4. Korea

Korea's geological features are of relatively old rocks and various formations from the Precambrian era to the Quaternary period. Thick Cenozoic sedimentary layers are not common except in limited regions in the southeastern part. Although Korea has two distinct volcanoes (Jeju and Ulleung islands), there has not been any volcanic activity for more than a thousand years, so that one can hardly expect high-temperature geothermal resources near the surface in the country. Thus, deeper development is essential to get high-temperature geothermal resources for power generation. This relates directly to high exploration costs, weak economic feasibility, and various technological barriers. Because there have been no industries that relate to deep subsurface development or exploration in Korea, infrastructures, technologies, and legislations for securing rights of developers are far from being ready.

4.1 Current situation of geothermal energy use and national policy

4.1.1 Brief history, current energy policy, and energy mix

1) Brief history

Korea does not have high enthalpy geothermal energy related to volcanic or tectonic activities. Some anomalous regions, however, show high geothermal gradient. Pohang is one of such regions that show high heat flow and geothermal gradient. Geothermal anomaly in Pohang area was reported in the 1960s from several deep drillings for oil exploration. Based on the anomalous geothermal regime, a low-temperature geothermal development project in Pohang was done by Korea Institute of Geoscience and Mineral Resources in 2003–2008 (Lee and Song, 2008).

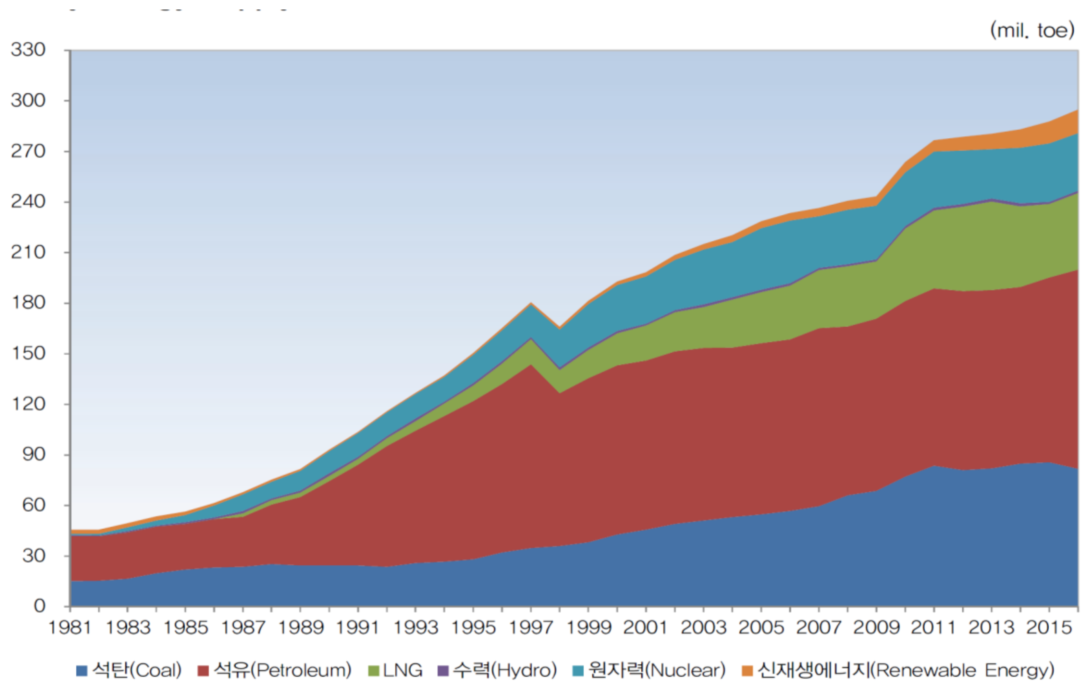
Intensive geological and geophysical surveys such as airborne gravity and magnetic surveys; radioactive, geochemistry, and magnetotelluric surveys were conducted to delineate possible fractures that could carry deep geothermal water to near surface. Four wells were drilled to figure out the geological and geothermal structure of the target area. Well logging from the four wells showed common geothermal gradient higher than 30°C/km (national average of geothermal gradient is about 25°C/km) (Lee and Song, 2008). Assessment of geothermal resources in Korea showed that the temperature at 5 km deep in the Pohang area is expected to be about 180°C and the enhanced/engineered geothermal system (EGS) technical potential for geothermal power generation is about 20 GW_e (Song et al., 2011).

In 2010, the first geothermal power generation project was launched by Enhanced Geothermal Technology. It was supposed to be a 5-year-term, government-funded and industry-matching project, with Pohang field as target area of higher heat flow in the southeastern part of the Korean Peninsula. The project was to be of two phases: I) site preparation, drilling a 3-km deep well and confirming the temperature anomaly in two years, and II) extending the 3-km deep well down to 4.5–5 km, hydraulic stimulation and reservoir creation, drilling another well and completing doublet system, and finally installing a MW_e class binary power plant in another three years (Song et al., 2015). The overall progress of the project was quite slow than what was originally planned due to extra budget demand for the unexpectedly high cost of procurements and mostly due to lack of experience. The project was suspended immediately after the Pohang earthquake that occurred in the vicinity of the EGS site.

2) Current energy policy and energy mix

The total primary energy supply (TPES) in Korea in 2016 was recorded at 294.8 million tonnes of oil equivalent (see Figure 3.4.1-1). Fossil fuels, including oil, coal, and liquefied natural gas (LNG) cover 83.3% of TPES in Korea, while only 4.8% is covered by new and renewable energy (See Table 3.4.1-1).

Figure 3.4.1-1. Yearly TPES Changes in the Last 36 Years in Korea



LNG = liquefied natural gas, toe = tonne of oil equivalent.
Source: Korea Energy Economics Institute, 2017.

Korea's total electricity generation in 2016 was 540 billion kWh (Table 3.4.1-1). Major sources for power generation are coal, nuclear power, and LNG, covering more than 90% of total electricity generation.

Table 3.4.1-1. Share of TPES and Power Generation in Korea in 2016

Source	Oil	LNG	Coal	Nuclear	Hydro	New & Renewable
TPES	40.1%	15.4%	27.8%	11.6%	0.4%	4.8%
Power	2.6%	22.4%	39.6%	30.0%	1.2%	4.2%

LNG = liquefied natural gas, TPES = total primary energy supply.
Source: Korea Energy Economics Institute, 2017.

