COUNTRY UPDATE REPORT ON GEOTHERMAL DEVELOPMENT AND UTILIZATION IN KOREA

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ABSTRACT

Geothermal utilization in Korea has been direct use, especially with geothermal heat pump (GHP) installation, because there is no high temperature resources associated with active volcano or tectonic activity. Total installed capacity for direct use is estimated 262.36 MWt at the end of 2010, most of which is for GHP installation followed by hot spring usage. GHP installation in Korea has increased more than 50% annually for the last five years and total installed capacity exceeded 200 MWt in 2010. This rapid increase was possible thanks to active government support programs and legislation and we expect it will continue to increase at least for the next five years.

An EGS potential assessment was made following a recently announced protocol. Theoretical potential for EGS power generation in the depth range 3-10 km was estimated 6,975 GWe which is 92 times of total power generation capacity in 2010. Technical potential considering depth limit, land accessibility, recovery factor and temperature drawdown factor reaches 19.6 GWe. Increasing interests in geothermal power generation has resulted in launching the first EGS pilot plant project at the end of 2010. It is a five-year term, government funded and industry matching project and the target area is Pohang field of higher heat flow in south-eastern part of Korean Peninsula. The project consists of two phases: I) site characterization, drilling down to a 3 km deep well and to confirm the temperature higher than 100 °C in two years, and II) extending the 3 km deep well down to 5 km to make it injection well, hydraulic stimulation and reservoir creation, drilling production well of 5 km and completing doublet system, and installing 1.5 MW binary power plant in another three years.

Keywords: geothermal heat pump (GHP), enhanced geothermal system (EGS), direct use, power generation, EGS potential

1. INTRODUCTION

Korea is one of the fastest increasing countries in geothermal development especially ground-source or geothermal heat pump (GHP) installation. Since its first installation at the beginning of 21st century, it has rapidly increased and more than 50% of annual increase can be seen for the last five years. This rapid increase was possible thanks to active government support through various subsidy programs and special legislation. A special subsidy program for GHP application to greenhouses in rural area started in 2010 offering subsidy of 80% of total installation, which will make GHP installation quite active not only in building sector but also in agricultural area.

Because there is neither active volcanism nor tectonic activity in in-land Korea, deep geothermal development has been for hot spring usage and space heating application, if any. However, recent successful stories of low-temperature power generation including enhanced geothermal system (EGS) in Europe and US have made decision makers and industries in Korea be interested in geothermal power generation. Reflecting these interests, exploration of low-temperature hydrothermal resources suitable for binary cycle power generation is underway in a small island close to Incheon. Assessment of power generation potential using EGS technology in terms of theoretical and technical potentials has just been made following a recently announced protocol. Finally, the EGS pilot plant project has been launched at the end of 2010 aiming power plant of net 1.5 MWe using a doublet system down to 5 km by the end of 2015.

In this country report, we first introduce national policy for energy and renewable energy, legislation for renewable deployment and barriers, various supportive schemes and R&D investments. Characteristics of geothermal resources are briefly outlined. Total installation capacity and annual geothermal energy uses are summarized with emphasis on increasing trend of GHP installation. Major recent R&D activities are described with focuses on the geothermal power generation.

2. POLICY, LEGISLATION AND SUPPORTIVE MEASURES

2.1. National policy

In 2008, Korean government proclaimed ‘The First National Energy Master Plan (2008-2030)’ according to ‘The Energy Law’ passed in 2006 and amended in 2008 under the slogan of “*low-carbon, green-growth*”. There are four basic strategies:

a low-carbon and energy-conscious society, increased clean energy supply, green-driven growth, and affordable energy for all. This plan also emphasizes balancing of the 3-E's; energy security, energy efficiency, and environmental protection. According to the master plan, 'The Third Basic Plan on New & Renewable Energy Technology Development, Utilization and Diffusion (2009-2030)' has been set up aiming new & renewable energy's share of 11% of total primary energy supply and of 7.7% of electricity generation by 2030. Target of geothermal energy is 3.8% of total new & renewable energy contribution by 2030 which means only 0.42% of the total primary energy. However, geothermal community expects that much more portion can be covered by geothermal; more than 1 % of total considering the rapid increase of GHP installation in these days.

