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Geothermal Development in Korea: Country Update 2005-2009

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ABSTRACT

There is no geothermal power generation in Korea due to absence of high temperature resources. It is not until early 2000's either that direct-use geothermal development has become active except hot springs which are related with deep fractures in granite area and thus quite localized. Currently, however, direct-use geothermal development is getting more active in both exploration and in utilization especially in geothermal heat pump installation. Installed capacity exceeds 200 MWt and annual usage approached 2,000 TJ in 2009, which is mainly from geothermal heat pump. A small scale district heating started its operation in 2008 and the system is also connected to a greenhouse.

Geothermal R&D is quite active thanks to strong government support to renewable energy RD&D program. By the end of 2008, more than 2,000 rock samples were collected throughout the territory, of which physical properties including thermal conductivity were measured and compiled into GIS database. The database also includes surface temperature, geothermal gradient and heat flow distribution and is ready to open to public for the purpose of providing design parameters for borehole heat exchanger system. Geothermal resource assessment became available with the database through a volumetric method and heat content down to 5 km depth is estimated to be around 100,000 EJ corresponding to 10,000 times the total primary energy consumption in 2006.

1. INTRODUCTION

Direct use geothermal utilization in Korea has been quite active for the last five years, especially geothermal heat pump installation. The rapid increase of geothermal heat pump is mainly due to active government subsidizing programs for renewable energy deployment, but recently the number of installations without subsidy is also increasing. There are several areas producing hot spring water of discharge temperature higher than 60 °C, which circulates through deeply extended fractures in crystalline rocks. This hot water has been utilized for floor heating in a hot spring area for more than 20 years. In another place, a small-scale district heating and greenhouse heating with hot spring water have been started in 2008.

There are neither high temperature geothermal resources for power generation nor the regional anomalous zones such as deep sedimentary basin for large-scale district heating in Korea. However, we recently identified a geothermal anomaly in terms of high heat flow and geothermal gradient at the Tertiary sediment area in southeastern part of the Korean Peninsula, which also more or less extends following a big fault system in the region. The Pohang low-temperature geothermal development project, which is the first systematic approach beyond hot spring exploration, is currently under way at the Tertiary sediment area.

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. Among the new & renewable energy, photovoltaic (PV), wind and hydrogen/fuel cell are of primary concern. 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 geothermal heat pump installation continue to increase in the future.

2. GEOLOGIC SETTINGS

Figure 1 shows digital geologic map of South Korea (KIGAM, 1995). The geology of Korea is composed of relatively old rocks and also various formations that age from Precambrian to Quaternary. The Precambrian metamorphic rocks (PR and AR groups in Figure 1) crop out extensively in the Korean Peninsula from the north to south covering almost a half of the territory. Especially in South Korea, Archean (AR) groups mainly consist of gneiss and schist complexes and exposed in the Gyeonggi Massif, central Korea and in the mountainous area over southern part of the Peninsula.

The Paleozoic sediments (PT, O, and og group) are distributed mainly in central-eastern part of South Korea forming high mountains. It is hard to find hot spring or geothermal manifestation in those areas composed of Precambrian and Paleozoic (PAL group) rocks. The major outcrop of the Jurassic granite (J group) occurs as batholith stretching along NE direction in the middle part of the Peninsula across the country from the east to the west. Cretaceous granite is mainly limited in the southeastern part. Following the granite intrusion and tectonic movement in the southeastern part during the Cretaceous (K group) and the early Tertiary (P group), several linear structures has formed with direction of NNE, parallel to the southeastern coast line. Major hot springs are mostly found in these granite areas.

Quaternary volcanic rocks (Q group) are exposed in some islands in the South and East Sea, and in some areas in the main land of Korea. There is no geothermal manifestation such as hot springs or high subsurface temperatures in those volcanic areas.