Following the Second National Energy Master Plan, which was officially announced at the beginning of 2014, the 4th Basic Plan for New and Renewable Energy was fixed in September 2014. The new and renewable energy supply target by 2035 is 11% of TPES (Table 3.4.1-2).

Table 3.4.1-2. Target of New and Renewable Energy Supply by 2035

Year	2012	2014	2020	2025	2030	2035
Target	3.2%	3.6%	5.0%	7.7%	9.7%	11%

Source: Korea Energy Economics Institute, 2017.

Table 3.4.1-3 shows the target share of each new and renewable source to achieve the 11% of renewable energy goal by 2035, where the average increase rate of TPES is assumed at 0.88% annually. Photovoltaic and wind power are the main drivers of renewable power generation. Note that their average annual increases are 11.7% and 16.5%, respectively. Geothermal power, mainly GSHP system, and solar thermal power are expected to be two major sources for thermal energy supply. Target is 18.0% average annual growth of geothermal energy (GSHP).

Table 3.4.1-3. Target Share of New and Renewable Energy Sources in Korea

Year	2012	2014	2020	2025	2030	2035	Annual Increase
Solar Thermal	0.3	0.5	1.4	3.7	5.6	7.9	21.
Photovoltaic	2.7	4.9	11.7	12.9	13.7	14.1	11.7
Wind	2.2	2.6	6.3	15.6	18.7	18.2	16.5
Bio	15.2	13.3	18.8	19.0	18.5	18.0	7.7
Hydro	9.3	9.7	6.6	4.1	3.3	2.9	0.3
Geothermal	0.7	0.9	2.7	4.4	6.4	8.5	18.0
Ocean	1.1	1.1	2.5	1.6	1.4	1.3	6.7
Waste	68.4	6.70	49.8	38.8	32.4	29.2	2.0

Source: Korea Energy Agency, 2017.

On 10 May 2017, the newly installed government declared ‘Sustainable KOREA!’ and on 29 December 2017 announced the 8th Basic Plan of Long-term Electricity Supply and Demand (2017–2031). The key issue of the plan is energy transition to clean energy from nuclear power and fossil fuels. According to the plan, 20% of electricity will be generated by renewables by 2030. The following six major action plans were set up to achieve 20% of the target by 2030.

1) Increasing by 28% the mandatory rate of renewable portfolio standard (RPS) by 2030; currently at 10% by 2024.

2) Promoting large-scale renewable projects, including offshore wind farm and so on.

3) Local community participation; agricultural solar villages, etc.

4) Investment for grid stability.

5) Efficient demand side management using smart grid infrastructures.

6) R&D investment of US$1.4 billion, including US$1.0 billion for renewables (2016–2020)

4.1.2 Geothermal energy use in Korea

Despite the 19.6-GW_e geothermal technical potential across the country, there is no geothermal power generation in Korea (Table 3.4.1-4). A pilot EGS project had been performed since 2010 until an earthquake with a magnitude of 5.4 occurred on 15 November 2017 in the vicinity of the EGS site. It occurred two months after injection and subsequent bleeding-off had been done, but the local community were strongly concerned about possible link between the earthquake and the stimulation process, and the government eventually decided to stop the project temporarily to be able to conduct a scientific investigation.

Table 3.4.1-4. Geothermal Energy Utilisation in Korea by 2017

Electricity		Direct Use	
Total installed capacity (MW_e)	-	Total installed capacity (MW_{th}) (GSHP excluded)	**43.6**
Total running capacity (MW_e)	-	Total heat used (PJ/year) [GWh/year] (GSHP excluded)	**0.594** **[164.9]**
Total generation (GWh)	-	GSHP total installed capacity (MW_t)	**1,210.3***
Target (MW_e)	**200**	**GSHP total net use [GWh/year]**	**678.8***

GSHP = ground source heat pump, GWh = gigawatt hour, MW_e = megawatt electric, MW_t = megawatt thermal, PJ = petajoule.
Note: * indicates estimated values.
Source: Song and Lee, 2018.

On the other hand, GSHP installation in Korea has increased rapidly since the middle of the 2000s, with more than 100 MW_t new installations annually. Total installed capacity was estimated to have exceeded 1,200 MW_t at the end of 2017 (See Table 3.4.1-4). Geothermal direct use, excluding GSHP, is mainly hot spring water for bathing and space heating.

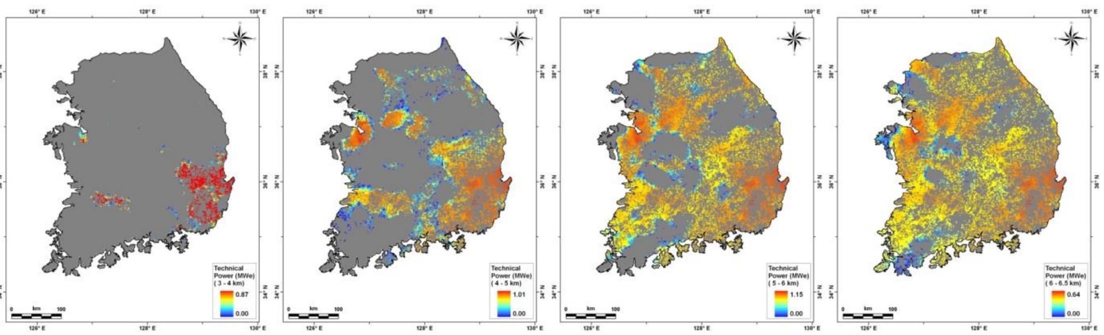
The main drivers of the rapid increase in GSHP installation are the active government subsidy programmes and a special Act for new and renewable energy ('Mandatory Act'). The subsidy programmes include Deployment Subsidy Program, Rural Deployment Program, and 1 Million Green Home by 2020 Program. For the latter programme, the government subsidises 50% of total installation cost based on competition with pre-determined budget each year. Another powerful subsidy programme, established in 2010, is the Greenhouse Deployment Program wherein the central government subsidises 60% and local governments cover 20%, which means that rural farmers pay only 20% of GSHP installation cost for greenhouses and aquaculture. In 2012, the Mandatory Public Renewable Energy Use Act (Mandatory Act) was amended to state that '[i]n all public buildings bigger than 1,000 m^2 in area, more than 10% of annual energy uses should be from new and renewable energy sources'. The minimum percentage is to increase annually: 11% in 2013, 12% in 2014, and so on.