For renewable energy deployment, an ambitious deployment project named 'One Million Green Home by 2020' has also been launched. This is to be fulfilled by developing the 'Smart Energy System' that combines various renewable sources such as PV, solar, geothermal, wind and fuel cell. This project will help GHP installation continue to increase in the future. The total primary energy consumption at the end of 2010 reached around 260.595 million ton of oil equivalent (toe) while geothermal provided 35,752 toe which covered only 0.014% of the total primary energy consumption. Status and prospect of geothermal energy in national target still does not seem significant because government program mainly focuses on the three major items for electricity generation such as photo voltaic, wind power and fuel cell. Fortunately, however, importance of geothermal utilization is being acknowledged by the government and the public side and the geothermal's share of market stimulating incentive came to be significant. Therefore, we could see some remarkable progress of GHP installation in recent years.

2.2. Legislation and barriers

From 2004, the 'Mandatory Public Renewable Energy Use Act' ('Mandatory Act') has become into effect and states that "in construction of all public buildings bigger than 3,000 m^2 in area, more than 5 % of total budget must be used to install renewable energy equipments." According to the Act, GHP has been playing major role in construction of public buildings; for example, GHP installation plans amounting total of 70 MWt in 2009 and 78 MWt in 2010 were reported, which will become installed two or three years (sometimes more) after planning when considering construction period.

A barrier to progress of GHP deployments in technical and scientific points of view may be explained by relative negligence of importance of accurate information on the thermal properties of subsurface materials and lack of scientific knowledge on hydrological conditions influencing heat extraction/injection rate. Such technological drawbacks often lead to over-design of the system and thus weaken economical competitiveness. Although there are huge amount of alluvial groundwater resources in agricultural areas and towns, utilization of groundwater thermal energy is still quite limited because of unnecessary concerns about running out the water resources without understanding the natural water cycle.

There is increasing concern for geothermal power generation with low-temperature geothermal water through deeply-extended fractures and/or EGS technology. But, insufficient understanding of low-temperature power generation technology available with temperature even lower than 100 °C and lack of deep drilling experience are technical barriers. Lack of legal frame supporting deep geothermal development is major barrier; deep geothermal water in Korea is dealt with only in 'Hot Spring Law' which states that warm water must be firstly used for hot spring. For that reason, there is no risk guarantee or insurance frame for deep drilling.

2.3. Supportive scheme and R&D investment

Main drive for renewable energy deployment other than the 'Mandatory Act' is the active subsidy programs supporting 50-60% of total installation cost based on annually allocated budget and on competition. Subsidies for geothermal installation through various renewable energy deployment programs amounted US$ 65.5 million in 2010. A special subsidy program for supporting economic competitiveness of greenhouse started in 2010 which offers 80% of total installation cost. The Korean government also offers long-term low-interest loans and tax benefits for those using renewable energy. Table 1 shows the annual amount of subsidy and installed capacity through various subsidy programs for the past four years.

Governmental investment to geothermal R&D has steadily increased since 2003. Investment from industry has also increased as a matching fund to government R&D budget, which was mostly for GHP. R&D and RD&D programs on geothermal are mainly funded by the Korea Institute of Energy Technology Evaluation and Planning (KETEP), government R&D funding agency under the Ministry of Knowledge Economy. In 2010, total nine R&D projects including six new ones were granted for geothermal developments by KETEP; amounting US$ 6.4 million in budget. R&D in geothermal investigation, exploration and exploitation has been mainly performed by Korea Institute of Geoscience and Mineral Resources (KIGAM), the only government funded research institute on geoscience field in Korea. The Geothermal Resources Department of KIGAM is leading another government funded R&D program for resource mapping and exploration of deep geothermal water in Seokmo-Do.

