An Introduction of Kyuden Group's Geothermal Power Plants in Kyushu Island, Japan

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ABSTRACT

Kyushu island, located in the southern part of Japan, is one of Japan's most famous geothermal resource areas.

Kyushu Electric Power Company, a major power company in Japan, supplies over 16 GW of electricity to Kyushu island. Together with its subsidiaries, the company forms the Kyuden Group, which owns geothermal power plants with a combined capacity of 224 MW across eight sites in Japan. In addition to domestic operations, the group is also actively investing in overseas geothermal power plants.

The development of Japan's first commercial geothermal power plant began with a resource survey at the Otake site in 1949. Initial findings revealed that the geothermal fluid was hot water dominated, which at the time was considered unsuitable for power generation, leading to the suspension of the project. Meanwhile, New Zealand succeeded to operate a single flash geothermal power plant with the separation of steam and hot water. Kyushu Electric Power was encouraged by this fact and resumed the development of the geothermal power plant in Otake area and completed it in 1967. This power plant is still in operation as of today, following a major upgrade in 2020, that increased the capacity from 12.5 MW to 14.5 MW. The success of the Otake power plant led to further development of flash geothermal power plants such as Hatchobaru (55 MW x 2 units), Yamagawa (30 MW), Ogiri (30 MW), Takigami (27.5 MW) and binary power plants (totaling approximately 12 MW).

This paper presents a historical overview and the latest developments of geothermal power generation by the Kyuden Group, with a particular focus on Otake and Yamagawa Power Plant, which includes both flash and binary systems.

1. INTRODUCTION

Currently the Kyuden Group is engaging in geothermal development through its group companies. These include Kyuden Mirai Energy, which is responsible for the development and operation of domestic renewable energy power plants; WestJEC, which provides technical consulting services; and Kyuden International, which focuses on investment in overseas power projects.

1.1 History of Kyuden Group's geothermal development

The Kyuden Group's geothermal development history began in 1949, when Kyushu Electric Power started surveying and development in Otake and Hatchobaru areas. After overcoming numerous difficulties, Otake Geothermal Power Plant started operations in 1967 as the first hot water dominated and single-flash type geothermal power plant in Japan. Furthermore, based on the achievements of Otake Geothermal Power Plant, Hatchobaru Geothermal Power Plant Unit No.1 was commissioned in June 1977. It introduced the world's first two-phase flow transportation pipeline system and became the first double-flash type geothermal power plant globally. Hatchobaru Unit No.2 started to operate in June 1990, bringing the total output of the facility to 110 MW, positioning it among the leading geothermal power plants worldwide.

Subsequent developments included the Yamagawa Geothermal Power Plant, which started commercial operation in March 1995, followed by the Ogiri Geothermal Power Plant in March 1996, and the Takigami Geothermal Power Plant in November 1996.

Subsequently a 2 MW binary cycle power facility was built at Hatchobaru. After successful pilot testing, it started commercial operation in April 2006 as the Hatchobaru Binary Power Plant. In June 2010, the rated output of Takigami Power Plant was changed to 27.5 MW. Further modernization efforts led to an upgrade of the Otake facility in October 2020, increasing the rated output to 14.5 MW. As a result, Kyushu Electric Power's geothermal power generation capacity reached 214 MW.

In parallel, Kyuden Mirai Energy started to operate Sugawara Binary Power Plant in June 2015, as one of the largest binary power plants in Japan. It effectively utilize low temperature geothermal fluid that is unsuitable for conventional flash geothermal power plants. The Yamagawa Binary Power Plant followed, starting commercial operation in 2018.

1.2 Geothermal features of Kyushu Island

Kyushu, the third-largest island in Japan, is located in the southwest of Japan. It is home to prominent active volcanoes, such as Mt. Aso and Sakurajima, and is widely known for its abundant hot springs and sand baths. These natural features have contributed to a long-standing familiarity with geothermal energy among local communities. Utilizing these rich geothermal resources, the Kyuden Group has consistently surveyed geothermal resource and developed geothermal power plants in this region. Currently, Kyuden Mirai Energy holds approximately 40% of the total permitted output capacity for geothermal power generation in Japan, underscoring its leading role in the sector.

The location of Kyuden Mirai Energy's geothermal power plants in Kyushu are shown in Figure 1.