4.2 Target capacity estimation for geothermal power generation and direct use

4.2.1. Target for geothermal power generation in Korea

The technical potential for geothermal power generation by EGS technology was calculated by Song et al. (2011), adopting the protocol for EGS potential proposed by Beardsmore et al. (2010), which is endorsed by International Geothermal Association (2011) and International Energy Agency Geothermal Implementation Agreement (2011). The technical potential considers the technological depth limit (down to 6.5 km deep), land accessibility, and recovery ratio of 0.14. Total technical potential is calculated at 19,567 MW_e.

Fig. 3.4.2-1. EGS Technical Potential at Various Depths in Korea



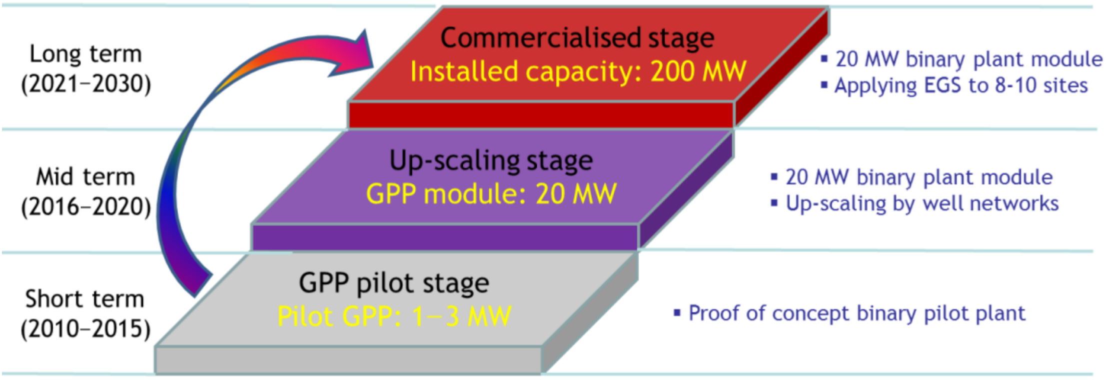
(a) 3~4 km (b) 4~5 km (c) 5~6 km (d) 6~6.5 km

Source: Song et al. 2011.

A national technological roadmap was set up in 2011, right after the start of the pilot EGS project. The scenario is to build a 1~3-MW_e pilot plant by 2015 as proof of a concept pilot plant. The next move is to scale up the plant to about 20 MW_e by 2020 using the well network concept. A geothermal power plant with total capacity of 200 MW_e is to be installed by applying 20-MW_e module to about 10 sites by 2030. It is, however, already behind the schedule and delay of at least 5 years is expected.

The target geothermal power generation in Korea can be estimated from the EGS technical potential and the national technological roadmap. Assuming delay of 5 years for the national technological roadmap, 20 MW of installed capacity can be a target geothermal power plant potential by 2025 and 200 MW by 2035. Assuming a double geothermal power plant capacity every 10 years, a total of 800 MW can be achieved by 2050, which corresponds to about 4% of total technical potential in Korea.

Figure 3.4.2-2. National Technological Roadmap for Geothermal Power Generation in Korea



EGS = enhanced/engineered geothermal system, MW = megawatt, GPP = geothermal power plant.
Source: Original figure of this project.

4.2.2. Target GSHP use in Korea

The annual increase of GSHP installations in Korea in the last 5 years was more than 100 MW_t (Song and Lee, 2015). However, installations due to subsidy programmes are slightly decreasing, and installations due to the mandatory Act are expected to decrease as well because of reduced activities in construction of public buildings.

- The estimated total installed capacity at the end of 2015 using the business-as-usual model is 900 MW_t.
- If we assume an annual decrease of installations of as much as 5 MW_t supported by subsidy programmes and the mandatory Act, then the expected installation by 2025 will be

$900 + 10 \times (100 + 55) / 2 = 1{,}675\ MW_t$

- Thus, we can say that expected GSHP installation by 2025 with the business-as-usual scenario is 1.675 GW_t.

Socio-economic and technical barriers are main hurdles for active GSHP installation for the residential sector. Installations for residential houses as a result of the subsidy programmes peaked at 11 MW_t in 2012 and decreased afterwards due to reduced subsidies. However, according to a government plan (called 1 Million Green Home Program), each GSHP installation should have covered at least 100,000 residential houses with 17.5 kW_t. Thus, we can expect 10,000 new annual installations until 2025 by removing barriers and by encouraging private business to enter the residential market. As potential GSHP installation is expected to be as much as 1,750 MW_t (= 0.0175 MW_t/house × 100,000 houses) by 2025, our target value in that year would be 1675 + 1750 = 3425 MW_t.

4.3 Barriers to geothermal power generation, and necessary innovations

4.3.1 Barriers

Thirty-two domestic experts including professors, researchers, students, and experts from energy authority and geothermal industry replied to the inquiry. Excluding six students, most have longer than 10 years of experience in geothermal business. Figure 3.4.3-1 and Table 3.4.3-1 show the results of inquiry on barriers to geothermal power generation in Korea. Since these experts cover all aspects of geothermal power generation and know the current situation well, the authors take these results (not those from foreign experts in AGS11) for barrier contribution analysis.

Based on these results, the major barriers in geothermal power generation in Korea are high exploration cost (14.3%), drilling technology (9.7%), lack of experts (8.7 %), and national energy policies (8.3 %).

Most of the major barriers to geothermal power generation in Korea are mainly related to the geological situation in Korea. It is essential to explore deeper to get high-temperature geothermal water for power generation. This directly relates to economic feasibility and various kinds of technological barriers, such as high exploration cost, drilling technology, lack of experts, and so on.

