# Development of Hybrid Geothermal-Biomass Power Plant in Japan

**Yoshinobu Nakao**

**Central Research Institute of Electric Power Industry, Yokosuka-shi, Kanagawa-ken, Japan**
**y-nakao@criepi.denken.or.jp**

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## ABSTRACT

Geothermal energy is the clean and sustainable heat that lies beneath the earth's surface, and it is considered a renewable energy resource. A geothermal power plant has negligible environmental impact (approximately 0.015kg-$CO_2$/kWh) and can help reduce carbon dioxide emissions to the atmosphere. Although geothermal energy is potentially a very valuable domestic power source for Japan, much of the geothermal resource base in Japan cannot yet be economically used. Therefore, many industries and research institutes in Japan have researched and developed technologies to harness geothermal energy.

We have started to develop highly efficient hybrid geothermal power plants combined with other thermal energy sources such as biomass, solar heat and exhaust heat from fuel cells. It is expected that the thermal efficiency of these systems can be improved by superheating the main flow of steam through the use of the other energy sources. We have looked into the feasibility of these hybrid power plants in terms of their engineering, economic performance, environmental laws and regulations. To report the latest status of this project executed by CRIEPI in 2015, in this paper, we discuss the plant performance of our hybrid geothermal power generation systems.

This project was supported by the New Energy and Industrial Technology Development Organization (NEDO) program (2013 - 2017). NEDO is a semi-governmental organization in Japan set up to promote the development and introduction of new energy technologies.

## 1. Introduction

Japan has about 100 active volcanoes and the world's third largest reserves of geothermal resources after United States and Indonesia. However, its geothermal generation capacity is ranked only eighth and has not improved in the last decade. The last commercial geothermal plant to be built in Japan was in 1999 on Hachijo Island, which is located about 300 kilometers south of Tokyo and is operated by Tokyo Electric Power Company.

Currently, 35 geothermal power plants (flash and binary) at 32 sites, mainly located in northern Honshu and Kyushu are in operation with a total generation capacity of 521MWe, amounting to about 5% of the world's total capacity of geothermal power plants.[1]

### *1.1 Obstacles to Geothermal Development*

As stated above, even though Japan has one of the largest reserves of geothermal resources (geothermal potential) in the world, the geothermal power generation capacity in Japan is very limited. This is because of various mainly social and political obstacles.[2]

The first obstacle is national parks. More than 80% of Japan's geothermal potential lies within national parks. Because of environmental protection laws, the development of geothermal energy plants and the drilling of wells have been strictly restricted. Rules set in the 1970s suspended the construction of new geothermal power plants inside national parks except for at six sites in operation or under construction at the time. Without reforming the regulations that restrict the development of geothermal power plants within national parks, the geothermal potential that Japan possesses has limited use and cannot be effectively used to produce electricity.

The second obstacle is hot springs. Japan's rich geothermal potential has made it famous for its numerous hot springs and the culture that developed with them. Currently Japan has more than 25,000 hot springs, and 90% of the direct use of geothermal energy in Japan is for hot springs. This means that geothermal development in Japan has been focused on its use for hot springs. Many hot spring owners worry about a reduction or the exhaustion of their resources, thus many of them resist or disagree with the development of geothermal energy plants. Some of them even refuse to permit research on the geothermal potential near their hot springs.

The third obstacle is, until recently, a lack of governmental support for geothermal development. Geothermal energy was recognized as a "new energy" until 1997. However, since then geothermal energy has been excluded from the definition of new energies, subsidies were reduced every year. On the other hand, Japan enacted a renewable portfolio standard law (RPS law) in 2003. This law requires electric companies to produce a certain amount of electricity by renewable resources to increase their use and expand the market for renewable energy. However, geothermal energy (flash steam power plants) was also excluded from the RPS law. Since then, geothermal energy has lost support from the government.

The fourth obstacle is the cost. Normally, it takes at least 15 years to recover the capital through profits in Japan. Their high initial cost gives geothermal energy plants a high risk and low return compared with other power plants. Furthermore, in addition to the construction cost, the drilling of wells, PR to ensure public acceptance and the cost of land increase the total cost. There is even a research cost in finding out the amount of available geothermal energy. These facts make geothermal energy a difficult industry to develop. Moreover, since the government has stopped supporting geothermal energy, the cost problem has become even more critical.

