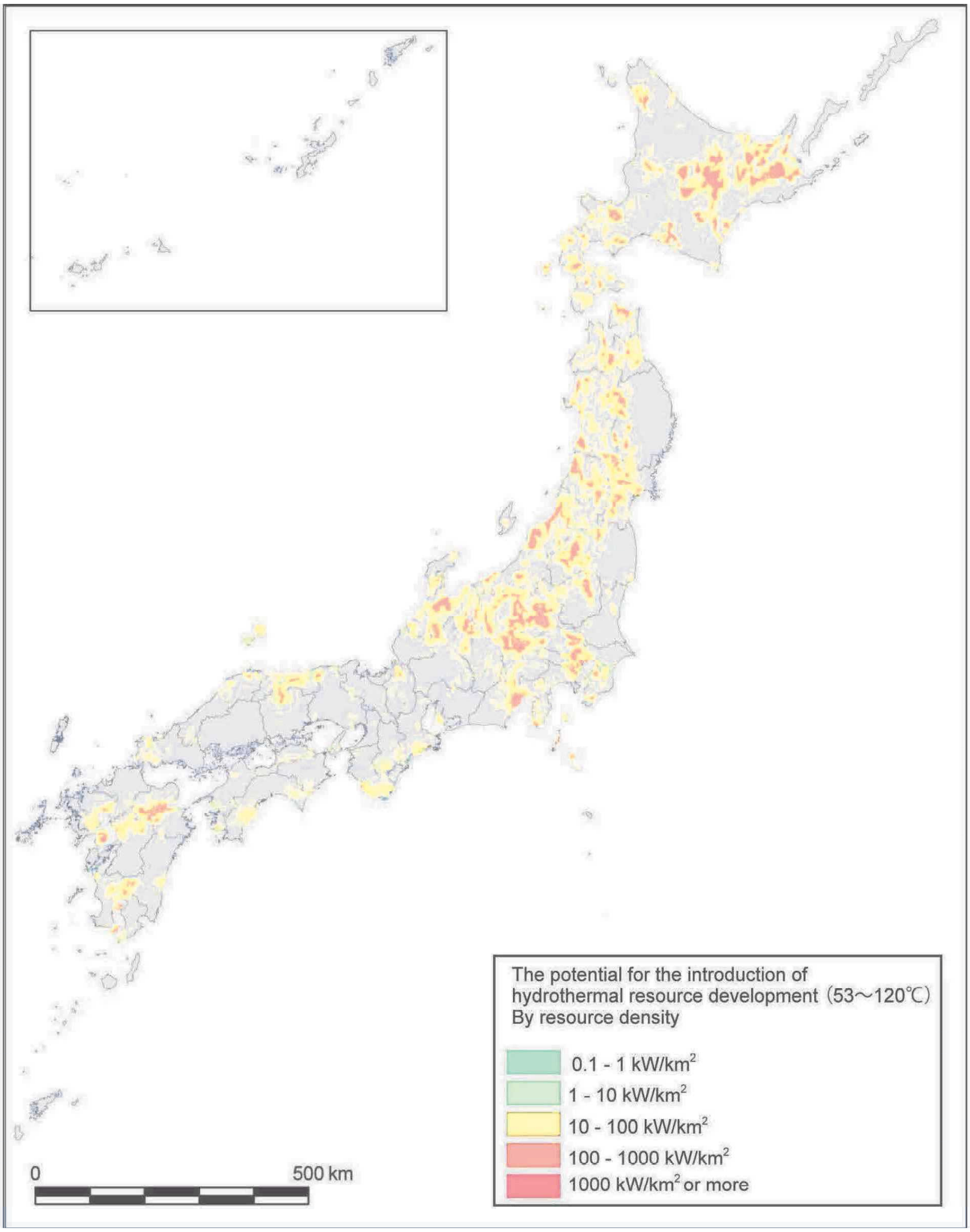


Figure 2-18: Distribution Map showing Potential for Introduction of Hydrothermal Resource Development (53°C ~ 120°C)

Source: EX Research Institute Co., Ltd. • Asia Aeronautical Corporation Co., Ltd. • Pacific Consultants Co., Ltd. • ITOCHU Techno-Solutions Co., Ltd. (2011): FY 2010 Potential for introducing Renewable Energy Investigation Report, 2010 Ministry of Environment commissioned project, pp.213-225
https://www.env.go.jp/earth/report/h23-03/chpt6.pdf

2.3.6 Geothermal power generation by institution

The geothermal power plants in Japan are concentrated in Tohoku and Kyushu due to the distribution of volcanoes and geothermal areas. The total installed capacity of power generation nationwide is about 520,000kW and the total electricity output is 2,559GWh (FY 2015), which covers roughly 0.3% of the electricity demand in Japan.