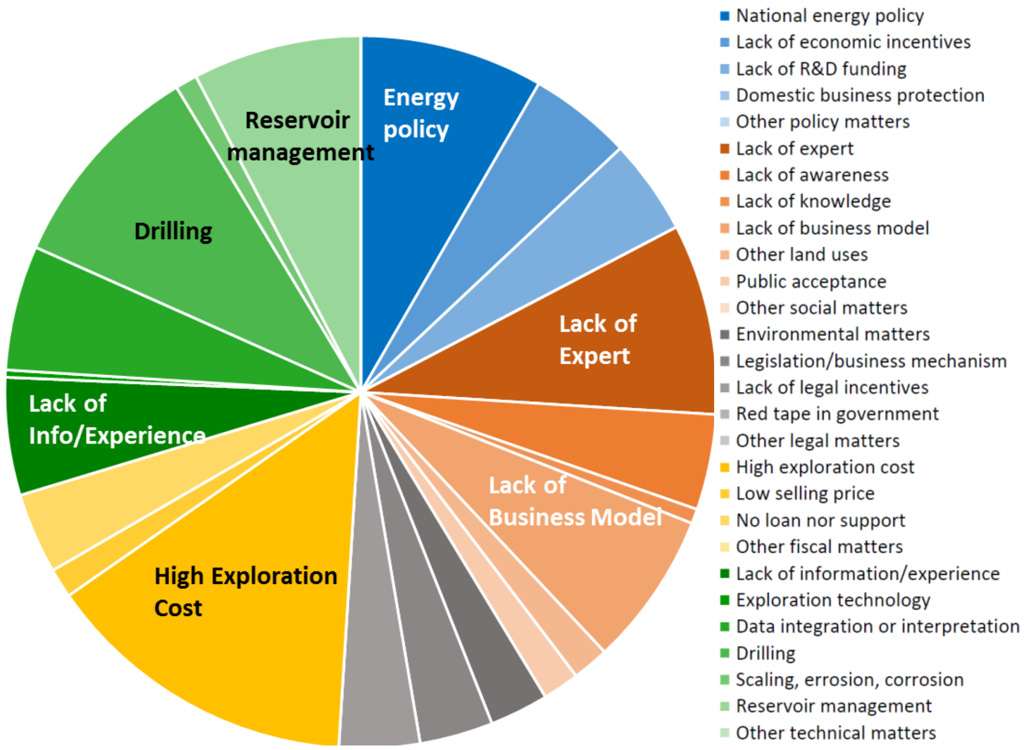
Due to the social debate that ensued regarding the possibility that the Pohang earthquake was triggered/induced by the geothermal exploration in the area, public acceptance became another big barrier for geothermal power generation.

Table 3.4.3-1. Summary of Results of Inquiry on Barriers to Geothermal Power Generation in Korea

Policy	17%	National energy policy	8.3%
		Lack of economic incentives	4.7%
		Lack of R&D funding	4.3%
		Other policy matters	0.0%
Social	24%	**Lack of expert**	8.7%
		Lack of awareness	4.3%
		Lack of knowledge	0.7%
		Lack of business Model	7.0%
		Other land uses	1.7%
		Public acceptance	1.7%
		Other social matters	0.0%
Legal	10%	Environmntal matters	2.7%
		Legislation/business mechanism	3.3%
		Lack of legal Incentives	3.7%
		Other legal matters	0.0%
Fiscal	19%	**High exploration cost**	14.3%
		Low selling price	1.3%
		No loan nor support	3.7%
		Other fiscal matters	0.0%
Technical	30%	**Lack of information/experience**	5.3%
		Exploration technology	0.3%
		Data integration or interpretation	5.7%
		Drilling	9.7%
		Scaling, errosion, corrosion	1.0%
		Reservoir management	7.7%
		Other technical matters	0.0%
TOTAL (%)	100%		100.0%

R&D = research and development.
Source: Authors.

Figure 3.4.3-1. Results of Inquiry to Domestic Experts on Barriers to Geothermal Power Generation in Korea



R&D = research and development.
Source: Authors.

4.3.2 Necessary innovations

The main technical huddles or barriers to power generation in Korea are economic feasibility, and various kinds of technological barriers such as drilling and reservoir creation at depths, and legal and supporting schemes.

1) Renewable portfolio standard system

Geothermal power generation is now included in renewable portfolio standard (RPS) with renewable energy certificate of 2.0, the highest value in Korea. RPS is a kind of obligation where power companies with more than 500 MW of installed capacity are required to generate a certain percentage of power from renewable energy sources. The percentage gets bigger annually from 2012 until 2024 (Table 3.4.3-2).

Table 3.4.3-2. Yearly Renewable Energy Contributions in the RPS System

Year	2012	2013	2014	2016	2017	2018	2019	2020	2021	2022	2023	2024
Renewable EnergyRatio (%)	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0	7.0	8.0	9.0	10.0

RPS = renewable portfolio standard.
Source: Korea Energy Agency, 2017.

Renewable energy sources are in different stages of technological development or economic feasibility. To cope with the difference, renewable energy credit (REC, a kind of weighing factor, was set up. Power companies can get the credit certificate by multiplying their power generation (MWh) with REC of corresponding renewable source. Table 3.4.3-3 shows the REC scheme that has been activated since 2015. Excluding energy storage system + wind which will be supported only for 3 years, geothermal energy has the highest value along with offshore wind and tidal energy.

In fact, studies on the economic feasibility of geothermal power generation in Korea are yet to be enough. But unit price for electricity generated from geothermal energy should be higher than those from the countries in volcanic zones. Considering costs for exploring such depths and the fact that the technologies for geothermal power generation are far from maturity, stronger incentives and more active R&D investments are needed for the industry to actively invest in geothermal power generation.

Table 3.4.3-3. Renewable Energy Certificate for Various Renewable Energy Sources

Category	REC	Type	Remarks
Solar	1.2	Utilisation on land	< 100 kW
	1.0		> 100 kW
	0.7		> 3,000 kW
	1.5	Utilisation on structures including buildings, houses, etc.	< 3,000 kW
	1.0		> 3,000 kW
	1.5	Utilisation on surface of water of dams or rivers	
Other Renewables	0.25	IGCC	
	0.5	Waste, gas from waste disposal	
	1.0	Hydro, wind, bio, tidal (embankment)	
	1.5	Biomass (wood), wind (offshore, less than 5 km)	
	2.0	Fuel cell, tidal current	
	2.0	Wind (offshore, farther than 5 km),	Constant
	1.0~2.5	Geothermal Tidal (without embankment)	Variable
	5.5~4.5	ESS + Wind	2015~2017

ESS = energy storage system, IGCC = integrated gasification combined cycle, kW = kilowatt, REC = renewable energy certificate.
Source: Korea Energy Agency, 2017.

2) R&D investments

Lack of experience and technologies is another obstacle to geothermal power generation in Korea. As an example, a pilot geothermal power generation plant project was started at the end of 2010, targeting 1 MW_e capacity from a doublet system from the depth of about 4.5 km. Most of the development technologies used came from abroad including deep drilling technologies, stimulations at depth, well loggings, etc.

