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Long-Term Prospects of Geothermal Energy Uses and Their Environmental Effects in Japan

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ABSTRACT

Long-term prospects of geothermal energy uses in Japan were estimated for sub-divisions, such as power generation, conventional direct use and geothermal heat pump The prospects show possible increases of geothermal energy uses in Japan in years 2020 and 2050, respectively, along three scenarios: 1) Base Scenario, which should be done by efforts of people involved in geothermal businesses, 2) Best Scenario, which may be full-filled if the social system will be supportive for geothermal energy development, and 3) Dream Scenario, which may be realized with drastic breakthrough in technical and/or social systems. In this paper, logical bases in our estimation are presented. The problems that should be solved to realize each scenario is also discussed. As results of calculation for Dream Scenario, in 2050, total power generation of 85.69 TWh/a, contributing 10% of electricity in the nation, and total direct use of 311.6 PJ/a, contributing 7% of heat supply, are obtained. The sum of these energy amounts equivalent to 80.1×10^9 *l* of oil, reduceing 61.6×10^9 kg of CO_2 gas emission.

1. INTRODUCTION

A recent IPCC report indicates that the serious global warming is an anthropogenic phenomenon caused by greenhouse gas emissions and that reduction of CO_2 emission in each sector is a matter of great urgency (IPCC, 2007). To achieve both sustainable economical growth and reduction of CO_2 emission, replacement of fossil fuels into renewable energy sources would be essential.

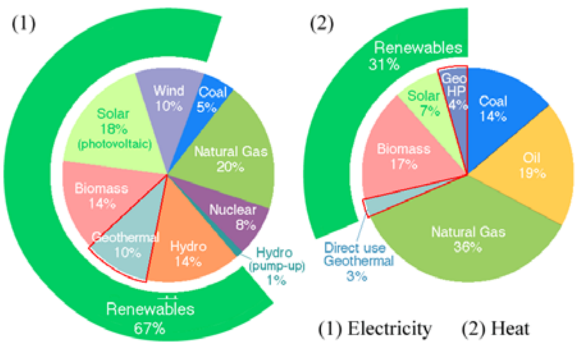

Fig. 1 Power and heat supply in Japan, 2050 prospect (ISEP, 2008)

In a scope of reduction of CO_2 emission, Institute of Sustainable Energy Policy (ISEP), Japan edited "Natural Energy Vision 2050", a prospect of possible energy supply by renewable energies in Japan in 2050, by combining prospects for various renewable energies, including geothermal (ISEP, 2008). Fig. 1 shows the resultant prospect for electricity and heat supplies, respectively. According to this prospect, geothermal energy may contribute to power generation for 10% while to heat supply for 7% by both conventional direct use and geothermal heat pumps. This paper describes the logical bases of the prospect values for geothermal energy supply in 2050. It also introduces possible contribution to saving petroleum oil and reducing CO_2 emission in 2050 accordingly to the prospect.

1.1 Categories

To estimate the increase of future geothermal energy use, various ways of geothermal uses are categorized as shown in Table 1. These categories may differ from commonly used ones. However they look most practical to sum up the total, covering all aspects of geothermal use including the ones to be realized with future technologies: *ex*., EGS may be included either in geothermal power plant or in hot spring power plant depending on its enthalpy.

1.2 Scenarios

The prospects were made along three scenarios: 1) Base, 2) Best and 3) Dream Scenarios. Base Scenario "should" be achieved with our basic efforts, solving basic problems. Best Scenario is what we "want to" achieve with our best efforts, solving quite difficult problems. Dream Scenario "may" be achieved with progressive break-throughs in both/either technical and/or social systems. The prospect shown in Fig. 1 is the case of Dream Scenario.

Table 1. Divisions of geothermal energy use in this paper

energy form	category in this paper	technology	energy source
Electric power generation	Geothermal power plant (GPP)	Steam turbine	Geothermal reservoir
		Binary system (Rankin cycle, >~150℃)	Geothermal reservoir, Reinjection water from GPP
	Hot spring power plant	Binary system (Kalina cycle, <~100℃)	Hot spring
			Reinjection water from GPP
Direct use	Heating	Conventional direct use	Hot spring
			Reinjection water from GPP
	Bathing	Conventional direct use	Hot spring
	Geothermal Heat pump	Heat pump	Heat exchange well, Ground water

2. BASES AND RESULTS OF THE CALCULATIONS

2.1 Calculation for Power Generation

2.1.1.Geothermal Power Plant

Geothermal power generation in Japan in 2005 is 3,228 GWh with a capacity of 534 MWe by 21 units in 18 areas (TENPES, 2008). In Base Scenario, essential geothermal prospects, for which resource characterization and economical evaluation have been already done, should be developed by 2050. NEDO reported the sum of possible developments in such essential areas is 950 MWe (NEDO, 2002). Therefore the goal of Base Scenario in 2050 was set to be 1,484MWe (534+950). As for 2020, a prospect by Japan Geothermal Developer's Council (Chikaikyo, 2002), 78.55 MWe is referred. It shows a load map for development of most promising 17 prospects.