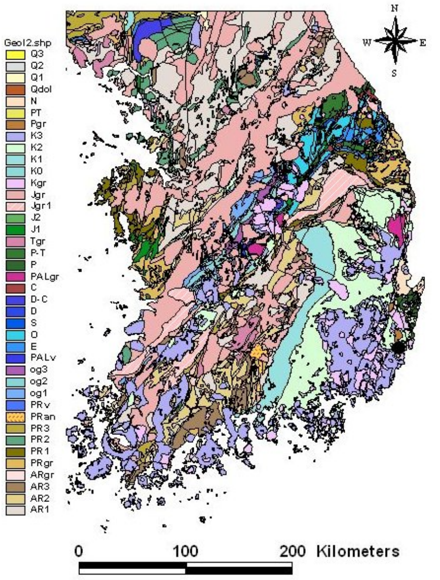

Figure 1: Digital geology map of South Korea (KIGAM, 1995).

3. GEOTHERMAL POTENTIAL

By the end of 2007, total 1,516 rock samples have been gathered throughout the country, of which density, heat capacity, thermal conductivity and thermal diffusivity have been measured and compiled into a database. Total 710 and 492 geothermal gradient and terrestrial heat flow data are available, respectively (Kim et al., 2010). Figure 2 shows location of samples and distribution of measured quantities. Note that in Figure 2 (c), high heat flow measurements at the southeastern part can be correlated with a big fault systems along the region as can be seen in Figure 1. We can also find higher heat flows in the northwestern part, but it is not clear yet whether these have something to do with geologic structure or not. Number of rock samples exceeded 2,000 by the end of 2008.

Annual mean ground surface temperature distribution is also available from the analysis of observed data from 54 meteorological stations (Koo et al., 2006). Combining the above information we can come up with temperature distribution at depth *z* through following formula (Lee et al., 2008);

$$T(z) = \frac{A_0 b^2}{\lambda}(1 - e^{-z/b}) + \frac{Q_0 - A_0 b}{\lambda} z + T_0 , \qquad (1)$$

where T_0 is surface temperature, Q_0 the surface heat flow, A_0 the heat production, λ the thermal conductivity and b the attenuation depth. Figure 3 shows temperature distribution at depth of 5 km as an example (Lee et al., 2010).

A volumetric method the same as in MIT report (Tester et al., 2006) can be applied to resource assessment using some other quantities and temperature distribution estimated above;

$$Q = \rho C_p V \{T(z) - T_0\}, \qquad (2)$$

where V the total volume in the depth interval, ρ the density, C_p the specific heat. Thus estimated heat content in South Korean territory down to 5 km reaches some 10^5 EJ, which is approximately 10,000 times the primary energy consumption in 2006. Because this estimate is based on the volumetric method of static heat contents, practically available resources are far less considering the available fluid contents with the currently viable technologies. Nevertheless, this estimate is important as the first quantitative geothermal assessment in Korea.