### *1.2 Decision of Japanese Government [3]*

The Japanese Minister of the Environment, N. Ishihara, issued the statement below at COP19. As a result, industry, academia and the government are making efforts to reduce costs by improving technology and changing regulations to enable the wider utilization of geothermal energy. "Japan will establish a low-carbon society through various policy tools and we strategically promote mitigation measures. We will enhance the development and demonstration of renewable energy-related technologies such as offshore wind power, geothermal power and rechargeable batteries."

### *1.3 Potential for the Introduction of Geothermal Energy [4]*

The Ministry of the Environment (MoE) in Japan conducted a study on the potential for introducing renewable energies in 2012. Its aim was to estimate the abundance of renewable energies (PV power, wind power, small and medium-scale hydroelectric power, geothermal power, solar heat and geothermal heat) as well as the amount of power that could be produced under different scenarios with a view to obtaining basic data for the examination of viable measures to introduce and spread the use of renewable energies in future years as well to prepare basic zoning information.

In the final report, the basic introduction potential of geothermal energy was estimated as 2.33 million kW, the conditional introduction potential 1 was estimated as 5.34 million kW and the conditional introduction potential 2 was estimated as 8.48 million kW. The estimated conditions of each potential, are as follows.

- the Basic Introduction Potential ： Non National / Quasi-National Park, Non Slant Drilling
- the Conditional Introduction Potential 1 ： Non National / Quasi-National Park, Slant Drilling
- the Conditional Introduction Potential 2 ： National / Quasi-National Park, Non Slant Drilling

## 2. Project Overview

In Japan, over 10 projects related to geothermal technology are currently in progress. At MoE, three demonstration projects have been conducted to promote social acceptance and to maintain a balance between the development of geothermal power and the protection of national parks. Also, at national institutes under the jurisdiction of Ministry of Economy, Trade and Industry (METI), 11 practical studies have been conducted with the aim of reducing the cost and development risk of geothermal power plants. Currently, when some projects under local coordination are added, we have 21 big projects in Japan and their total generation capacity is approximately 560 MWe.

Our project is supported by New Energy and Industrial Technology Development Organization (NEDO). NEDO is a semi-governmental organization under the jurisdiction of METI set up to promote the development and introduction of new energy technologies. We have started to develop highly efficient hybrid geothermal power generation systems combined with other thermal energy sources such as biomass, solar heat and exhaust heat from fuel cells. It is expected

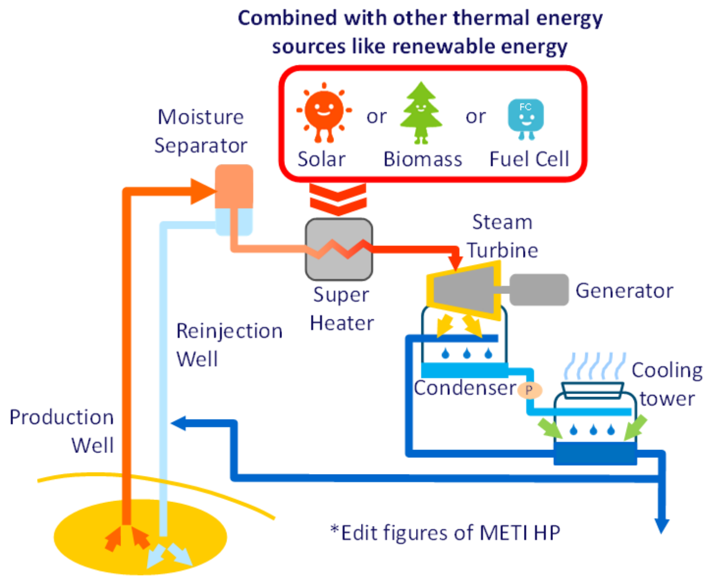


Figure 1. System configuration of hybrid power plant.

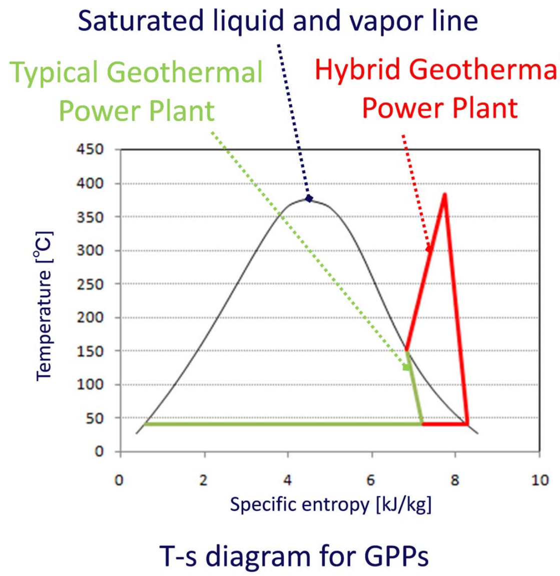


Figure 2 .T-s diagram of hybrid power plant.

that the thermal efficiency of these systems can be improved by superheating the main flow of steam through the use of the other energy sources. Although a Japanese patent was obtained for this technology more than 30 years ago, a detailed study of a system based on this technology has never been carried out in Japan.