The largest power plant in Japan is Hatchobaru Power Plant in Oita prefecture, which generates 110,000kW. Other geothermal power plants, for example, are the Hachijojima Geothermal Power Plant in Tokyo, the only plant in Japan located on an isolated island, and the Matsukawa Geothermal Power Plant in Iwate Prefecture. The Matsukawa plant has a 50-year history and was started as the first commercial operation in Japan.
Figure 2-19 shows the location map of major geothermal power plants in Japan.
Table 2.5 shows power generation business operations and their authorized output, power generation systems, and operation start date.

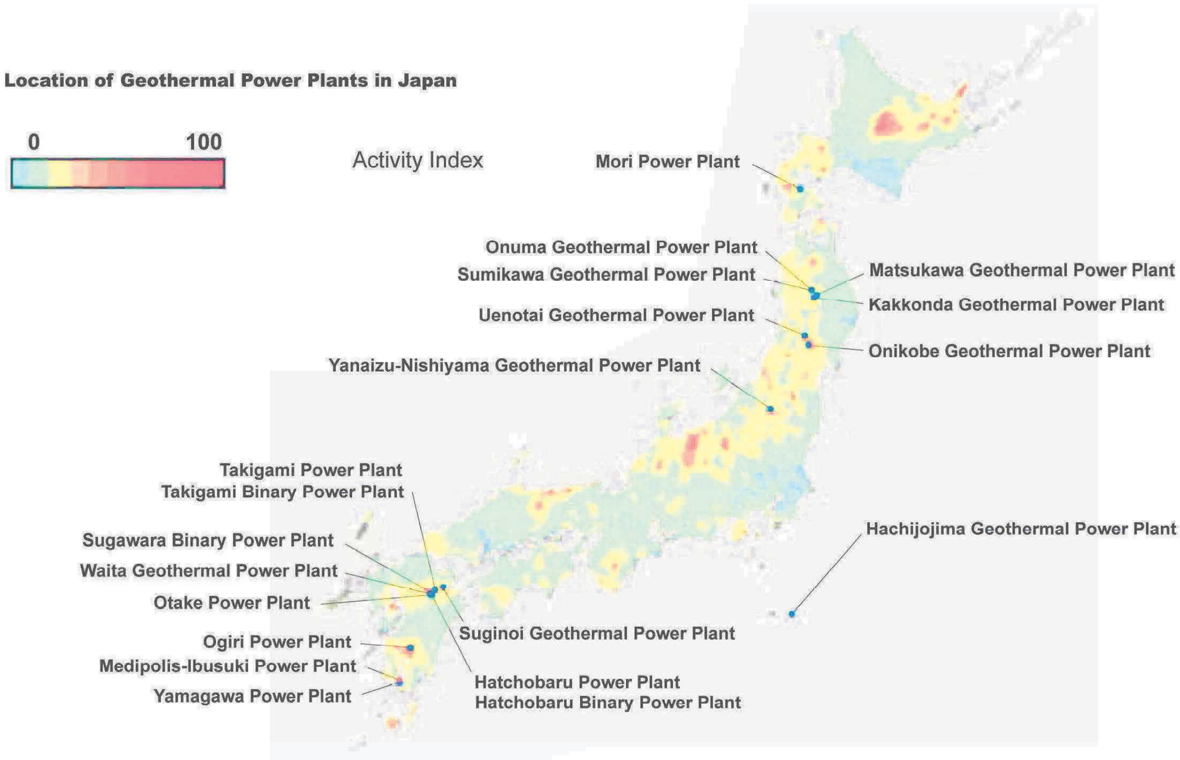


Figure 2-19 Location of Geothermal Power plants in Japan

Source: JOGMEC 2018 : Geothermal Energy to Coexist with the Region and Nature, Brochure
http://geothermal.jogmec.go.jp/report/file/jogmec_geothermal.pdf