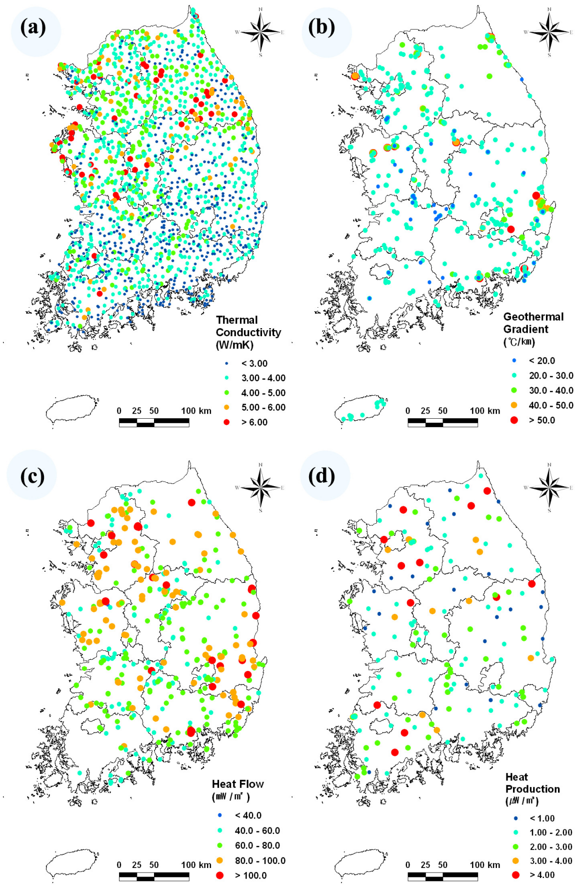

Figure 2: Location of samples and distribution of measured values; (a) 1,516 thermal conductivities, (b) 710 geothermal gradients, (c) 492 heat flows, and (d) 180 heat productions (Kim et al., 2010).

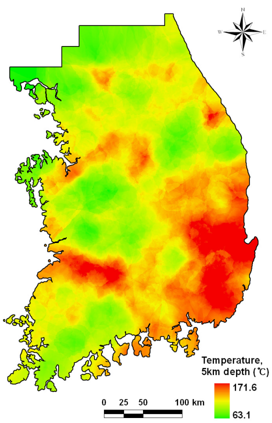

Figure 3: Temperature distribution at depth of 5 km estimated from equation (1) (Lee et al., 2010).

4. GEOTHERMAL UTILIZATION – STATISTICS AND DISCUSSION

There is no geothermal power generation in Korea as can be found in TABLE 1. Although substantial increase of other renewable is expected by 2015, it includes mainly landfill gas, waste combustion and combined heat and power generation.

As for direct use, TABLE 3 shows the statistics on 13 major hot spring areas showing discharge temperatures higher than 42 °C, some of which have been used for more than a thousand years. Note that in BuGok (13 in Figure 4) area, hot spring water of temperature with 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 (1) area. These two areas contribute some numbers to individual space heating in TABLE 5. In GangHwa (3), saline hot spring water from an artesian well at a small island is utilized for a small greenhouse and small-scale district heating since 2008, and then supplied to public bath. Figure 4 shows location of the 13 hot springs superimposed on the tectonic map of Korea. Note that granite exposures are marked with different colors corresponding to those geologic ages.

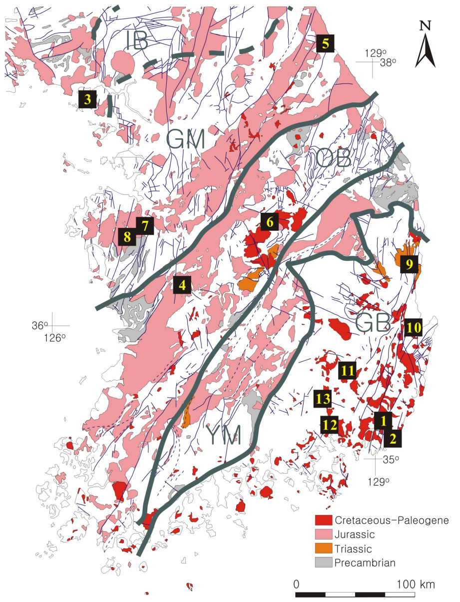

Figure 4: Location of hot springs in TABLE 3 superimposed on tectonic map. Colored regions represent granite exposures.

Geothermal or ground-source heat pump installation is rapidly increasing since 2003 and total installed capacity exceeded 100 MWt in 2008 and showed a big jump in 2009 thanks to an active rural subsidy program for greenhouse. Note that heat pump installation in Korea is mainly for office and public buildings and relatively large buildings such as dormitory, university campus and hospitals and thus typical capacity of heat pump is rather big such as in the range of 30-100 kW (see TABLE 4). Table 1 shows recent increase of installed capacity and annual thermal energy used, from which we can find more than 50% of annual increase in energy uses. This rapid increase is mainly thanks to strong government subsidizing programs that support a half of installation cost for selected cases based on competition. Big increase in 2009 is mainly from greenhouses in rural area supported by a special rural subsidy program. Recently, some private universities installed large systems without government subsidy in order to reduce operation cost of heating and cooling the campus buildings.