In Best Scenario, the goal in 2050 is to develop essential areas (950 MWe) and their surrounding areas (950 MWe) as well. The value for 2020 is calculated by equation of growth for "complex systems (Taguchi, 2004)".

In Dream Scenario, the goal for 2050 is to use 50% of all resources with temperature of 150℃ or higher in shallower subsurface than a depth of gravity basement (Miyazaki et al., 1991), by means of binary power plants, etc. As for 2020, the final goal of Best Scenario is applied.

2.1.2.Hot spring Power Plant

The concept of "hot spring power plant" is to produce electricity by cascade use of heat from hot spring water that has been used only for bathing. A Kalina cycle system enables to generate electricity even by hot water of 60℃. However, since its efficiency is rather low, it may not be economically competitive if exploration and drilling costs are included. Therefore we consider uses of hot spring water that is already available at ground surface. Also reinjection water from liquid dominated GPPs may be used for Kalina systems. Thus the temperature range of this category is under 100℃ because of its source temperature.

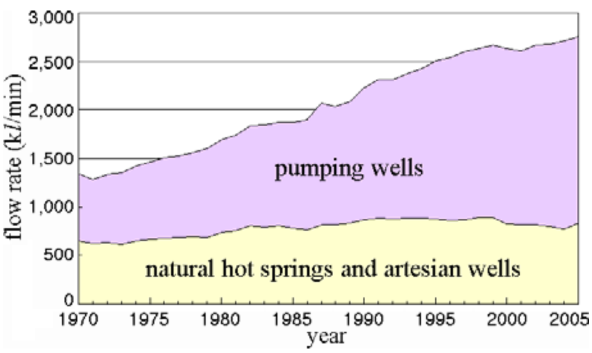

Fig. 2 Total hot spring discharge rate in Japan[9]

Using nationwide temperature and flow rate data of hot springs (Kimbara, 2005) and considering the mechanical efficiency of a Kalina cycle, a potential capacity of hot spring power plant is currently 722 MWe (Ehara et al., 2008). In 2050 it may reach to 1,123MWe because the total hot spring discharge rate increases 43.6 kl/min every year as shown in Fig. 2.

In Base Scenario, 95% of the potential, 1,070 MWe is assumed to be used in 2050. In Best Scenario, the energy of reinjection water from GPPs is added to the base level; 60 % of reinjection water will be used with efficiency of 14.62%. In Dream Scenario, the same assumption is used as for Best Scenario, but higher value is obtained because of higher power generation at GPPs and its corresponding higher injection rate in this scenario. The value for 2020 is estimated by equation of growth for "complex systems".

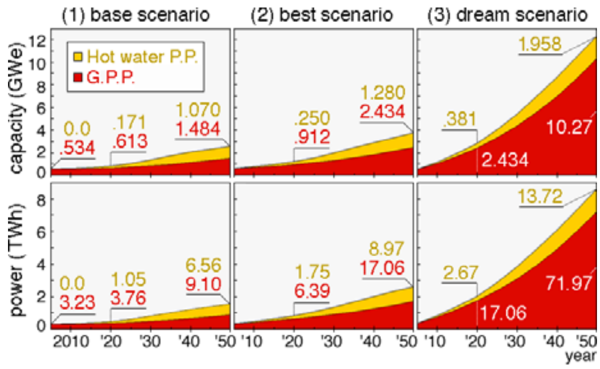

Fig.3 Prospects for power generation (capacity and generated power)

2.2. Calculations for Direct Use

2.2.1 Heating

Similar to hot spring power plant, for economical feasibility, the potential in this category is assumed to be heat energy that is already available on the ground surface. To avoid overlap with hot spring power plant, 5% of hot springs and 40% of reinjection water will be the potential in this category.

Heat energy of hot springs over 50℃ may be used by an ideal cascade use until it reaches to limit temperature of 45℃ (shown as *a* in Fig. 4). Then it will be used for bathing. Next, at 35℃, it will be re-used until it reaches to 20℃(b_1). Hot springs under 35℃ will also be used till 20℃ (b_2). In current Japan, energy amount in *a* is almost double of that in *b*. As for reinjection water from GPP, potential is calculated by average injection rate per capacity *N* (MWe). For limit temperature of 45℃ (*A*), available energy is *N*×36.42 TJ/a while it is *N*×52.98 TJ/a for 20℃ (*B*), assuming its initial temperature is 100℃.