Table 1. Subsidy for geothermal heat pump installation for the period 2007-2010* (Data from Korea Energy Management Corporation).

In Thousand US dollars (1 $ = 1,000 KRW until 2009 and 1,227 KRW for 2010)

	2007		2008		2009		2010	
	Capacity (MW)	Subsidy (1,000 USD)	Capacity (MW)	Subsidy (1,000 USD)	Capacity (MW)	Subsidy (1,000 USD)	Capacity (MW)	Subsidy (1,000 USD)
Deployment Subsidy Program	15.37	8,351	14,11	7,689	6.83	4,153	5.11	2,498
Rural Deployment Program	2.63	1,998	89.55	73,728	14.39	9,093	11.08	4,702
1 Million Green home Program	-	-	-	-	5.02	3,868	13.82	9,905
Greenhouse Subsidy Program	-	-	-	-	-	-	57.3	48,443**
Total	18.01	10,349	103.66	81,417	26.24	17,114	87.31	65,548

* Note: Data correspond to year of subsidy support, so actual operations are to be one or two years later.

** 80% (central government 50% + local government 30%) of total costs are subsidized, while for the other programs 50% are covered by government.

3. CHARACTERISTICS OF GEOTHERMAL RESOURCES IN KOREA

The geology of Korea is composed of relatively old rocks and also various formations that age from Precambrian to Quaternary. Because there is neither active volcanism nor tectonic activity, geothermal resources in Korea are characterized by non-active magmatic, low-temperature nature. Characteristics of geothermal resources in Korea are well described in Kim and Lee (2007) based on heat flow and in Lee et al. (2010) based on thermal properties and resources potential. According to those researches, the weighted average of heat flow values over Korea with an areal window of 500 m by 500 m is 60±11 mW/m^2, with heat flow anomaly zone of higher than 80 mW/m^2 in south-eastern part. Average heat production rates of granite (132 samples) and gneiss (48 samples) are 2.040±0.086 $\mu W/m^3$ and 2.041±0.162 $\mu W/m^3$, respectively, which cover most of in-land area except south-eastern Mesozoic sedimentary formation.

There are historical records of hot spring usage dating back to more than a thousand years ago. Figure 1 shows hot spring locations with discharge temperature of higher than 45 °C, superimposed on Mesozoic granite outcrop distribution map. We can see that these hot springs are related with deeply extended fractures in granite rocks not related with magmatic heat source. Since hydrothermal resources can be found through factures in crystalline rocks, flow rate and temperature are not likely enough to produce electricity even with binary cycle technologies. This is the main reason why geothermal utilization in Korea has been mainly focused on direct-use. However, crystalline rocks of higher thermal conductivity are ideal for GHP application throughout the country, especially since those are hydraulically saturated system due to relatively shallow groundwater table. Furthermore, both the heating needs in winter season and cooling needs in summer season lead to the balanced thermal utilization of subsurface through ground heat exchanger, which in turn makes GHP application more efficient in Korea.

4. CURRENT STATUS OF GEOTHERMAL UTILIZATION

Because there are no high temperature hydrothermal resources in Korea, geothermal utilization has been on direct uses, especially on GHP application for the last five years. Table 2 shows the statistics of direct uses, fossil fuel saving and avoided CO2 emission as of December 2010. As can be seen in the table, most of installed capacity is for GHP being followed by hot spring usage. There are only two places for individual space heating, one place for green house and small scale district heating. In BuGok (marked as 12 in Figure 1) area, hot spring water with temperature of 76 °C is first pumped up to the storages in roofs of small hotel buildings, and then is utilized for floor heating of guest rooms prior to supply to hot spar or bath. Similar systems are found in DongRae (marked as 1 in Figure 1) area. These two areas contribute some numbers to individual space heating in Table 2. In the small island, Seokmo-Do (marked as 3 in Figure 1), saline hot spring water from an artesian well is utilized for a small greenhouse and small-scale district heating since 2008, and then supplied to public bath.