Table 1. Increasing trend of geothermal heat pump installation in recent 5 years

	2005	2006	2007	2008	2009*
Installed Capacity in MWt (Cumulative)	8.20 (17.51)	35.2 (52.7)	20.5 (73.2)	32.2 (105.4)	80.3 (185.7)
Annual Energy Used in Toe (TJ)	2,558 (109.0)	6,208 (260.74)	11,114 (473.5)	18,394 (772.5)	31,984 (1,361)

* Statistics on 2009 are estimated based on the amount of government subsidy in 2008 (assuming 70% of the total project completed by 2009).

TABLE 5 shows summary of geothermal direct heat uses as of 31 December 2009. District heating and greenhouse heating has just started in 2008. Total installed capacity exceeded 200 MWt and thermal energy used was almost 2,000 TJ in 2009.

As can be seen in TABLE 6, there have been two exploration drillings from 2005 and 2008 for Pohang low-temperature geothermal development program, which has not produced successful flow rate yet. We can also see 150 production wells all of which are for private hot spring development. Depths of the wells are typically 800 m – 1,000 m to meet legal condition that the well head discharge temperature should be higher than 25 °C. This means that the hot spring developers are rather looking for groundwater along the fracture zones in areas with normal geothermal gradient than exploring geothermal water resources. Number of wells drilled for hot springs is decreasing year after year.

TABLE 7 shows allocation of professional personnel to geothermal activities. Note that from this country report we include the national authority and government funded research organizations into 'Public Utilities'. Almost all of the private industry and two third of the universities are related with geothermal heat pump installation.

For R&D investments in geothermal, government funding and corresponding matching funds (25-50% of government funding) cover almost the whole budget (see TABLE 8). For utilization, there is strong government subsidizing program offering a half of installation cost of geothermal heat pump for selected ones. Note that we do not include private hot spring development because it is no longer possible to get reliable information.

5. MAJOR RECENT R&D EFFORTS

5.1 Pohang low-temperature geothermal development program

Korea Institute of Geoscience and Mineral Resources (KIGAM) started the Pohang project to develop geothermal water for district heating and agricultural application in the area showing high geothermal anomaly, north of Pohang city in the southeastern part of Korea, in 2003. The target area was selected first by the geothermal anomaly shown from heat flow and geothermal gradient maps. Then, lineament distribution analysis using Landsat image and structural geological mapping was applied to find possible deep fractures that would work as geothermal water conduits. The area belongs to the Tertiary Pohang Basin overlying Cretaceous sedimentary rocks, Eocene volcanic rocks such as tuff and Permian grano-diorite basement. The Pohang Basin consists of Miocene marine sediments and bottommost clastic sediments layer. The Heunghae basin, the main target of the geothermal exploration, is covered with Quaternary alluvium underlain by these thick Tertiary sediments with relatively low thermal conductivity and thus preserving high geothermal gradient of 35-40 °C/km, which is quite uncommon in Korea (see Figure 5).

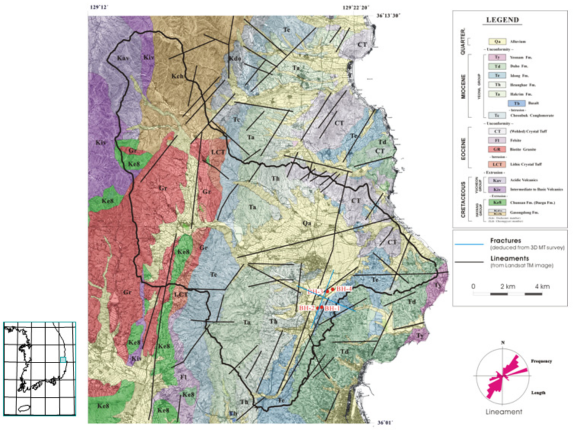

Figure 5: Geology, lineaments map of Pohang area. Four borehole locations are superimposed as pink dots.