Table 2-5 Specifications of Major Power plants

	Location	Generator	Steam/Hydrothermal Supplier	Authorized Output (kW)	System	Start Date	FIT
Mori Power Plant	Mori, Hokkaido	Hokkaido Electric Power Co., Inc.		25,000	DF	1982.11.26	
The Matsukawa Geothermal Power Plant	Hachimantai, Miyagi	Tohoku Sustainable & Renewable Energy Co., Inc.		23,500	DS	1966.10.08	
The Kakkonda Geothermal Power Plant	Shizukuishi, Iwate	Tohoku Electric Power Co., Inc.	Tohoku Sustainable & Renewable Energy Co., Inc	No 1 50,000	SF	1978.05.26	
				No 2 30,000		1996.03.01	
The Onikobe Geothermal Power Plant	Osaki, Miyagi	J-Power		15,000	SF	1975.03.19	
The Onuma Geothermal Power Plant	Kazuno, Akita	Mitsubishi Materials Corporation		9,500	SF	1974.06.17	
The Sumikawa Geothermal Power Plant		Tohoku Electric Power Co., Inc.	Mitsubishi Corporation	5,000		1995.03.02	
The Uenotai Geothermal Power Plant	Yuzawa, Akita	Tohoku Electric Power Co., Inc.	Tohoku Sustainable & Renewable Energy Co., Inc	28.800	SF	1994.03.04	
Yanaizu-Nishiyama Geothermal Power Plant	Yanaizu, Fukushima	Tohoku Electric Power Co., Inc.	Oku Aizu Geothermal Co., Ltd.	65,000	SF	1995.05.25	
The Hachijojima Geothermal Power Plant	Hachijo, Tokyo	Tokyo Electric Power Co., Inc		3,300	SF	1999.03.25	
The Waita Geothermal Power Plant	Oguni, Kumamoto	Waita LLC.		1,995	SF	2014.12	F
The Suginoi Geothermal Power Plant	Beppu, Oita	Kyushu, Beppu Suginoi-Hotel		1,900	SF	2006.04.01	
The Takigami Power Plant	Kokonoe, Oita	Kyushu Electric Power Co., Ltd.	Idemitsu Oita Geothermal Co., Ltd.	27,500	SF	1996.11.01	
The Takigami Binary Power Plant		Idemitsu Oita Geothermal Co., Ltd.		5,050	B	2017.03.01	F
The Otake Power Plant		Kyushu Electric Power Co., Ltd.		12,500	SF	1967.08.12	
The Hatchobaru Power Plant		Kyushu Electric Power Co., Ltd.		(No 1) 55,000	DF	1977.06.24	
				(No 2) 55,000	DF	1990.06.22	
The Hatchobaru Binary Power Plant				2,000	B	2006.04.01	
The Sugawara Binary Power Plant		Kyuden Mirai Energy Company, Incorporated	Kokonoe-machi	5.000	B	2015.06.29	F
The Ogiri Power Plant	Kirishima, Kagoshima	Kyushu Electric Power Co., Ltd.	Nittetsu Mining Co., Ltd.	30,000	SF	1996.03.01	
The Yamagawa Power Plant	Ibusuki	Kyushu Electric Power Co., Ltd.		25,960	SF	1995.03.01	
The Medipolis Ibusuki Power Plant	Kagoshima	Medipolis Energy Co., Ltd.		1,410	B	2015.02.18	F

Power generation system FS Single Flash DF Double Flash B Binary F: Feed-in Tariff system certified power Plant among 38 geothermal power plants, the power plants with approved/certified output of 1000 kW or more are posted.