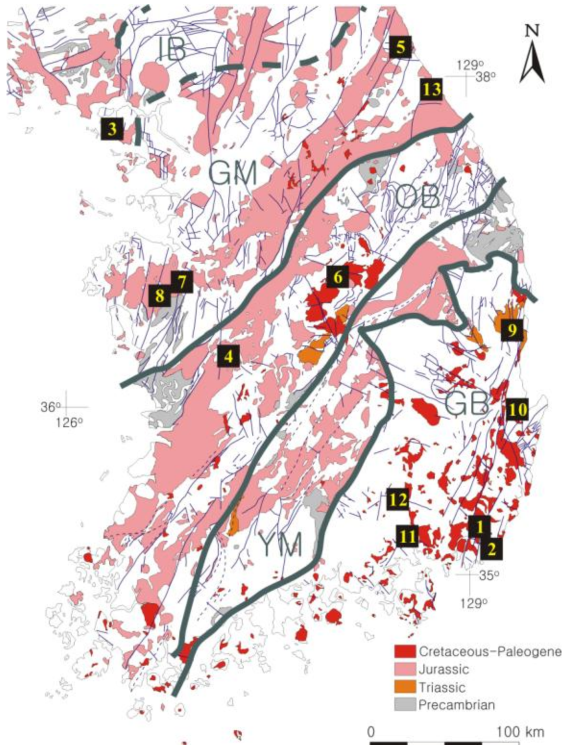


Figure 1. Locations of hot springs with discharge temperature higher than 45 °C, superimposed on Mesozoic granite outcrop distribution map (modified from Lee et al., 2005). 1: Dongrae; 2: Haeundae; 3: Seokmo-do; 4: Yuseong; 5: Sokcho; 6: Suanbo; 7: Onyang; 8: Deoksan; 9: Baekam; 10: Pohang; 11: Mageumsan; 12: Bugok; 13: Gangreung.

Table 2. Geothermal direct heat uses, fossil fuel saving and avoided CO_2 emission in Korea as of December 2010.

Use	Installed Capacity (MWt)	Annual Energy Use		Capacity Factor	Fossil fuel saving** (toe/yr)	Avoided CO_2 emission** (ton)
		TJ/yr	GWh/yr			
Individual Space Heating	8.66	53.43	14.84	0.20	1,881	6,070
District Heating	2.21	31.28	8.69	0.45	1,101	3,554
Greenhouse Heating	0.17	1.33	0.37	0.25	47	151
Bathing and Swimming	32.56	507.61*	141.0*	0.49	17,864	57,669
Geothermal Heat Pumps***	229.8	903.24 4)	250.9 4)	0.23	31,786	102,618
Total	262.36	1,496.9	415.8		52,679	170,054

* ∑ [(supplying water temp.: 42 – leaving water temp.: 27)×flow rate×operating time]
** uses 35.2 toe/TJ (126.7 toe/GWh) and 113,611 CO_2 kg/TJ (409 kg/MWh) assuming 70% of oil boiler (following IEA-GIA conversion rate; Mongillo, 2005)
*** estimates for 2010 based on the amount of subsidy and plans reported according to the 'Mandatory Act'.
4) use 'Pure Geothermal Contribution' according to E = Q*(1-1/SPF); SPF: Seasonal Performance Factor.

Increasing trend of geothermal utilization in Korea directly reflects rapid increase of GHP installation. As can be seen in Figure 2, GHP installation has increased more than 50 % annually for the last five years. Total cumulative installed capacity exceeded 200 MWt in 2010 and we expect that it will continue to increase at least for the next five years considering active government subsidy programs and 'Mandatory Act'. Note that energy uses shown at right diagram in Figure 2 differ from Table 2, in that we used 'pure geothermal contribution' in Table 2 for which electric power is subtracted using (1-1/SPF).