Figure 1 shows the system configuration of hybrid power generation system, and Figure 2 shows the T (Temperature) - s (Entropy) diagram of it. In this project, our aim is to develop systems with high efficiency by effectively combining geothermal energy and other types of thermal energy. In a typical geothermal power plant, the turbine inlet steam is saturated. To obtain only a small heat drop in the turbine, the thermal efficiency of the system must be much lower than that of a thermal power plant. Therefore, we have investigated the idea of improving both the power output and the thermal efficiency of geothermal power plants by superheating the turbine inlet steam up to approximately 400°C.

In this study, we have looked into the feasibility of these hybrid power generation systems in terms of their engineering, economic performance, environmental laws and regulations [5].

## 3. Target Capacity

In this project, the generation capacity of the hybrid geothermal power plant was determined to be approximately 4,000 kilowatts for the following reasons.

In the feed-in tariff (FIT) scheme, geothermal energy is purchased for 40yen/kWh for smaller plants.

When constructing a power plant, it is necessary to investigate the environmental impact by performing an environmental assessment. If the generation capacity is small, the procedure of the environmental assessment could be simplified.

As an example of best practice with minimum impact on the environment, MoE is promoting the Hachijo Island geothermal power plant.

### *3.1 FIT Scheme [6]*

The bill to introduce the FIT scheme for renewable energy was adopted by the Japanese parliament in July 2011. Table 1 shows FIT rate and period. The purchase rate and period are decided every year and depend on the type of energy, the form of installation and the scale of the renewable energy source. All of the generated renewable electricity

Table 1. FIT rate and period [6].

| Source | Capacity or Category | Rate w/o tax (JPY per kWh) | Period (year) |
|---|---|---|---|
| Geothermal | ≧15,000 kW | 26 yen | 15 |
| | < 15,000 kW | 40 yen | |
| PV | ≧10 kW | 27 yen | 20 |
| | < 10 kW | 33 – 35 yen | 10 |
| Wind | ≧20 kW | 22 yen | 20 |
| | < 20 kW | 55 yen | |
| Offshore wind | ≧20 kW | 36 yen | |
| Hydro | ≧30,000 kW | 24 yen | 20 |
| | ≧1,000 kW | 29 yen | |
| | < 200 kW | 34 yen | |
| Biomass | Biogas | 39 yen | 20 |
| | Lumber, unused (≧2,000 kW) | 32 yen | |
| | Lumber, unused (< 2,000 kW) | 40 yen | |
| | Lumber, general | 24 yen | |
| | Waste biomass | 17 yen | |
| | Lumber, recycled | 13 yen | |

$1 (USD) ≒ 100 yen (JPY)

(excess electricity produced by residential renewable energy equipment) is purchased at a fixed price. It has been decided that geothermal energy will be purchased for 26 yen/kWh for plants with a capacity of 15,000kW or larger and 40 yen/kWh for smaller plants for the next 15 years. At the date of 6 May 2016, Wasabizawa geothermal power plant is the only project, that was applied FIT scheme.

### *3.2 Environmental Assessment*

In Japan, when a power plant of more than 7,500kW is constructed, it is necessary to carry out some kind of an environmental assessment. However, if the generation capacity is less than 7,500 kilowatts, the procedure of the environmental assessment is simplified.

### *3.3 Relaxation of Regulations on Development in National Parks*

Although geothermal power generation should be promoted as an environmentally friendly energy system, more than 80% of Japan's geothermal reserves lie in national parks. Therefore, MoE has relaxed regulations on geothermal power generation in national parks. As an example of best practice with minimum impact on the environment, MoE is focusing on Hachijo Island geothermal power plant. On all occasions, maintaining a balance between geothermal power and the national park has been a very big issue.

In the case of the Hachijo Island geothermal power plant, the initial permitted output was 3,300kW, but an upgrade to 6,000kW is being planned. Therefore, we are expecting that MoE will permit the construction of hybrid geothermal power plants with output of the same scale.