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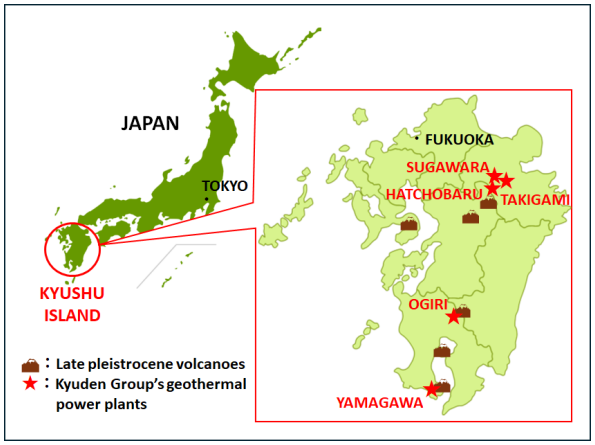

Figure 1: Location of Kyuden Group's Geothermal Power Plants

2. OTAKE GEOTHERMAL POWER PLANT

The Otake Geothermal Power Plant is located in Kokonoe Town, Oita Prefecture, near the Kuju Mountains Range. This area is geographically notable for its proximity to a national park to the east and south, and quasi-national park mountains to the west. The plant began operations in 1967 with an installed capacity of 11.0MW, which was then increased to 12.5 MW in 1979. Although the facility had experienced challenges such as reductions in steam supply and scale deposition, it had achieved a high cumulative utilization rate of approximately 80%. After decades of operation since its launch in 1967, the plant underwent a major renovation in 2020, boosting its generation capacity to 14.5 MW.

In addition to power generation, this power plant contributes to the local community by providing hot water, heated by geothermal brine after power generation, for free of charge to be utilized for heating system etc. To address concerns about potential impacts on local businesses such as spas, agriculture and daily life, regular monitoring of adjacent rivers and hot springs are being provided. These efforts contribute to mutual prosperity and sustainable coexistence between the local community and the power plant.

2.1 History of development in the Otake geothermal area

The development of the Otake Geothermal Power Plant was influenced by geothermal practices originating from New Zealand. Kyushu Electric Power initiated exploratory drilling in the Otake area to obtain sufficient baseline data in pursuit of commercializing geothermal power generation. From 1953 to 1956, four test wells were drilled to depths of appriximately 300 to 450 meters. Although all of the wells produced steam, it was wet steam mixed with hot water, rather than the anticipated superheated steam. At that time, geothermal power generation was largely based on the use of superheated steam, as exemplified in Italy. An European third-party review concluded that the potential of discovering a viable reservoir was low, leading to a temporary suspension of the Otake development project.

After a two- to three-year hiatus, Kyushu Electric Power learned of New Zealand's successful implementation of the hot water separation method for geothermal power generation. Encouraged by this breakthrough, Kyushu Electric Power initiated the research of this separation system. In collaboration with Kyushu University, a centrifugal separator was installed in one of the test wells, and operational tests were conducted. Based on the results of geophysical surveys and geological investigations in addition to the operational test, a promising geothermal area in the Otake region was identified. After the drilling of production steam wells in 1963, Otake Geothermal Power Plant was commissioned in 1967.

After more than 50 years of continuous operation, the plant faced increasing challenges in maintenance because of significant equipment deterioration over time and the discontinuation of spare parts production. Despite these operational constraints, geothermal reservoir assessments confirmed that the subsurface resources remained stable and sufficient. In response, a decision was made to upgrade the facility to enhance the efficiency of geothermal energy utilization and ensure long-term sustainable operation.

2.2 Specifications of the Otake Geothermal Power Plant

The power plant specifications before and after upgrading are indicated in Table 1.

Table 1: Specification of the Otake Geothermal Power Plant before and after upgrading

		Before upgrading	After upgrading
Commissioned Date		August 1967	October 2020
Rated output		11.0 MW (Increased to 12.5 MW in 1979)	14.5 MW
Manufacture of STG		Mitsubishi Heavy Industries	
Turbine	Type	Single flash, condensing	Double flash, condensing
	Steam pres./ temp	0.235 MPa / 125 °C	0.320 MPa /135.7°C, 0.205 MPa / 121.0 °C
Steam Generation System	New	-	Flash tank
	Existing	Separator	
Production well		5 wells	
Injection well		6 wells	

As part of the Otake Geothermal Power Plant upgrade project, only the surface facilities were renewed, while the existing wells and steam gathering system were retained.