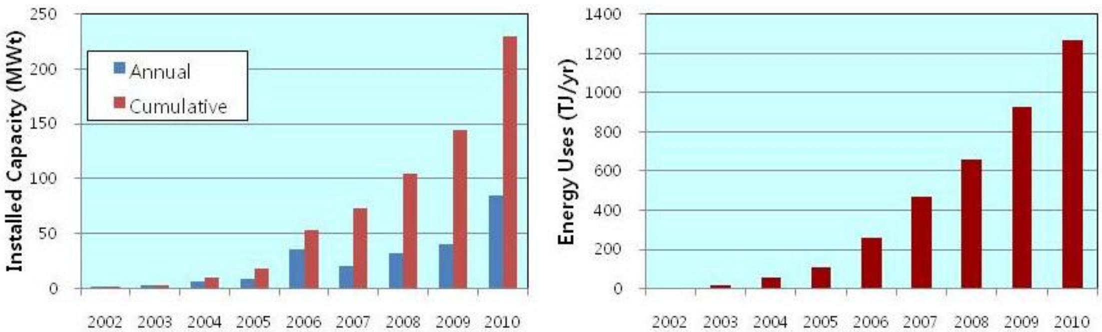


Figure 2. Increasing trend of ground-source heat pump installation.

5. RECENT MAJOR R&D ACTIVITIES

Almost all of the research activities in Korea are initiated by government fund. R&D activities can be categorized into two main fields: 1) shallow geothermal utilization using various GHP types, and 2) deep geothermal exploration and exploitation. For shallow geothermal utilization, there were several successful R&D works such as sampling & measurement of subsurface thermal properties for borehole heat exchangers resulting in a big database (Kim et al., 2010a), and simulation of T-H-C coupled behavior with borehole heat exchanger under groundwater flow (Kim et al., 2010b). There are also researches on efficiency of borehole heat exchanger types and on utilizing groundwater thermal energy along with aquifer thermal energy storage (ATES).

For deep geothermal, there is an on-going research on exploration and exploitation of low-temperature geothermal water for district heating, and characterization and assessment of geothermal resources is also an important research topic. There have been increasing interests in geothermal power generation among decision makers and industries as well as researchers, especially for EGS technology. These resulted in launching of the first EGS pilot plant project at the end of 2010.