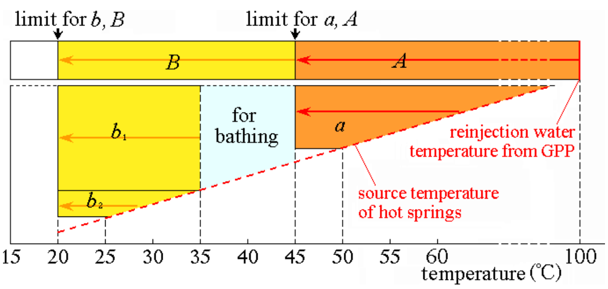

Fig. 4 Temperature ranges for direct uses

In Base Scenario, the growth of direct use in Turkey in 2000-2005 is referred to assume a possible infrastructure. Since the population of colder areas in Japan is 30 million while Turkish population is 70 million, the annual growth is assumed to be 3/7 of that in Turkey. The status of 2005 is referred from a literature (Lund, et al., 2005).

In Best Scenario, 65% of *a* and *A* in 2020, and 65% of all potential in 2050 will be used, assuming infrastructure for higher temperature systems may be developed first. In Dream Scenario, 65% of potential will be used in both 2020 and 2050. Potentials *A* and *B* increase accordingly to the capacity of GPP in different scenarios.

2.2.2 Bathing

For current state, the amount of heat energy provided for bathing at hot springs is calculated as energy required to heat water from atmospheric temperature of 15℃ to a hot bath temperature of 42℃. For cases of pumping wells, as shown in Fig. 2, the energy needed to pump up the hot water in the well is deducted from the provided energy. Thus current amount for capacity is 2,971 MWt and used energy is 36,562 TJ/a, respectively.

For Base Scenario, increase of the used energy was estimated from the trend of discharge rate as shown in Fig.2. For Best and Dream Scenarios, in addition to hot spring water, 25% of hot water used in hot spring power plant by injection water from GPP is assumed to be used for bathing. It is 15% of whole injection water because 60% of injection water will be used for hot spring power plant.

2.2.3 Geothermal Heat Pump

The number of installed GHP systems in Japan is still only few hundreds. The major obstacle of its promotion is high installation cost. This problem may not be solved only by technical innovation because of economical principals. However the government's policy for environmental protection and recent high oil price may help GHP to be more economically competitive. In consideration of such current situations, the assumptions in each scenario, shown in Table 2, were made.

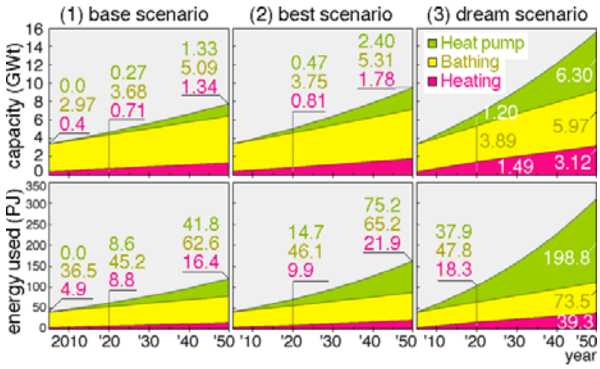

Fig.5 Prospects for direct use (capacity and used heat energy)

Table 2 Assumptions for prospect of GHP utilization

building types		(1) Base Scenario	(2) Best Scenario	(3) Dream Scenario
Residential buildings	houses	5,000 units for new houses on 2010, increase rate: 2%/a.	10,000 units for new houses on 2010, increase rate: 3%/a. From 2015, also for reform houses (5% of new houses)	5% of new houses on 2010, increase rate: 5%/a. From 2015, also for reform houses (10% of new houses)
	apartments	5% of new buildings on 2015, increase rate: 1%/a.	10% of new buildings on 2015, increase rate: 2.5%/a.	10% of new buildings on 2015, increase rate: 5%/a.
Industrial buildings	shops offices factories	5% of new buildings on 2010, increase rate: 1%/a.	5% of new buildings on 2010, increase rate: 2.5%/a.	5% of new buildings on 2010, increase rate: 5%/a.
Public buildings	public schools	1% of schools in 2050	10% of schools in 2050	50% of schools in 2050
	public offices	1/prefecture on 2010, adding 1/prefecture/a.	1/prefecture on 2010, adding 2/prefecture/a.	1/prefecture on 2010, adding 5/prefecture/a
	stations airports	1GW×1 on 2010, adding 1GW×1/5a	1GW×2 on 2010, adding 1GW×2/5a	1GW×10 on 2010, adding 1GW×10/5a
Hospitals	large hospitals	500kW×5 on 2010, adding 500kW×5/a	500kW×10 on 2010, adding 500kW×10/a	500kW×20 on 2010, adding 500kW×20/a
Roads	snow melting	50kW×10 on 2010, adding 50kW×5/a	50kW×10 on 2010, adding 50kW×10/a	50kW×10 on 2010, adding 50kW×20/a

2.3 Discussions

The resultant values for each scenario are shown in Figs. 3 and 5. The difference among scenarios is bigger for GPP than hot spring power plant in Fig. 3 while that is biggest for GHP among direct uses in Fig. 5. This is because the drastic increases of GPP and GHP installations are largely depending on the government's policies both for environmental and energy security. Each scenario may require following conditions to realize the objectives.