## 4. Analysis of Plant Performance

### *4.1 EnergyWin™*

At our institute, we have developed general purpose software to analyze the thermal efficiencies of various power generation systems, such as BTG (boiler, turbine, and generator) systems, GTCC (gas turbine combined cycle) systems, IGCC systems, fuel cells, and geothermal power plants, and we have applied it to more than 43 existing BTG and GTCC power units and seven existing geothermal power units in Japan. Because we have created the entire program using a new algorithm that we developed, this software has the ability to solve the nonlinear simultaneous equations of a power generation system very rapidly and the flexibility to set a range of calculation conditions. This software can not only identify the pieces of equipment that reduce the performance in a power generation system but also provide quantitative estimations of the electric power output and thermal efficiency for each piece of equipment. [7],[8],[9]

### *4.2 Performance of Typical Geothermal Power Plant*

Figure 3 shows the heat and mass balance diagram of a typical geothermal power plant, it was calculated using EnergyWin™. The main conditions of the steam were 0.5MPa / 151.7°C (saturated steam), and the flow rate was determined from the gross power output. The flow rates of the turbine leakage, grand seal steam,

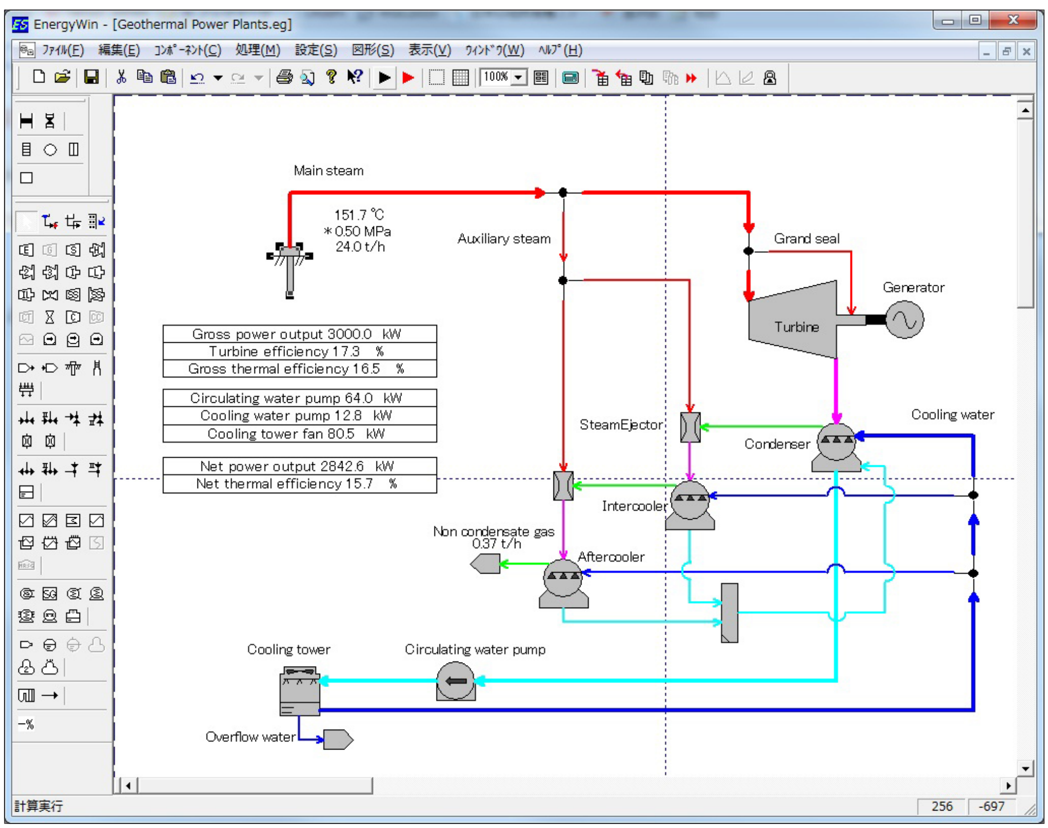


**Figure 3.** Heat and mass balance diagram of a typical geothermal power plant.

and cooling water in the oil cooler and other system components were estimated from the specifications of existing units in Japan. Here, major analysis conditions were followings.

