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Renewable Energy Essentials: Geothermal

- Geothermal energy is energy available as heat contained in or discharged from the earth's crust that can be used for generating electricity and providing direct heat for numerous applications such as: space and district heating; water heating; aquaculture; horticulture; and industrial processes. In addition, the use of energy extracted from the constant temperatures of the earth at shallow depth by means of ground source heat pumps (GSHP) is also generally referred to as geothermal energy.
- World geothermal energy installed capacity at the end of 2009 was 10.7 gigawatts (GW_e) for electricity generation and 50.6 GW_{th} for direct use. Approximately 67 terawatt hours (TWh) of baseload electricity were generated with typical capacity factors of 75%. Almost 440 petajoules (PJ) of direct heat were used, with ground source heat pumps (GSHPs) the largest contributor at about 50%.
- Positive characteristics of geothermal include: capability to provide base load power; no seasonal variation; immunity from weather effects and climate change impacts; compatibility with both centralised and distributed energy generation; resource availability in all world regions, particularly for direct use. Barriers to deployment include high capital cost, resource development risk, lack of awareness about geothermal energy and perceived environmental issues.
- Geothermal investment worldwide exceeded USD 2.5 billion in 2008, up 40% on 2007. In 2008, the global geothermal sector employed about 25 000 people, and more than 6 GW of new projects were under development and are expected to be completed in 2015.
- In 2008 capital costs for greenfield geothermal flash plant developments ranged from USD 2000/kW_e to USD 4 500/kW_e, with lower temperature binary developments at USD 2400->5900/kW_e. Capital cost pay-back times for ground source heat pumps typically range from four to eight years in Europe.
- Recent electricity generation costs for flash plant developments range from USD 0.05/kWh to USD 0.12/kWh for higher temperature resources and USD 0.07/kWh to USD 0.20/kWh for lower temperature binary developments. Production costs for district heating in Europe vary between USD 0.06/kWh_t and USD 0.17/kWh_t; average GSHP costs amount to USD 0.08/kWh_t.
- Geothermal power production could increase up to more than 1 000 TWh by 2050, according to the IEA *Energy Technology Perspectives* (*ETP*) *2010* BLUE Map scenario. Forecasts for 2050 presented at the World Geothermal Congress 2010 indicate a possible increase of geothermal direct use (including GSHP) of almost twenty times compared to current levels.

Market status

Electricity generation and capacity

In 2009, the global geothermal energy installed capacity was 10.7 GW_e and generated 67.2 TWh of electricity, at an average of 6.3 GWh/MW_e. Geothermal power provides a significant share of total electricity demand in Iceland (25%), El Salvador (22%), Kenya and the Philippines (17% each), and Costa Rica (13%). In absolute figures, the United States produced the most geothermal electricity: 16 603 GWh from an installed capacity of 3 093 MW_e (Table 1).

Table 1. Top 15 countries using geothermal energy

Geothermal electricity production		Geothermal direct use	
Country	GWh/yr	Country	GWh/yr*
United States	16 603	China	20 932
Philippines	10 311	United States	15 710
Indonesia	9 600	Sweden	12 585
Mexico	7 047	Turkey	10 247
Italy	5 520	Japan	7 139
Iceland	4 597	Norway	7 000
New Zealand	4 055	Iceland	6 768
Japan	3 064	France	3 592
Kenya	1 430	Germany	3 546
El Salvador	1 422	Netherlands	2 972
Costa Rica	1 131	Italy	2 762
Turkey	490	Hungary	2 713
Papua New Guinea	450	New Zealand	2 654
Russia	441	Canada	2 465
Nicaragua	310	Finland	2 325

Data source: Bertani, WGC 2010; Lund et al., WGC 2010

** 1 000 GWh = 3.6 PJ*

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Direct use capacity

Over 70 countries utilise geothermal energy for direct heat applications, such as: ground source heat pumps (GSHPs); space heating; greenhouse and aquaculture pond heating; crop drying; industrial processes; bathing; cooling; and snow melting. Total estimated thermal energy use in 2009 was 438 PJ, 60% higher than in 2005 (Table 1). Significant growth in the GSHP market continues worldwide, with about 2.9 million units installed, >35 GW_{th} capacity and >214 PJ heat production.