One of the most critical technical barriers is reservoir creation to commercial scale. Reservoir creation in EGS technology depends upon the success of hydraulic stimulation by massive injection of water accompanying real-time monitoring of induced seismicity along with injection pressure. Injection strategy based on in-situ hydraulic parameters is not mature enough and there is not enough experience to go with it. Thus, a novel approach of enhancing injectivity as a result of hydraulic stimulation should be a main focus of technology innovation. Target injectivity or productivity is an order of 1.0 L/sec/bar or 10.0 L/sec/MPa while magnitude of induced seismicity should remain lower than 2.0 in M_L scale. Investment in infrastructure for those technologies is also needed such as drilling tools and logging tools for high pressure and high temperatures.

Table 3.4.3-4. Geothermal R&D Expenditures in 2012–2017 (in *US$1,000)

	2012	**2013**	**2014**	**2015**	**2016**	**2017**
Government	11,056	7,259	11,603	9,232	6,464	**5,842**
Industry	3,577	1,628	15,171	5,772	2,530	**2,073**
Total	**14,633**	**8,887**	**26,775**	**15,004**	**8,994**	**7,915**

*Exchange rates (in W–US$) are as of 01 July each year such as W1,174 (2012), W1,165 (2013), W1,029 (2014), W1,140 (2015), W1,168 (2016), and W1,165 (2017).
Source: Song and Lee, 2018.

Table 3.4.3-4 shows the geothermal R&D expenditures for the past six years (Song and Lee, 2018). One can see a considerable decrease of R&D investment in 2016 due to the government's decision to end funding to the Pohang EGS project in 2015. R&D funding for geothermal power development was further decreased in 2017. Unfortunately, geothermal power exploration may not be expected for the time being due to the Pohang earthquake.

3) Legal and supporting schemes

There is no legal framework or supportive measures for geothermal power generation other than the RPS system. This lack of legal framework is a major barrier hindering active industry participation in geothermal business. Depending on sites and situations, geothermal power development in Korea is related to various laws on groundwater, hot spring, construction and environment, and mining. A separate geothermal law is yet to be set up but is expected to be part of mining laws.

The geothermal industries are continuously asking the government to provide stronger incentives or supporting schemes for geothermal power generation. Geothermal resource exploration for prospective regions over the country, risk sharing, or insurance schemes for deep drilling or exploration drilling can promote the geothermal business.

4.4 Benefits of geothermal power generation in Korea

4.4.1 CO_2 emission reduction (kg-CO_2/kW)

So far, enhanced/engineered geothermal system (EGS) is the only way of generating geothermal power in Korea. The capacity factor of the EGS binary system is assumed to be 85%, slightly higher than conventional geothermal power plant. The CO_2 emission factor of electricity generation in Korea is 0.443 tonne-CO_2/MWh (Korea Power Exchange, 2011), which is the average for all power sources. Assuming that the CO_2 emission factor by EGS geothermal is 0.038 tonne-CO_2/MWh (https://en.wikipedia.org/wiki/Life-cycle greenhouse - gas emissions of energy sources) and applying the short-term target of 20 MW_e and the long-term target of 800 MW_e additional capacity with estimated EGS capacity factor of 85%, the annual CO_2 reduction is:

For short-term target: $405 \times 20 \times 24 \times 365.25 \times 0.85 = 60,353,910$ kg-CO_2/year.

For long-term target: $405 \times 800 \times 24 \times 365.25 \times 0.85 = 2,414,156,400$ kg-CO_2/year.

4.4.2 Other direct and indirect effects to local economy

Because Korea does not have an operational geothermal power plant, no data are available for new employment as well as other direct or indirect effects to local economy of geothermal power generation. Thus, benefits of geothermal power generation in Korea has been calculated using common reference data as described in Chapter 2 except electricity sales price. In Korea, electricity sales price (system marginal price) fluctuates all the time depending on world oil price and domestic electricity consumption. The average system marginal price for 2017 was W81.5/kw-h, which is about US$0.076/kw-h. Sales tax is fixed to 10%.

4.4.3 Summary of barriers to and benefits of geothermal power generation

Table 3.4.4-1 and 3.4.4-2 show barriers to geothermal energy use in Korea and expected benefits for short-term and long-term targets if barriers are removed.

Table 3.4.4-1. Barriers to Geothermal Power Generation in Korea and Expected Benefits for Short-term Target by 2025

item		unit	Policy	Social	Legal	Fiscal	Technical	Total	remarks		
Barrier		%	17	24	10	19	30	100			
Target capacity		MW	3.4	4.8	2	3.8	6	20	from "CO2-Cost" Table		
Target power generation		MW-h/year	25,334	35,765	14,902	28,314	44,707	149,022	85%	capacity factor	
	electiricity	J(elect)/year	9.12E+13	1.29E+14	5.36E+13	1.02E+14	1.61E+14	5.36E+14	kWh= 3.6×10^6J		
	equivalent	J(heat)/year	2.28E+14	3.22E+14	1.34E+14	2.55E+14	4.02E+14	1.34E+15	suming 40% efficiency		
Saving land (compared to same power by PV)		m^2	4.53E+05	6.40E+05	2.67E+05	5.06E+05	8.00E+05	2.67E+06	from "Land" Table		
Electricity sales	developer's benefit	USD/year	1,950,698	2,753,927	1,147,469	2,180,192	3,442,408	11,474,694	0.08	USD/kW-h	USD
Electricity sales tax	government's benefit	USD/year	195,070	275,393	114,747	218,019	344,241	1,147,469	10%		
Saving oil (barrel of oil equivalent)		boe/year	37,256	52,596	21,915	41,639	65,745	219,150	1boe≈ 6.12×10^9J(heat)		
CO2 mitigation		(kg-CO2/yr)	10,260,165	14,484,938	6,035,391	11,467,243	18,106,173	60,353,910	from "CO2-Cost" Table		
Saving energy cost compared to PV	Factor	USD/MWh	5.100	7.200	3.000	5.700	9.000	30			compared to PV
	Total saving	USD	760,012	1,072,958	447,066	849,425	1,341,198	4,470,660			
Saving CO2 reduction cost compared to PV	Factor	USD/kg-CO2	0.013	0.018	0.008	0.014	0.023	0.08			
	Total cost	USD	772,422	1,090,478	454,366	863,295	1,363,098	4,543,659			
Land Saving for CO_2 reduction compared to	Factor	m2/kg-CO2	-	-	-	-	-	30.34	from "Land" Table		
	Toal saving	m2	311,252,851	439,415,789	183,089,912	347,870,833	549,269,737	1,830,899,122	for mitigation of 19I		
Benefit for local economy											
new employment			22	31	13	24	38	127		2.71x+73	
new business profit		USD	6,081	8,585	3,577	6,796	10,731	35,769	1,788	1788.47x	NZ example
new business sales tax		USD	608	858	358	680	1,073	3,577	10%		
new business economic effect		USD	7,602	10,733	4,472	8,497	13,416	44,720	2,236	2236x	NZ example