For Base Scenario, improvements may be needed on; RPS law to include all GPPs as renewable energy source, NEDO's "geothermal development promotion survey" to realize business projects, economical supports on geothermal developments, tax reduction for Tradable Green Certificates, safety regulations on geothermal developments, admittance of survey in national park special areas, relation improvement with hot spring owners.

For Best Scenario, additionally followings may be needed; introduction of carbon emission tax, permission for cascade use of reinjection water from GPP, admittance of partial development in national park special areas, technical innovation in reservoir maintenance.

For Dream Scenario, additionally followings may be needed; fixed price purchase system of renewables, enactment of geothermal laws, admittance of entire development in national park special areas, and technical innovation for development of new prospect.

3. SAVINGS OF OIL AND CO_2 EMISSION IN 2050

The amount of oil savings and reduction of CO_2 emission in 2050 are roughly calculated for Dream Scenario. The results are shown in Table 3.

For electricity, total power in 2050 is 85.69 (GPP 71.97 + hot spring power plant 13.72) TWh. This is equivalent to

1028.3 PJ of heat and 71.971×10^9 *l* of petroleum oil, when energy efficiency in conversion from heat to electricity is 30% and heat per 1 *l* of oil is 38.2 MJ.

In Japan, CO_2 emission at binary GPP is 0.016 kg/kWh for plant construction (Shu-ei-sha, 2000), while conventional steam GPP additionally emits approximately 100 kg/kWh at cooling tower for power generation. Therefore, assuming half of installed capacity of GPP in 2050 is binary system, average CO_2 emission at a GPP will be 0.058 kg/kWh. Applying average CO_2 emission value at oil thermal plant in Japan of 0.533 kg/kWh, CO_2 reduction by geothermal power generation is 0.475 kg-CO_2/kWh. Therefore, multiplied by annual power generation in 2050, it reduces 40.0 x 10^9 kg of CO_2 emission annually.

For direct use, total energy in 2050 is 311.6 (heating 39.3 + bathing 73.5 + GHP 198.8) PJ. This is equivalent to 8.161× 10^9 *l* of petroleum oil. Applying CO_2 emission by burning oil of 2.649 kg/ *l*, CO_2 reduction by direct use is calculated as 21.61×10^9 kg.

Therefore in total, achievement of Dream Scenario may allow us to save 80.11×10^9 *l* of oil and to reduce 61.61×10^9 kg of CO_2 gas emission.

Table3. Equivalent oil amount and CO_2 savings in dream scenario in 2050

Category	total energy	equivalent oil	CO2 savings
Power generation	85.69 TWh	71.97 x10^9 *l*[*]	40.0 x10^9 kg[**]
(equivalent heat)	1028.3 PJ[****]		
Direct use	311.6 PJ	8.16 x10^9 *l*[*]	21.6 x10^9 kg[***]

[*] heat per 1 *l* of oil : 38.2 MJ

[**] CO_2 emission at thermal (oil) power plant: 0.533, at GPP: 0.058 (0.016 at binary GPP, additional ~0.1 at steam GPP. Assuming half of GPP in 2050 is binary system, average CO_2 emission is 0.058) kg/kWh. Their difference is 0.475 kg-CO_2/kWh

[***] CO_2 emission per 1 *l* of oil : 2.649kg

[****] energy efficiency in conversion from heat to electricity : 30%

4. CONCLUSIONS

For encouragement of geothermal energy use, a prospect of possible energy supply by geothermal energy in Japan in 2050 is made along three scenarios; Base Scenario, Best Scenario and Dream Scenario. According to the result of Dream Scenario, geothermal energy may contribute to power generation for 10% and to heat supply for 7% in 2050. To realize this most challenging scenario, drastic increase of geothermal power generation and geothermal heat pump installation is needed. Improvements in legal regulations may be needed in addition to technical innovation to achieve such high objectives.

The amount of oil saving and reduction of CO_2 emission in dream scenario in year 2050 are roughly calculated. Energy of geothermal power generation in 2050, 85.69 TWh, is equivalent to 71.97×10^9 *l* of petroleum oil that reduces 40.0× 10^9 kg/a of CO_2 emission, while heat energy of geothermal direct use, 311.6 PJ, is equivalent to 8.16×10^9 *l* of petroleum oil that reduces 21.61×10^9 kg/a of CO_2.

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