| | | |
|---|---|---|
| A) | Generating system | Single flash type |
| B) | Turbine adiabatic efficiency | 82% |
| C) | Vacuum | 685mmHg |
| D) | Cooling water temperature | 28°C |
| E) | Wet-bulb air temperature | 20°C |
| F) | Pump efficiency | 80% |
| G) | Flow ratio of steam ejector | 0.6 |

It was found that this system had a gross thermal efficiency of 16.5% (HHV). Since the gross power output was set to 3,000kW in the analysis, the flow rate of the main flow of steam was calculated to 24.0t/h, the net power output was 2,843kW and the net thermal efficiency was 15.7% (HHV). Here, these efficiencies were defined respectively as follows:

Gross thermal efficiency [%] = Generator output [kW] / Enthalpy of main steam [kW] (1)

Net thermal efficiency [%] = (Generator output [kW] – Auxiliary input [kW]) / Enthalpy of main steam [kW] (2)

### *4.3 Performance of Hybrid Power Plant*

Figure 4 shows the heat and mass balance diagram of a hybrid power plant. We have investigated the idea of improving both the power output and the thermal efficiency of geothermal power plants by superheating the turbine inlet steam up to 372°C. Here, major analysis conditions were followings. However, A) – G) are same as above.

| | | |
|---|---|---|
| H) | Boiler efficiency (Biomass) | 80% |
| I) | Auxiliary power ratio(Biomass) | 16% |

In our analysis, the power output increased by 928 kilowatts owing to the conditions of the main flow of steam and the thermal efficiency increased by an absolute value of approximately 2%. And then, biomass-based net thermal ef-