boe = barrel of oil equivalent, CO_2 = carbon dioxide, kWh = kilowatt-hour, m^2 = square metre, MW = megawatt, MWh = megawatt hour, NZ = New Zealand, PV = photovoltaics.
Source: The study team.

Table 3.4.4-2. Barriers to Geothermal Power Generation in Korea and Expected Benefits for Long-term Target by 2050

item		unit	Policy	Social	Legal	Fiscal	Technical	Total	remarks		
Barrier		%	17	24	10	19	30	100			
Target capacity		MW	136	192	80	152	240	800	from "CO2-Cost" Table		
Target power generation		MW-h/year	1,013,350	1,430,611	596,088	1,132,567	1,788,264	5,960,880	85%	capacity factor	
	electiricity	J(elect)/year	3.65E+15	5.15E+15	2.15E+15	4.08E+15	6.44E+15	2.15E+16	kWh= 3.6×10^6J		
	equivalent	J(heat)/year	9.12E+15	1.29E+16	5.36E+15	1.02E+16	1.61E+16	5.36E+16	suming 40% efficiency		
Saving land (compared to same power by PV)		m^2	1.81E+07	2.56E+07	1.07E+07	2.03E+07	3.20E+07	1.07E+08	from "Land" Table		
Electricity sales	developer's benefit	USD/year	78,027,919	110,157,062	45,898,776	87,207,674	137,696,328	458,987,760	0.08	USD/kW-h	USD
Electricity sales tax	government's benefit	USD/year	7,802,792	11,015,706	4,589,878	8,720,767	13,769,633	45,898,776	10%		
Saving oil (barrel of oil equivalent)		boe/year	1,490,220	2,103,840	876,600	1,665,540	2,629,800	8,766,000	1boe≈ 6.12×10^9J(heat)		
CO2 mitigation		(kg-CO2/yr)	410,406,588	579,397,536	241,415,640	458,689,716	724,246,920	2,414,156,400	from "CO2-Cost" Table		
Saving energy cost compared to PV	Factor	USD/MWh	5.100	7.200	3.000	5.700	9.000	30			compared to PV
	Total saving	USD	30,400,488	42,918,336	17,882,640	33,977,016	53,647,920	178,826,400			
Saving CO2 reduction cost compared to PV	Factor	USD/kg-CO2	0.013	0.018	0.008	0.014	0.023	0.08			
	Total cost	USD	30,896,883	43,619,130	18,174,637	34,531,811	54,523,912	181,746,373			
Land Saving for CO_2 reduction compared to	Factor	m2/kg-CO2	-	-	-	-	-	30.34	from "Land" Table		
	Toal saving	m2	12,450,114,031	17,576,631,573	7,323,596,489	13,914,833,328	21,970,789,466	73,235,964,886	for mitigation of 19I		
Benefit for local economy											
new employment			381	538	224	426	672	2,241		2.71x+73	
new business profit		USD	243,232	343,386	143,078	271,847	429,233	1,430,776	1,788	1788.47x	NZ example
new business sales tax		USD	24,323	34,339	14,308	27,185	42,923	143,078	10%		
new business economic effect		USD	304,096	429,312	178,880	339,872	536,640	1,788,800	2,236	2236x	NZ example

boe = barrel of oil equivalent, CO_2 = carbon dioxide, kWh = kilowatt-hour, m^2 = square metre, MW = megawatt, MWh = megawatt hour, NZ = New Zealand, PV = photovoltaics.
Source: The study team.

4.5 Summary of barriers to and benefits of geothermal power generation, and policy recommendations

Because high-enthalpy geothermal source cannot be expected near the surface in Korea, it is inevitable to go deeper to get high-temperature geothermal resources for power generation. Most major barriers to geothermal power generation in Korea directly relate to this fact, such as high exploration costs, weak economic feasibility, and various technological barriers. In terms of technology development for deep drilling and reservoir management, the top five barriers based on survey results are high exploration cost (14.3%), lack of drilling technology (9.7%), lack of experts (8.7 %), national energy policy (8.3 %), and reservoir management (7.7%).

According to the national roadmap, geothermal power's installed capacity will be 20 MW_e by 2030, which can generate 149.0 GWh of electricity and contribute 60,354 tonnes of CO_2 mitigation. To reach the goal, stronger governmental support is essential especially on infrastructure, technologies, and legislation for deep subsurface exploration and development.

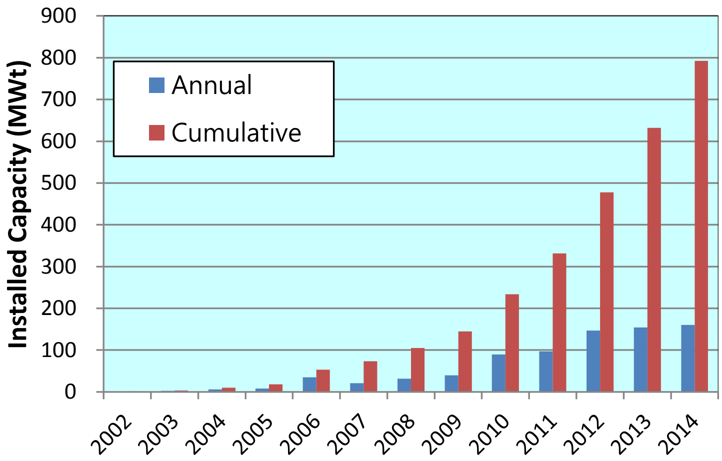
- Although the RPS system secures one of the highest RECs to geothermal power development, more incentives are needed until the EGS technology matures.
- Strong R&D investments are needed, especially to infrastructure for deep exploration and EGS technology such as reservoir creation in commercial scale.
- Legal framework and supportive schemes, such as separate geothermal law and risk sharing by insurance systems for deep drilling and exploration.
- Also needed is direct support for exploration in prospective regions and risk sharing or insurance schemes for exploration drilling.