Numerous geophysical survey methods have been applied such as gravity and magnetic surveys for interpretation of the regional geologic setting, magnetotelluric (MT) and controlled-source audio-frequency MT (CSAMT) surveys for mapping the resistivity structure and possible fracture zones, and self-potential survey for examining hydrologic condition associated with geothermal flow. Drilling of two pilot wells 165 m apart, one is a rotary well and the other is a coring borehole, started in August 2003 to confirm the existence of the geothermal reservoir. The rotary well went down to 1.5 km and the coring borehole to 1.1 km. The drilling results showed a geothermal gradient of 40 °C/km in Tertiary sediments and existence of several permeable zones related with fracture systems in lower part.

After finishing the pilot wells, pumping tests along with monitoring of self-potential over the area and draw-down at the adjacent well, and chemical analyses of pumped water have been performed to confirm that there exist several permeable zones associated with deep fractures. The pumping test produced geothermal water of 51 °C in temperature and of 560 m^3/day in flow rate, which is fairly good condition in Korea. A three-dimensional imaging of subsurface structures using MT data has been made and it was identified that the fracture zone extended down to at least 2 km in depth as shown in Figure 6.

Based on these results, another well has been drilled down to 2.383 km to find basement at depth of 2.265 km at the end of 2006. Several geophysical loggings were performed only down to less than 2 km due to instruments durability against high pressure and temperature at its bottom. Drilling and geophysical logs, however, indicated that there are several permeable zones, where considerable amounts of leakage of the drilling mud and abrupt change in temperature profile was observed. The temperature was 82.5 °C at 1.98 km and is expected to be over 90 °C at 2.3 km depth.

There have been met various problems in the well, such as incomplete well casing, partial collapse in uncased depth interval, remaining mud cakes in permeable zones, etc. All of these problems have resulted from lack of experience in deep drilling in a large diameter well (deeper than 1.5 km). Trouble shooting for the well has been completed in 2009 but pumping test do not provide enough flow rate and there still remain needs for additional borehole surveys to characterize fracture system nearby. Nevertheless, it is quite important experience in Korea in that this is the first systematic trial of deep geothermal development beyond hot spring exploration and made people learn valuable lessons.

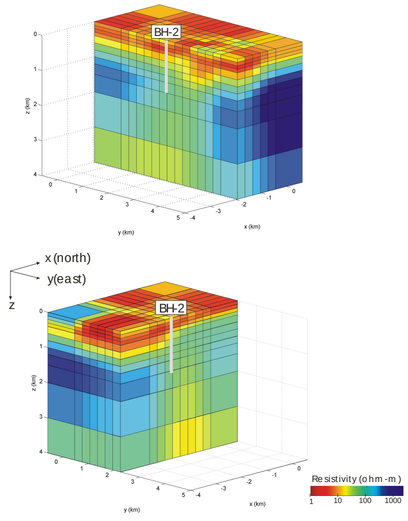

Figure 6: Three dimensional image of subsurface out of inversion of MT survey data in Pohang area.

5.2 Geothermal heat pump system with alluvial groundwater-source

Annual groundwater use in Korea amounted to 3.75 billion m^3 in 2006 (MOCT, 2007), 54% of which is for residence and industry use (approximately 5.5 million m^3/day). The fact that it does not require any drilling cost when connecting heat pumps to existing groundwater well heads or pipe lines and that the temperature of groundwater varies little throughout the year, offers a great opportunity for expanding geothermal utilization. Groundwater in crystalline rocks flows through fractures and thus it is not easy to find or tap groundwater in regions other than alluvial areas in Korea. In alluvial areas, on the other hand, relatively sufficient amount of groundwater is ready for use for agriculture, living, industry and even for municipal water supply system.