One of the major upgrades of the new power plant, was the change from single flash system to double flash system. In the previous facility, steam from production wells with various wellhead pressures was gathered in one header and supplied to the steam turbine. In contrast, the upgraded turbine uses dual pressure steam, primary steam from high-pressure production wells and the low-pressure steam which is generated by low-pressure production wells and flashing the separated hot water from the primary steam system. This modification provides an additional 2 MW of electricity output compared to the original power plant.

A system overview of the upgraded Otake Geothermal Power Plant is indicated in Figure 2.

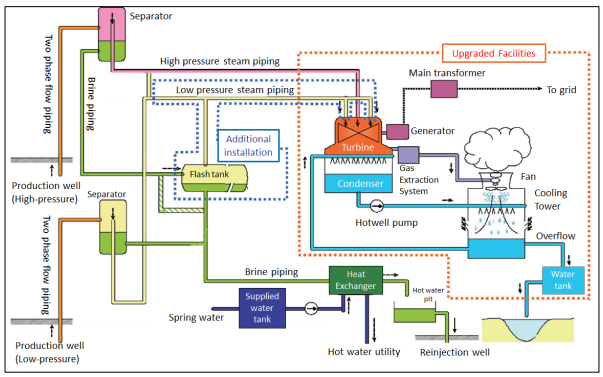

Figure 2: System overview of upgraded Otake Geothermal Power Plant

2.3 Construction of the new power plant

To minimize downtime and income loss of electricity sales, the existing power plant continued operation through the construction of the new facility. The new plant was built on adjacent land (as shown in Figure 3) and once it was completed, interconnection piping between the new and existing systems was installed. As a result, the total shutdown period was only 4 months.

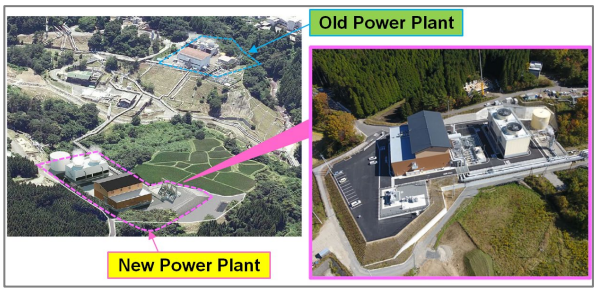

Figure 3: Overview of the former and upgraded Otake Geothermal Power Plant

The site of an inactive reinjection well from an existing facility was repurposed as the installation area for the new power plant, minimizing the need for land alteration. Because of this decision, the construction area was quite small which required careful planning and coordination, especially for the transport and placement of heavy machinery and large vehicles. To mitigate the impact on the surrounding community, including traffic congestion and construction-related noise, a dedicated access road was constructed specifically for the delivery of large equipment. Despite additional challenges posed by the COVID-19 pandemic and sub-zero temperatures due to the site's high elevation (approximately 900 meters), the project was successfully completed on schedule. This achievement reflects the effective management and resilience of the construction team under difficult conditions.

3. YAMAGAWA GEOTHERMAL POWER PLANT

The Yamagawa Geothermal Power Plant is situated in Ibusuki City, in the southern region of Kyushu Island, overlooking Kagoshima Bay. Unlike most geothermal power plants in Japan, which are typically located in mountainous terrain, Yamagawa is positioned on flat land surrounded by agricultural fields. The wells and the steam gathering system were originally developed by another company in 1995. However, in 2005, this company withdrew from the project, citing that the project would not be economically viable due to a higher-than-expected water ratio in the geothermal fluid. Initially, Kyuden Group was responsbible only for the surface facilities, but following the other company's withdrawal, Kyuden Group expanded its scope to include the resource gathering system.

In 2018, Kyuden Group implemented a dual reinjection strategy combining low-temperature pump reinjection in addition to the conventional high-temperature natural reinjection. This approach was designed to enhance reinjection performance and enable the supply of hot water to the binary system. The current system of Yamagawa power plant and the binary power plant is indicated in Figure 4.

Due to the plant's coastal location, the geothermal fluid contains salinity levels comporable to seawater. To manage this, both the flash and binary power plant apply high-performance brine separators. To mitigate corrosion in the binary power plant, super duplex stainless steel is used in the heat exchange tubes of both the preheater and evaporator.