4.6 Barriers to GSHP use, and necessary innovations

4.6.1. Brief history of GSHP use and barriers in Korea

Figure 3.4.6-1 shows the increasing trend of GSHP installation in Korea, with above than the average 50% annual increase up to 2010, and 100 MW_t installations per year since 2012, mainly due to the strong drive by the government through mandatory Acts and active subsidy programmes, such as the Deployment Subsidy Program, the Rural Deployment Program, the 1 Million Green home by 2020 Program, and the Greenhouse Deployment Program. About 75% of the installations use vertical closed loop system for ground heat exchanger, about 16% use groundwater source, mostly standing column well type, and 5.5 % use horizontal loop type (Kwon et al., 2012).

Figure 3.4.6-1. Trend of GSHP Installation in Korea



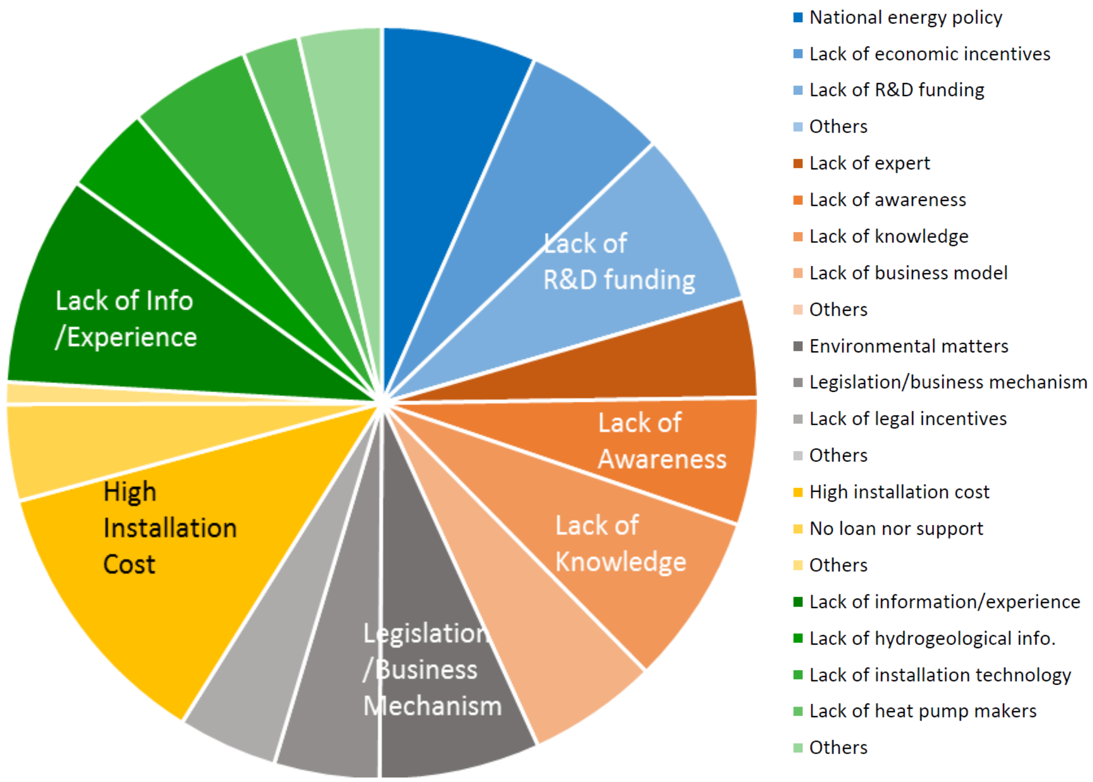
MW_t = megawatt thermal.
Source: Song and Lee, 2015.

4.6.2. Barriers

Figure 3.4.6-2 shows the results of survey among domestic experts on barriers to GSHP use in Korea. The results show that the major barriers to GSHP are high installation cost (11.9%), lack of information/experience (9.0%), lack of R&D funding (7.6%), lack of knowledge (7.4%), and environmental matters (6.9%).

Korea has seen remarkable increase of GSHP installation in the last ten years: more than 50% increase annually or more than 100 MW_t new annual installations since 2013. Such high increase is mainly due to legislation (renewable mandatory Act) and strong government subsidy programmes which may be terminated after some years although there is yet no clear target ending year. The government expects the private sector to be competent in the market without the supporting measures, but the business side is not mature enough in terms of either technology or business. This aspect may lead domestic experts to raise those issues as the most important barriers to be removed. High installation cost is the most common barrier to GSHP business and should be the top priority to be resolved. One thing to note is that domestic experts especially raise the issues of environmental matters (6.9%) including the leakage of circulation fluids within boreholes, and R&D funding (7.6%) for wider application of GSHP as well as reducing installation costs.

Figure 3.4.6-2. Results of Inquiry to Korean Experts on Barriers to GSHP



R&D = research and development.
Source: Authors.

4.6.3. Necessary innovations

The main technical barriers to GSHP systems in Korea are high installation cost, which relates to economic feasibility; and lack of knowledge, information, or awareness. Of the two major innovative ideas needed to hurdle such barriers, one must come from the government while the other one needs efforts from experts in GSHP.

1) Geothermal-specific policy

Amongst the various barriers to the GSHP system in Korea, one of the most significant is the lack of geothermal-specific policy that can drive more efficient installation accounting for climate condition, load characteristics of building type, and hydrogeologic situation. This affects business expansion to residential application.

2) Monitoring

Heating and cooling loads of buildings vary depending on their main functions or purposes. For example, residential houses generally need more heating than cooling and longer heating hours, which is not true for office buildings. Therefore, to estimate the environmental and economic benefits of GSHP and its potential, we must estimate how much loads a specific building type needs, measured as equivalent full load hours per annum.

Accurate monitoring of load factors and system COPs (or SPF_2) of major application types (residential houses, public and commercial buildings, greenhouses, etc.) is the most critical issue to be resolved both in terms of technical barriers and supportive schemes like renewable heat obligation, which is analogous to RPS in power generation. Monitoring of the system COP should include flow rates and temperature difference both at load side (building loops) and at source side (ground loops). In addition, there must be designed a standard procedure in proper installation of temperature sensors, flow meters and electricity (watt-hour) meter, and data logging system. Separate monitoring of electricity consumption of circulation pump for ground loop is critical in accurate estimation of the system COP.