Source: JOGMEC (2018): Geothermal Energy to Coexist with the Region and Nature, Brochure http://geothermal.jogmec.go.jp/report/file/jogmec_geothermal.pdf

3. Cases in Japan

3.1 Use of hot springs

(1) History of hot springs

With rich geothermal resources, Japan has long utilized hot springs not only for bathing but also for drinking, recuperation, recreation, and sightseeing. Dogo Onsen, Ehime prefecture; Arima Onsen, Hyogo prefecture; and Shirahama onsen, Wakayama prefecture are recognized as the three oldest Japanese hot springs. Iyo-no-yu (currently Dogo onsen) is said to be the oldest referenced hot spring in literature, written about in "Kojiki," "Records of Ancient Matters." This text is the oldest existing chronicle in Japan, dating from the early 8th century (711–712). The Iyo-no-yu area was also the only hot spring county, "Yunokori," in Japan that was named after a hot spring. It was established through the local governmental system known as Kokugunrisei designated by the Taiho Code, the first Japanese administrative code established in 701.

The Iyokoku Fudoki (geographical record compiled by imperial order in 713 CE) mentions in a myth that *Okuni nushi no mikoto* made the hot spring, "Hayami-no-yu" in Oita prefecture. It gushed from the foot of Mt. Tsurumi in Oita, ran through the "shitabi" (culvert) into the Hoyo Channel to Dogo Onsen, and healed Sukunahikonomikoto from illness.

The word ONSEN first appeared in Fudoki. It describes the usage, efficacy, and features of hot springs in various locations. The scenery of the then hot spring areas can be vividly imagined. Some older records written in the Kamakura period (1185～1333) mention that provincial governors and influential temples took control of the hot springs. Samurai and high priests used hot springs as resorts for medical treatment and recreation. In the Edo period (1603～1868), besides the Shogun and Daimyo (feudal lords), farmers and townspeople could use hot springs with permission. Eventually, guidebooks and onsen rankings were published. Hot springs began to be widely used by various citizens throughout the nation.

In the modern age, with the development of drilling technology, the style of hot springs has shifted from the outdoor bath to the indoor bath as used in inns. As a result, hot springs began to have a variety of functions as not only health spas for medical treatment but also as places for recreation and sightseeing.

In the Showa period (1926-1989), the railroad network greatly advanced thus allowing many people to easily visit hot spring resorts. In addition to the remarkable development of hot spring resorts, research began to proceed in various fields such as hot spring geology, medicine, engineering, and planning, along with the establishment of the Geophysical Institute of Kyoto University, now known as Kyoto University Graduate School of Science and the Science Department of Geothermal Research Facility. Also, the Kyushu University Spring Therapeutics Research Institute (currently Kyushu University Hospital Beppu) began in this period.

(2) History and features of hot springs in Oita Prefecture

Hot springs in Oita Prefecture have an ancient history. The Bungo Fudoki (geographical record compiled by imperial order in 713 CE) describes Beppu Onsen, Nagayu Onsen, Amagase Onsen, and Iyokoku Fudoki. It also notes the well-known Beppu onsen "Hamawaki-no-yu" and "Bungo Beppu-no-yu" (both in Beppu). These two are both listed in the hot spring rankings of the period, which suggests that Beppu was already a very popular hot spring resort at the time of publication.

Depending on the quality of the water content, hot springs are classified into 10 types. The Beppu onsen are called "Beppu Hatto" or the Eight Hot Springs of Beppu. These springs contain eight different types of water quality. They do exclude two types: the "spring containing iodine" and the "radioactive spring."

In addition to boasting a varied number of spring sources and record amounts of gushing spring water, the Beppu onsen are attractive for other remarkable reasons. Beppu residents can draw hot spring waters into their homes; neighbors share communal bathhouses; and people living in the same apartment building can use a communal bathroom, thus making hot spring culture a vital part of life in the community.

【References】

Ishikawa Michio (2018): History of hot springs, hot springs in the Kojiki and the Nihon Shoki, warrior's secret hot spring, hot springs ranking, Chuko, p. 248

Daigin Economic Management Institute (2017): Oita hot spring white paper, p. 168

3.2 Examples of hot water utilization

3.2.1 Examples of greenhouse cultivation use

The most representative of the plants cultivated using steam and hot water in greenhouses throughout Japan are vegetables. These include tomatoes, cucumbers, mitsuba, paprika, fruits such as strawberries, tropical fruit, mangoes, fungal bed shiitake mushrooms, and flowers including the butter orchid and cyclamen.