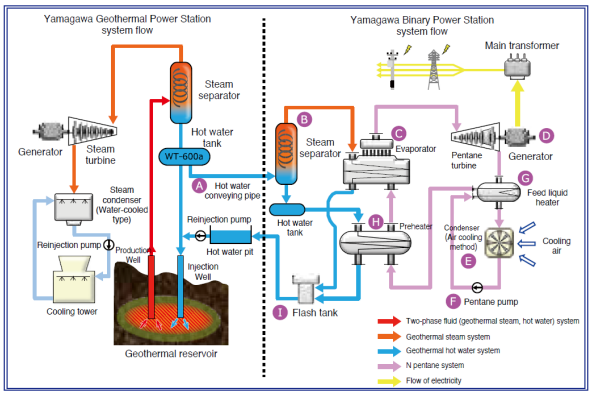

Figure 4: System overview of Yamagawa and the binary power plant

3.1 Specifications of Yamagawa Geothermal Power Plant (Flash)

The specifications of Yamagawa Power Plant are indicated in the following Table 2.

Table 2: Specifications of Yamagawa Power Plant

Rated output		30 MW
Manufacturer of STG		Mitsubishi Heavy Industries
Commissioned Date		March, 1995
Turbine	Steam pres./temp./flow rate	0.98 MPaA / 183.2 °C / 225 t/h
	Type	Single-flash, condensing
Condenser	Vacuum	88.1 kPa
	Type	Direct contact type
Land area		Approx. 157,800 m^2
Production well		7 wells
Reinjection well	high-temp -natural	5 wells
	Low-temp	4 wells

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	-pump	

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3.2 Specifications of the Yamagawa Binary Geothermal Power Plant

The Yamagawa Binary Power Plant is one of the largest binary power plants in Japan and is the Kyuden Group's third binary geothermal power plant, following Hatchobaru Binary Power Plant and Sugawara Binary Power Plant. Unlike its predecessors, which adopted foreign-manufactured binary systems, Yamagawa Binary is the first project to utilize a domestically manufactured binary system. The plant's specifications are indicated in Table 3 and an overview image is shown in Figure 5.

Table 3 : Specifications of the Yamagawa Binary Geothermal Power Plant

Rated output		4.99 MW
Manufacturer of main machine		Fuji Electric Co., Ltd
Commissioned Date		February 2018
Geothermal fluid	Pressure/ Temperature/ Flow rate	0.97 MPaA / 178.6 °C / 584.7 t/h
Steam of geothermal fluid		0.38 MPaA / 142.8 °C / 41.7 t/h
Hot water of geothermal fluid		0.40 MPaA / 143.6 °C / 543.0 t/h
Power generation facility size		Approx. 5,500 m^2

Figure 5: Overview of Yamagawa Binary Power Plant

The introduction of low-temperature pump reinjection has contributed to the capacity of reinjection wells at the Yamagawa (flash) Geothermal Power Plant, leading to improved utilization rates.

In recognition of its innovative efforts to address technical challenges, such as corrosion and scaling caused by high temperatures and high concentrations of hot water, the plant was awarded the "New Energy Award" in 2019. This award also acknowledged the plant's potential to promote the broader adoption of geothermal power generation.

3.4 Coexistence and prosperity with the local community

The Yamagawa Geothermal Power Plant utilize surplus steam to supply heat to nearby farms. Heat is supplied to greenhouses for growing phalaenopsis orchids, ornamental plants, mangoes and other crops. In addition to its heat contributions, the plant features an exhibition room that showcases the appeal of Ibusuki City, where the power plant is located. Ibusuki is renowned for its sand spa that utilize geothermal energy, and the people in this area have a long history of incorporating geothermal energy into their daily lives. The Yamagawa Geothermal Power Plant continues to operate as a community-based facility, beloved by the local community for its role in supporting both local agriculuture and tourism.

Figure 6 : Greenhouses heated by surplus steam from Yamagawa Geothermal Power plant (left) and local specialities of Ibusiki city displayed in the plant's exhibition room (right)

4. CONCLUSION

The Kyuden Group has a long-standing history in geothermal development and operations in Japan. Currently, the group is actively engaged in both the maintenance of aging facilities and the development of new geothermal projects, including both flash and binary systems in Japan. In a strategic move to strengthen its technological capabilities, Kyuden International acquired the U.S.-based comapny THERMOCHEM Inc. in 2020, complimenting its existing partnership with WestJEC.

Leveraging its extensive expertise in development, maintenance, operation, and community engagement, Kyuden Mirai Energy remains committed to ensure the stable operation and continued expansion of geothermal power generation in Japan. Meanwhile, Kyuden International is proactively advancing investments and providing support for geothermal power projects overseas.

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