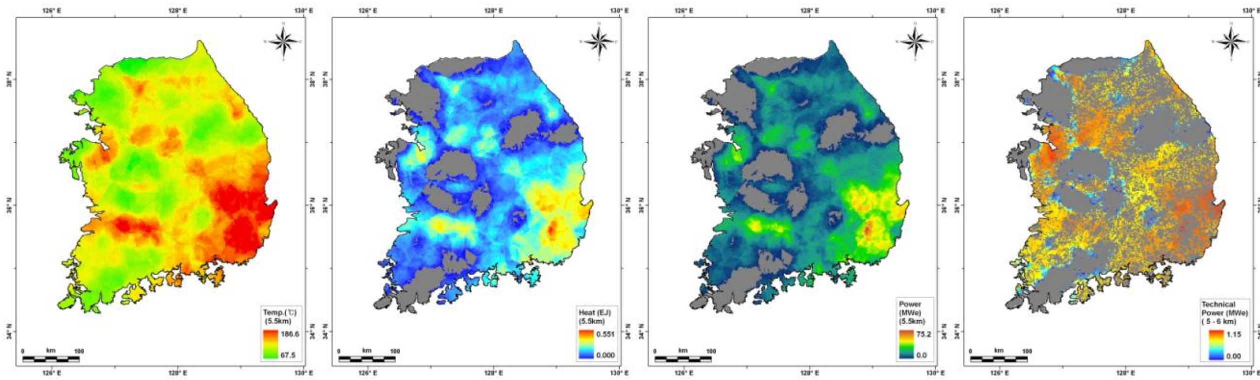
5.1. Assessment EGS potential

The first geothermal resources assessment was made by Lee et al. (2010) using a volumetric method. Lee et al. (2010) made temperature distribution map at each depth and estimated heat contents down to 5 km to be around 10^5 EJ. In 2011, KIGAM estimated power generation potential through EGS following recently announced protocol (Beardsmore et al., 2010). According to the protocol, we calculated the theoretical potential first, which assumes 30 year operation, minimum temperature being surface temperature+80 °C, depth range being from 3 km to 10 km. In this new assessment the in-land area was digitized by 1' by 1' blocks, which is much finer than suggestion of the protocol (5' by 5'). Thus estimated theoretical potential reaches 6,975 GWe which is 92 times of the total power generation capacity in 2010.

In the estimation of technical potential, we limited the depth range down to 6.5 km, assumed recovery factor as 0.14 and also counted for temperature drawdown factor of 10 °C following the protocol. Accessible in-land area excluding steep mountains, residence and industrial region, wet area and others covers 40.7% of total area. Finally, we could come up with 19.6 GWe for technical potential, which would be 56 GWe if we do not account for the temperature drawdown factor. These are important results in that we made the first potential assessment for geothermal power generation. Figure 3 shows an example of procedure for potential assessment.

5.2. Exploration of low-temperature hydrothermal resources in Seokmo-do

KIGAM has performed exploration of deeply extended fractures which may serve as conduit of geothermal water with temperature higher than 90 °C, in a small island Seokmo-Do in West Sea close to Incheon (the 3rd largest city in Korea) near Seoul, capital city of Korea. There are several artesian wells, discharge temperature of around 70 °C. Some drill wells of several hundred meters deep met deeply-connected fractures in Jurassic granite and a large amount of saline water overflowing the wells. One of the well has been drilled down to depth of 1,280 m according to the interpretation result of the magnetotelluric (MT) data acquired by KIGAM in 2005.



(a) (b) (c) (d)

Figure 3. Example of EGS potential assessment procedure: (a) temperature distribution at 5.5 km depth; (b) heat contents in depth range 5-6 km; (c) theoretical potential in depth range 5-6 km; (d) technical potential in depth range 5-6 km. Note that grey regions in (c) and (d) represent area of temperature lower than surface temperature+80 °C, while in (d) include in-accessible area as well.

Artesian geothermal water is being used for a small-scale district heating (21 households) since 2008 and a greenhouse heating since 2009. The greenhouse is 1,155 m^2 wide, inlet temperature of geothermal water is 68 °C and is cooled down to 56 °C through a plate heat exchanger, average flow rate is designed to be 6 m^3/hr. After heating the greenhouse, cooled geothermal water is supplied to a public bath.
Various surveys and investigations including lineament mapping, MT and seismic surveys, well loggings and hydrogeologic tests using existing wells were carried out. Since the hydrologic system in the island is governed by fracture network and thus by stress distribution, stress measurement with hydro-fracturing test was also performed to figure out current stress regime. The resultant stress fields are likely of super-critical thrust regime. In 2010, KIGAM started drilling of exploration/exploitation well. The purpose of well drilling is to see if we can find another deep permeable fracture beneath currently producing geothermal aquifer. The drilling plan consists of two phases: I) 1.5 km drilling vertically, and II) extending to 3 km according to survey results. The well will reach 1.5 km in 2011 and it is not decided yet whether the well is to be extended to 3 km or not.

Figure 4. Drill rig at Seokmo-Do island looking from East (a) and West (b).