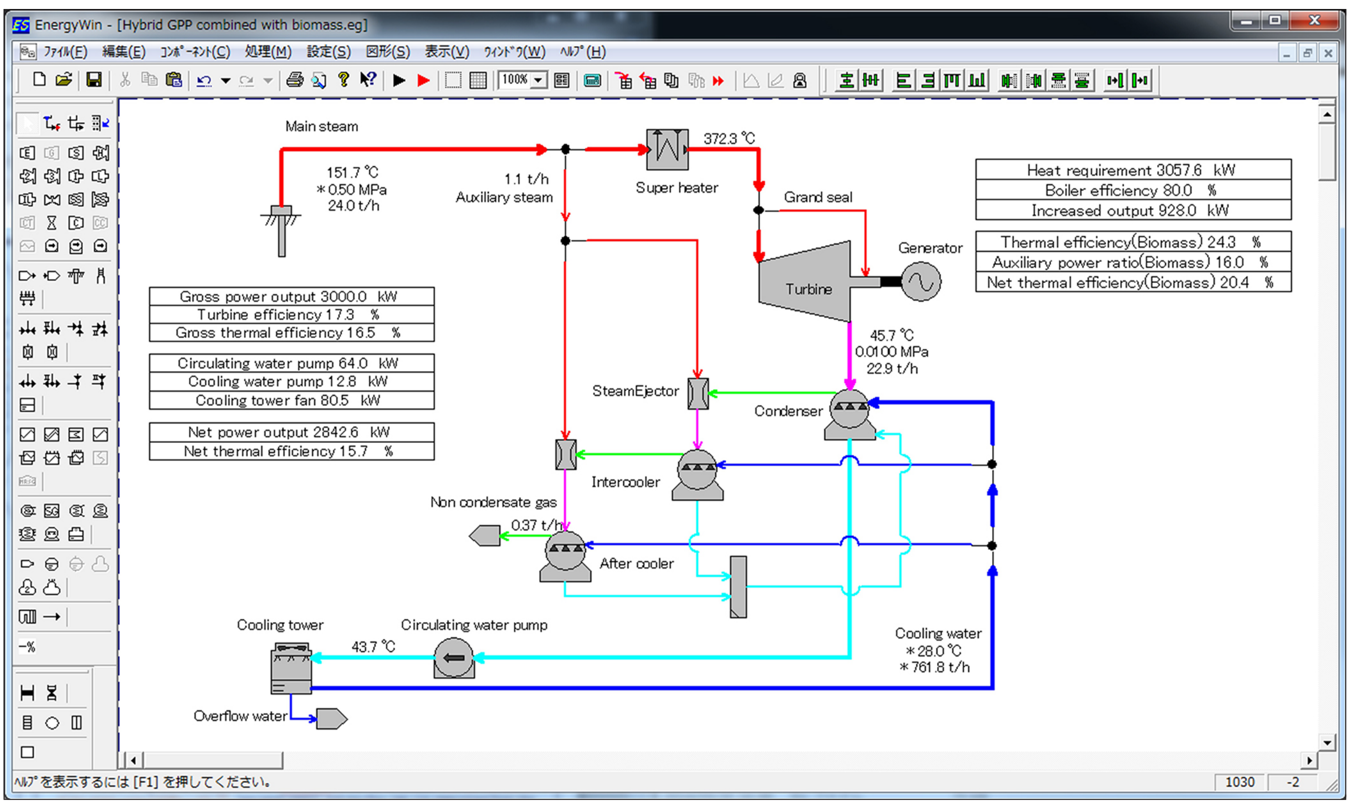


**Figure 4.** Heat and mass balance diagram of hybrid power plant.

ficiency of this system was calculated to be 20.4% (HHV). It is much higher than that of biomass fired power plant. Here, the efficiency was defined as follow:

Biomass-based net thermal efficiency [%] = (Increased output [kW] – Biomass auxiliary input [kW]) / HHV of biomass [kW]

Moreover, we have evaluated economic efficiency of hybrid geothermal – biomass power plant. According to our estimates, we have to collect biomass over 10,000 ton/year. And depending on the type of biomass, the COE was 24 - 39.7 JPY/kWh, that is below the rate of Feed-in tariff (Figure 5). It was also found that the cost of biomass significantly affects the economic viability of the hybrid system since 65% of the Cost of electricity depends on the cost of the biomass. Hybrid geothermal - biomass power plant can achieve environmental and economic sustainability.

Where COE (Cost Of Electricity) = CapEx + OpEx + Fuel

- CapEx : Equipment, Material cost etc.
- OpEx : Maintenance, Labor, Treatment cost etc.
- Fuel : Fuel cost (Biomass)

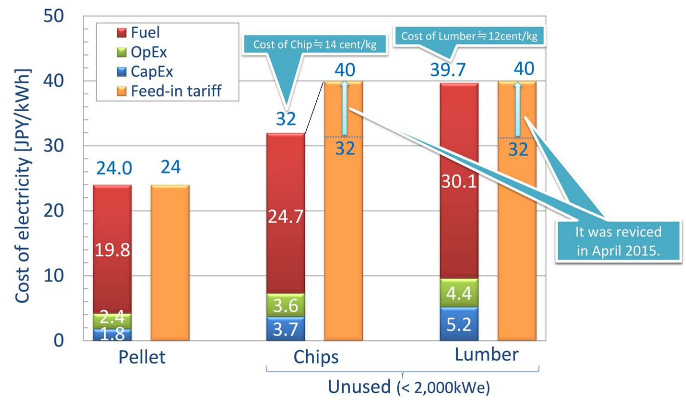


**Figure 5.** COE of hybrid geothermal - biomass power plant.

## 5. Conclusion

We have started to develop highly efficient hybrid geothermal power plants combined with other thermal energy sources such as biomass, solar heat and exhaust heat from fuel cells. It is expected that the thermal efficiency of these systems can be improved by superheating the main flow of steam through the use of the other energy sources. We have looked into the feasibility of these hybrid power plants in terms of their engineering, economic performance, environmental laws and regulations.


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## References


[1] “Geothermal Energy in Japan Resources and Technologies,” Brochure of The Geothermal Research Society of Japan(2009).

[2] BP Statistical Review of World Energy (2013).

[3] N. Ishihara, Statement by N. Ishihara, Japanese MoE, at COP19/CMP9, (2013).

[4] MoE, Study of Basic Zoning Information Concerning Renewable Energies (2013).

[5] Y. Nakao, KAIEDA Hideshi, MUGIKURA Yoshihiro, IWATSUBO Tetsushiro, IUCHI Masanao, WATANABE Yutaka, “Development of Hybrid Geothermal Power Plants Combined with other Thermal Energy Sources,” World Geothermal Congress 2015, Melbourne, Australia (2015).

[6] MoE presentation, Recent Development of Environmental Policies in Japan (2013).

[7] E. Koda, “Study on High Performance CAES Power Generation System Applying the Advanced Combined Cycle Technology,” Proceedings of International Gas Turbine Congress, Kobe, Japan (1999).

[8] T. Takahashi, Y. Nakao, E. Koda, “Analysis and evaluation about Advanced humid air turbine system,” International Conference on Power Engineering-2007, Hangzhou, China (2007).

[9] Y. Nakao, T. Takahashi, Y. Watanabe, “Development of Plant Performance Analysis System for Geothermal Power Plant,” Proceedings of the ASME 2011 Power Conference (2011).