One of the major recent cases of groundwater thermal energy utilization is the installation of the heat pump directly connected to the municipal water supply pipe line from a bank infiltration system. Another example is a heat pump system using drained groundwater underneath a building. In alluvial areas, there is substantial amount of effluent groundwater to be drained from the initial stage of building construction. The amount of groundwater changes depending on rainfall but in many cases the minimum amount is still enough to extract thermal energy for heating and cooling purposes. Proof-of-concept installations were made and the both showed fairly high performance in terms of coefficient of performance (COP): maximum 5.7 of heat pump COP and 4.1 of system COP (Song et al., 2008)

The performance of the systems is continuously being monitored and we expect this to be an important corner stone of expanding geothermal heat pump installation especially by utilizing groundwater thermal energy.

5.3 Compiling thermal property database and GIS implementation

Rapid increase of geothermal heat pump installation is mainly due to a strong government subsidizing program. Major portion of the heat pump systems so far are based on borehole heat exchangers, but quantitative information on the thermal properties of subsurface materials has not been readily provided. As a consequence, installed heat pump systems are likely to be over-designed, which can make the systems less competitive in terms of initial cost. In the year 2005, KIGAM initiated a government funded R&D program for compiling a map of thermal properties of subsurface materials throughout its territory to provide basic design parameters to geothermal heat pump installers. More than 2,000 rock samples were collected by the end of 2008, and all physical properties relevant to subsurface thermal behavior have been measured and compiled into GIS database. This GIS system will be open to public in 2010 (Kim et al., 2010).

6. DISCUSSION, CONCLUSIONS AND FUTURE OUTLOOK

Although some measurements of heat flow had been performed with a few rock samples from the 1970’s and there have been continuous measurements of geothermal gradients along wells deeper than 300 m for the purpose of hot spring investigation, it was not until Pohang low-temperature geothermal project started in 2003 that a systematic study on the geothermal characteristics and the development of direct-use geothermal resources initiated. For the past five years, a notable progress has been made; for example, geothermal gradient map and heat flow maps have been updated to represent geothermal characteristics and interpretation of heat flow distribution in terms of geology, age of formation and rock type became possible (Kim and Lee, 2007) as well. As a result, we came to find that geothermal phenomena such as hot springs in Korea have little to do with anomalous region in terms of heat flow, but rather are related with deeply extended fracture system in crystalline rock formation. Continuous efforts to collect rock samples and to measure the thermal properties have led to thermal property database compilation and also to the first geothermal assessment in Korea.

District heating with geothermal energy in Korea has started in 2008 from 20 houses at a small island with saline waters from an artesian well in GangHwa. This will be extended to cover the whole island with some 300 houses thanks to government subsidy. But the Pohang project, the first low-temperature geothermal development program in Korea, has not produced successful results yet. Due to lack of experience in deep drilling and in engineering through deep wells and other technical problems, the project schedule has been delayed several times and the well of 2.383 km depth was completed in 2009. Once we can see successful results from pumping tests and reservoir characterization, supply systems to nearby apartments would be designed.

Installation of geothermal heat pumps is a promising area in Korea in that ubiquitous geothermal energy can be tapped regardless of rock type and geothermal characteristics. The climate of Korea makes people need heating in winter and cooling in summer and thus high capacity factor is expected. However, drilling cost for installing borehole heat exchanger networks is still a weak point in an economic sense. Nevertheless, there are increasing challenges; for example a large borehole heat exchanger system in a private university with 245 boreholes of 150 m depth was installed in 2008. This covers the whole university campus buildings with heating and cooling load of 6,230 kW and invested by the university without government subsidy.

Another good example may be using groundwater-source (standing column well) heat pump installation in another private university covering total area of 89,694 m^2 combined with water heat storage system using the cheap, night electricity. Especially, heat pump using thermal energy of groundwater offers an emerging market since we can reduce the initial cost by a considerable amount. Successful results from the cases using groundwater thermal energy has led to launching other proof-of-concept R&D programs on alluvial groundwater thermal energy and aquifer thermal energy storage. Considering dense population especially in urban and suburban area most of which lies along river, we expect geothermal heat pump installation using alluvial water will continuously increase.