5.3. The EGS pilot plant project
There have been increasing interests in geothermal power generation among decision makers and industries as well as researchers, especially for EGS. These resulted in launching of the EGS pilot plant project at the end of 2010, which is the first attempt to realize geothermal power generation in Korea. It is a five-year term, government funded and industry matching project. Target area is Pohang field of higher heat flow in south-eastern part of Korean Peninsula (Lee et al., 2011). A long-term monitoring at an exploration well BH-4 in Pohang showed temperature of 91 °C at the depth of 2 km, which enables us to expect at least 180 °C at planned depth of 5 km. Two small businesses, a big industrial company, two

research organizations and a university are participating in the project with a small business as prime contractor.
The project consists of two phases: I) site characterization, drilling down to a 3 km deep well and to confirm the temperature higher than 100 °C in two years, and II) extending the 3 km deep well down to 5 km to make it injection well, hydraulic stimulation and reservoir creation, drilling production well of 5 km and completing doublet system, and installing 1.5 MW binary power plant in another three years (see Figure 5). Collaboration with international expert group is utmost important since experience of deep drilling and engineering along the deep well is completely lacked in Korea. Although it was initiated as government funded project, there is increasing opportunity of private investment. Once the pilot plant shows successful result, therefore, extension of doublet to triplet with one more production well and further enlarging to bigger plant are to be done through private investment.

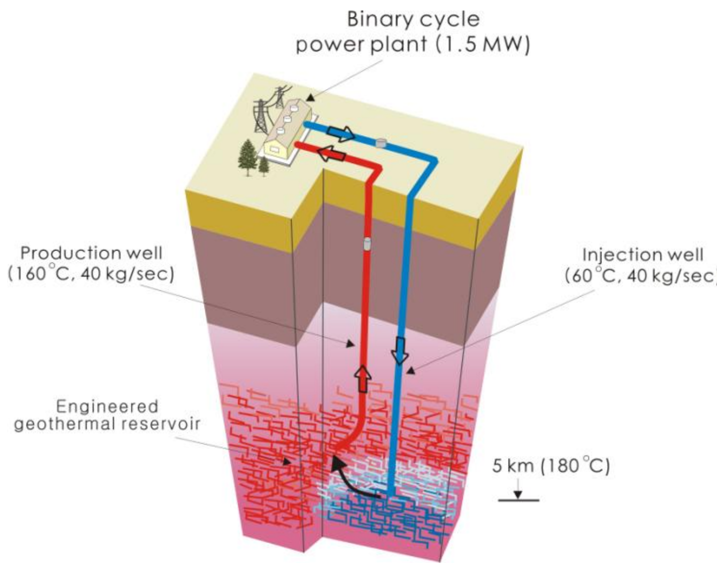


Figure 5. Conceptual model of Korean EGS pilot plant project.

6. DISCUSSION AND FUTURE OUTLOOK

Geothermal utilization in terms of GHP installation will continue to rapidly increase for the next five years: 50-100 MWt annually. This is possible thanks to active subsidy programs and the special 'Mandatory Act'. There are concerns for low performance or malfunctioning of GHP system because rapid increase of market may accompany bad installations without proper design and performance validation. Long-term performance modeling and validation are another important task to keep GHP installation growing especially for large systems (bigger than 1 MWt capacity). More than 90% of GHP installation uses borehole heat exchanger to extract and inject heat from/to ground. However, because there are huge amount of alluvial groundwater resources close to urban area, utilization of thermal energy of groundwater should be increased.
Rapid increase of GHP installation has been made through relatively large systems for office and campus buildings. There is a progressive electricity price system for residential house in Korea which resulted in very high electricity cost when using air-conditioner extensively in summer. This has been main barrier of GHP deployment for residence sector. However, from May 2009, GHP became free from this progressive electricity price system and so we expect there will be remarkable increase of GHP installation for residential house, especially large apartments.
In addition to lack of experience in deep drilling and engineering critical for geothermal power generation using EGS technology, lack of industry paying attention to geothermal is another problem to be resolved at the moment. The first EGS pilot plant project may lead to initiating other R&D projects regarding geothermal power generation such as induced seismicity, hydraulic stimulation and binary power generation cycles. These will draw more attention from industry, which in turn would make geothermal industry more active in power generation business both in domestic and overseas. We expect there can be seen successful cases of domestic development and oversea investment in the next five years.

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