The Mori geothermal power plant in Mori-machi, Hokkaido that started in 1982, is a typical example of hot spring use for vegetable cultivation. It has a rated output of 25,000 kW. At this power plant, after separating and extracting steam for power generation, a portion of the hot water, at 120°C, is returned to an underground reinjection well. That well leads to a heat exchanger and is then mixed with river water. That hot water, at around 65°C, is obtained by a heat exchanger and is then distributed to a neighboring greenhouse complex. Within the greenhouses, hot water piping is installed on the ground and heats the room to over 25℃, even when the outside air temperature is -15°C. Tomatoes and cucumbers are grown, throughout the year, and they are shipped to the Kanto region, earning revenue.

The mango of Teshikaga, Hokkaido is a typical example of fruit cultivation. Hot water is drawn from the source at 80°C and at 160L/min and is used to maintain greenhouse internal temperature from 23°C to 25°C throughout the year. The ripened mango has been developed into a brand known as "The Sunset of Lake Mashu" and is shipped to Tokyo, making a profit and contributing to the regional economy (See **Figure 3-1**).

Figure 3-1: Mango Cultivation in Teshikaga Town
(Photographed by Engineering Association)

Source: Okumura Tadahiko (2018): Case Study of Binary Power Generation and Hot Water Utilization, Geology, and Survey, No. 2, 2018, pp. 19-24

Another example of fruit cultivation is banana seedlings at the "Okuhida Farm" at the Okuhida Onsen in Gifu Prefecture. At an altitude of 800 m above sea level, hot spring water with an average temperature of 65°C and 25L/min flows into a waterway in the greenhouse and provides internal heat throughout the year. Because edible bananas are sold at low prices, ornamental banana seedlings are directly sold through the internet and are a source of revenue. (See **Figure 3-2**)

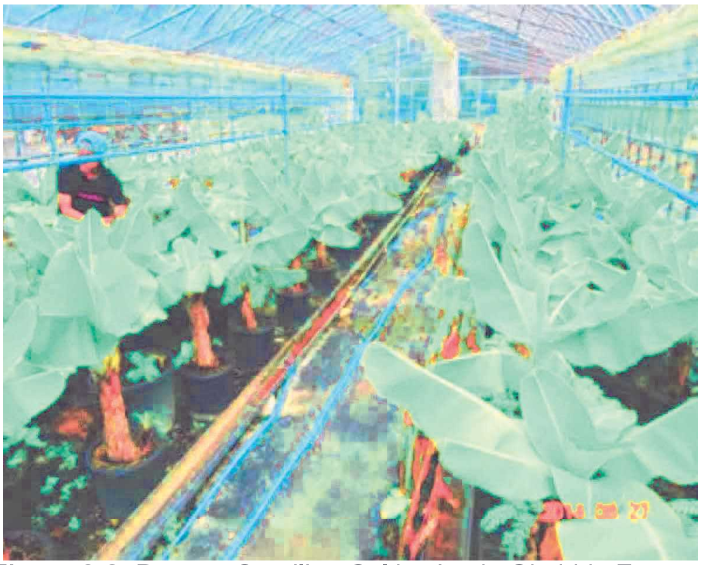


Figure 3-2: Banana Seedling Cultivation in Okuhida Farm
(photographed by Engineering Association)

Source: Okumura Tadahiko (2018): Case Study of Binary Power Generation and Hot Water Utilization, Geology, and Survey, No.2, 2018, pp. 19-24

Shiitake mushrooms are cultivated by the "Adonis Co., Ltd." in the Hotta hot spring district in Beppu, Oita Prefecture. A greenhouse was built to cultivate shiitake mushrooms using grants from the Ministry of Economy, Trade and Industry's geothermal development and promotion project. (See **Figure 3-3**) Oita prefecture is famous for its shiitake mushrooms and cultivation techniques. This method of growth is evaluated as being highly productive.

Figure 3-3: Shiitake cultivation at Adonis Co., Ltd.
(Photograph by Engineering Association)

Source: Okumura Tadahiko (2018): Case Study of Binary Power Generation and Hot Water Utilization, Geology, and Survey, No.2, 2018, pp. 19-24