Recently, we are facing strong government’s drive toward the low-carbon, green-growth and thus there are increasing investments on R&D funding to renewable energy development and on various deploying programs as well. Thanks to this ambitious fostering, public organizations including government funded corporations are paying attention to R&D on enhanced geothermal system (EGS). KIGAM, only one government funded research organization on geoscience and technology fields in Korea, is now in the initial stage of feasibility study of EGS including deep structural investigation. Once it turns out to be worth of long-term R&D investment, an exploration drilling down to 3 km or more in the southeastern part of Korean Peninsula showing higher heat flow would be started in near future; at earliest in 2011.

Another opportunity of low-temperature power generation may exist at a small island in GangHwa, which already shows 70 °C of artesian flow. KIGAM is performing various exploration works to characterize deeply connected fractures which could provide higher temperature such as 90 °C and thus possibly utilize it for small scale binary power generation as proof-of-concept (Lee and Song, 2010). This work will continue until 2011 and we expect that it would be the first demonstration of geothermal combined heat and power generation, if successful.

Summarizing all the above discussion, we can conclude that increasing RD&D activities and some successful deployment cases will lead to direct-use geothermal development, especially geothermal heat pump installation, being active at least for the next five years. Furthermore, through continuing R&D efforts on EGS and exploration of deeply circulated fluid through fracture system, we expect to realize geothermal power generation during the next decade.

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TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro**		Nuclear		Other Renewables * (see note)		Total	
	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr
In operation in December 2009			48,542	266,970	5,505	5,567	17,716	150,958	728	928	72,491	424,423
Under construction in December 2009			6,579		800		6,800		193		14,372	
Funds committed, but not yet under construction in December 2009							1,400				1,400	
Total projected use by 2015			56,773	273,993	6,380	6,400	25,916	199,726	4,499	37,748	93,568	517,867

* including landfil gas, waste and CHP as well as wind, PV, bio and ocean energy
** including pump-storage power generation

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2009 (other than heat pumps)

1) I = Industrial process heat
C = Air conditioning (cooling)
A = Agricultural drying (grain, fruit, vegetables)
F = Fish farming
K = Animal farming
S = Snow melting
H = Individual space heating (other than heat pumps)
D = District heating (other than heat pumps)
B = Bathing and swimming (including balneology)
G = Greenhouse and soil heating
O = Other (please specify by footnote)

2) Enthalpy information is given only if there is steam or two-phase flow

3) Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (^oC) - outlet temp. (^oC)] x 0.004184 ($MW = 10^6 W$)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

4) Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (^oC) - outlet temp. (^oC)] x 0.1319 ($TJ = 10^{12} J$)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

5) Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
Note: the capacity factor must be less than or equal to 1.00 and is usually less,
since projects do not operate at 100% of capacity all year.

Note: please report all numbers to three significant figures.

Locality	Type[1)]	Maximum Utilization					Capacity[3)]	Annual Utilization		
		Flow Rate	Temperature (^oC)		Enthalpy[2)] (kJ/kg)			Ave. Flow	Energy[4)]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5)]
1. DongRae	B	46.88	42	27			2.94	21.89	43.31	0.467
	H	46.88	64	44			3.92	10.62	28.02	0.226
2. HaeWunDae	B	36.2	42	27			2.27	17.85	35.32	0.493
3. GangHwa	B	44	42	27			2.76	15.4	30.47	0.350
	D	44	68	56			2.21	19.76	31.28	0.449
	G	3.34	68	56			0.17	0.84	1.33	0.251
4. YuSeong	B	81.79	42	27			5.13	32.87	65.03	0.402
5. SokCho	B	59.05	42	27			3.71	32.76	64.82	0.555
6. SuAhnBo	B	44.91	42	27			2.82	14.42	28.53	0.321
7. OnYang	B	44.03	42	27			2.76	24.29	48.06	0.551
8. DeokSan	B	12.91	42	27			0.81	8.61	17.03	0.667
9. BaekAm	B	74.27	42	27			4.66	40.43	79.99	0.544
10. PoHang	B	14.58	42	27			0.92	8.49	16.80	0.582
11. CheongDo	B	8.1	42	27			0.51	2.17	4.29	0.268
12. MaGeumSan	B	16.67	42	27			1.05	12.79	25.31	0.767
13. BuGok	B	35.41	42	27			2.22	24.6	48.67	0.694
	H	35.41	76	44			4.74	6.02	25.41	0.170
TOTAL							43.60		593.65	

TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF 31 DECEMBER 2009*

This table should report thermal energy used (i.e. energy removed from the ground or water) and report separately heat rejected to the ground or water in the cooling mode. Cooling energy numbers will be used to calculate carbon offsets.

1) Report the average ground temperature for ground-coupled units or average well water or lake water temperature for water-source heat pumps

2) Report type of installation as follows: V = vertical ground coupled

H = horizontal ground coupled

W = water source (well or lake water)

O = others (please describe)

($TJ = 10^{12}$ J)

3) Report the COP = (output thermal energy/input energy of compressor) for your climate

4) Report the equivalent full load operating hours per year, or = capacity factor x 8760

5) Thermal energy (TJ/yr) = flow rate in loop (kg/s) x [(inlet temp. (°C) - outlet temp. (°C)] x 0.1319

or = rated output energy (kJ/hr) x [(COP - 1)/COP] x equivalent full load hours/yr

Note: please report all numbers to three significant figures

Locality	Ground or water temp. (°C)[1]	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type[2]	COP[3]	Heating Equivalent Full Load Hr/Year[4]	Thermal Energy Used (TJ/yr)	Cooling Energy (TJ/yr)
more than 700 locations throughout the country	15-17	30-100	> 3,000	V,H,W	3.0-4.5	2,032	1,361	
TOTAL						2,032	1,361	

* Data from Korea Energy Management Corporation (KEMCO) and Korea New and Renewable Energy Association (KNREA)

* Note that official data includes installed capacity, thermal energy used and capacity factor only.

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2009

[1] Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

[2] Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

[3] Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^6 W)
Note: the capacity factor must be less than or equal to 1.00 and is usually less,
since projects do not operate at 100% capacity all year

Note: please report all numbers to three significant figures.

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]	8.66	53.43	0.196
District Heating [4]	2.21	31.28	0.449
Air Conditioning (Cooling)			
Greenhouse Heating	0.17	1.33	0.248
Fish Farming			
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]			
Snow Melting			
Bathing and Swimming[7]	32.56	507.61	0.494
Other Uses (specify)			
Subtotal	43.6	593.65	0.432
Geothermal Heat Pumps	185.7	1,361	0.232
TOTAL	229.3	1,955	

[4] Other than heat pumps
[5] Includes drying or dehydration of grains, fruits and vegetables
[6] Excludes agricultural drying and dehydration
[7] Includes balneology

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2005 TO DECEMBER 31, 2009 (excluding heat pump wells)

[1] Include thermal gradient wells, but not ones less than 100 m deep

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1]	(all)		2			3.38
Production	>150° C					
	150-100° C					
	<100° C*		150			124
Injection	(all)					
Total			152			127.38

* Note that all the production wells are for hot spring development, most of which produce groundwater of lower than 35 °C.

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Program
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2005		35	10			20
2006		35	20			30
2007		35	25			50
2008		35	25			60
2009		35	25			60
Total		175	105			220

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2009) US$*

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	0.15	92	184		99.9	0.1
2000-2004	6.3	14.53	No data		69.8	30.2
2005-2009**	41.8	No data	236.8		45.0	55.0

*Currency rate US$ 1 / 1,000 KRW

** From 2005, direct utilization includes only geothermal heat pump installation subsidized by government (50% of total installation cost)

Before 2005, investments for hot spring development was major part, which provides no longer reliable data