4.7 Benefits of GSHP use in Korea

Adding the business-as-usual model estimate of 1,675 MW_t, the additional potential of GSHP installation by 2025 is expected to be as much as 1,750 MW_t if barriers are removed. Thus, considering the load factors of different applications as described in Table 3.4.7-1 using equivalent full load hours, annual heating energy production of geothermal energy for heating in 2025 becomes

$$1{,}750 \times 1{,}800 \times (1\text{-}3.73)/3.73 = 2{,}305.8 \text{ GWh } (= 8{,}300.9 \text{ TJ})$$

and annual cooling energy production of

$$1{,}750 \times 540 \times (1\text{-}4.75)/4.75 = 745.6 \text{ GWh } (= 2{,}684.2 \text{ TJ})$$

which corresponds to additional annual CO_2 saving of 1,207,064 tonnes-CO_2 (Table 3.4.7-2) compared to conventional air conditioners, and 942,948 tonnes-CO_2 compared to oil boilers (Table 3.4.7-3), plus 244,204 tonnes-CO_2 by cooling compared to conventional air conditioners (Table 3.4.7-4).

Table 3.4.7-1. Equivalent Full Load Hours and Nominal Coefficient of Performance for Heating and Cooling of Different Application Types of GSHP

		EFLH	COP
Residential House	Heating	1,800	3.73
	Cooling	540	4.75
Industry Application	Heating	570	3.73
	Cooling	590	4.75

COP = coefficient of performance, EFLH = equivalent full load hours, GSHP = ground source heat pump.
Source: Paek et al., 2015.

Table 3.4.7-2. Calculation of CO_2 Savings by GSHP Compared to Conventional Air Conditioner (heating mode)

Installed capacity/ installation capacity (MW)	Equivalent full load hours (EFLH) per year (h)	System COP of GSHP for heating	System COP of AC for heating	Heating effect (GWh)	Electricity consumed by GSHP (GWh)	Electricity consumed by AC (GWh)	Electricity Saving (GWh)	National average CO_2 emission factor (kg-CO_2/kWh)	CO_2 mitigation (tonne-CO_2)
A	B	C	D	E	F	G	H	I	J
1750	1800	3.73	2	11749.5	3150.0	5874.8	2724.8	0.443	1,207,064

AC = air conditioner, CO_2 = carbon dioxide, COP = coefficient of performance, GSHP = ground source heat pump, GWh = gigawatt hour, kg = kilogramme, MW = megawatt.
Source: The study team.

Table 3.4.7-3. Calculation of CO_2 Savings by GSHP Compared to Oil Boiler (heating mode)

Installed capacity/ installation capacity (MW)	Equivalent full load hours (EFLH) per year (h)	System COP of GSHP for heating	System COP of AC for heating	Net heat energy production (GWh)	CO_2 saving factor (tonne/GWh)	CO_2 mitigation (tonne-CO_2)
1750	1800	3.73	2	2305.5	409	942,948

AC = air conditioner, CO_2 = carbon dioxide, COP = coefficient of performance, GSHP = ground source heat pump, GWh = gigawatt hour, MW = megawatt.
Source: The study team.

Table 3.4.7-4. Calculation of CO_2 Savings by GSHP Compared to Air Conditioner (cooling mode)

Installed capacity/ installation capacity (MW)	Equivalent full load hours (EFLH) per year (h)	System COP of GSHP for cooling	System COP of AC for cooling	Heating effect (GWh)	Electricity consumed by GSHP (GWh)	Electricity consumed by AC (GWh)	Electricity Saving (GWh)	National average CO_2 emission factor (kg-CO_2/kWh)	CO_2 mitigation (tonne-CO_2)
A	B	C	D	E	F	G	H	I	J
1750	540	4.75	3	4488.8	945.0	1496.3	551.3	0.4	244,204

AC = air conditioner, CO_2 = carbon dioxide, COP = coefficient of performance, GSHP = ground source heat pump, GWh = gigawatt hour, kg = kilogramme, MW = megawatt.
Source: The study team.

4.8 Summary of barriers to and benefits of GSHP use in Korea, and policy recommendations.

GSHP system installation in Korea increased remarkably in the last 10 years, mainly due to legislation and strong government subsidy programmes such as New and Renewable Energy Development Act, Greenhouse Subsidy Program, Mandatory Public New and Renewable Energy Use Act, as well as the support on the electricity price system. With those supporting schemes, the Korean government expects the private sector to be competent in the market without the supporting measures, but the business side is still not mature in terms of either technology or business.

Major barriers to GSHP in Korea that came from survey results are listed below. High installation cost is the most common barrier in GSHP business and should be the top priority to be resolved. It is worth noting that domestic experts especially raise the issues of environmental matters (6.9%) including the leakage of circulation fluids within boreholes, and R&D funding (7.6%) for wider application of GSHP as well as reduction of installation costs.

Also, according to domestic experts, most GSHP companies do not have long-term perspectives regarding their business. It is absolutely necessary that GSHP business show actual benefits or actual COP of GSHP based on the long-term monitoring to request the followings to the government:

- geothermal-specific policy to give high incentives to more efficient installation, accounting for the geological, hydrological, and load characteristics of the target building; and
- accurate monitoring schemes of load factors and the system COPs for both technical and social awareness of GSHP's benefits and supportive schemes such as renewable heat obligation.

Business-as-usual model estimates that total installation of GSHP systems in 2025 will be 1,675 MW_t that is equivalent to 1,226.7 GWh (= 4,416.2 TJ) of annual geothermal energy use for heating. Additional potential of GSHP installation by 2025 is expected to be as much as 1,750 MW_t, which corresponds to installation in 100,000 houses and annual heating energy production of 2,305.8 GWh (= 8,300.9 TJ). Total annual heating energy production can thus be 3,532.5 GWh in 2025. Noting the fact that Korea imports 95% of TPES, domestic energy production is very important. Additional GSHP installation by 2025 can mitigate 1.45 million tonnes of CO_2 emission (1.2 million tonnes from heating and 0.24 million tonnes from cooling) compared to conventional air conditioners.

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