Manufacturing and employment

Geothermal power is generated using steam and binary cycle plants, the latter dominant at temperatures <180 °C. Most geothermal steam turbines and generators are manufactured in Japan, while the United States produces the majority of binary cycle generators. Other major manufacturing countries include Italy, Germany, France and Mexico. The worldwide geothermal industry employed about 25 000 people in 2008.

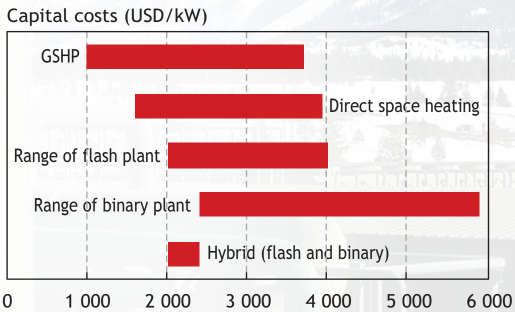
Economics

Investment costs

Electricity generation: Geothermal development costs depend on resource temperature and pressure, reservoir depth and permeability, fluid chemistry, location, drilling market, size of development, number and type of plants (dry steam, flash, binary or hybrid) used, and whether the project is greenfield or expansion (10-15% less). Development costs are strongly affected by commodity prices (oil, steel and cement), and the drop in oil and gas prices since 2008 has contributed to decreasing geothermal capital costs.

Figure 1. Capital costs

Data source: IEA Geothermal Implementing Agreement.



In 2008, the capital costs of a greenfield geothermal power development typically amounted to about USD 2 000–4 000/kW_e for flash plant developments and USD 2 400-5 900/kW_e for binary developments (Figure 1).

The cost breakdown is shown in Table 2.

Table 2. Breakdown of capital costs

Exploration and resource confirmation	10-15%
Drilling	20-35%
Surface facilities	10-20%
Power plant	40-60%

Capital costs are expected to decrease by about 5% by 2020. In Europe, small binary developments (a few MW_e) using low-medium temperature resources, like those now operating in Germany and Austria, are expected to multiply. Total investment costs are estimated to be about USD 5 900/kW. The availability of renewable energy feed-in tariffs and the sale of heat from CHP development (*e.g.* district heating) increase economic viability significantly.

Direct use: Capital costs of geothermal systems for direct space heating range between USD 1 700/kW_{th} and USD 3 950/kW_{th}. Capital costs of ground source heat pumps strongly depend on the system selected. Costs for GSHPs are USD 439-600/kW_{th} for China and India, USD 905-1 190/kW_{th} for North America, and USD 1 170-2 267/kW_{th} in Europe.[1]

Operation and maintenance (O&M) costs

Electricity generation: O&M costs are a small percentage of total costs because geothermal requires no fuel. Typical O&M costs depend on location and size of the facility, type and number of plants, and use of remote-control; they range from USD 9/MWh (large flash) to USD 25/MWh (small binary), excluding well replacement drilling costs.

Direct use: Ground source heat pump systems are low maintenance cost systems.

Generation costs

Electricity generation: Planned economic lifetimes of geothermal plants are typically 20-30 years, though they usually operate for much longer (the Wairakei [NZ] and Larderello [IT] plants now exceed 50 years). A recent 30 MW binary development (United States) has estimated levelised generation costs of USD 72/MWh.[2] New plant generation costs in some countries (*e.g.* New Zealand) are highly competitive (even without subsidies) at USD 50-70/MWh for known high temperature resources. For the United States, new greenfield levelised costs range up to USD 120/MWh; in Europe, costs range up to USD 200/MWh for lower temperature resources. Estimated Enhanced Geothermal Systems (EGS) production costs using current power plant technology range from USD 100/MWh (300 °C resource at 4 km depth) to USD 190/MWh (150 °C resource at 5 km) in the United States, while European estimates are USD 250-300/MWh (Figure 2).

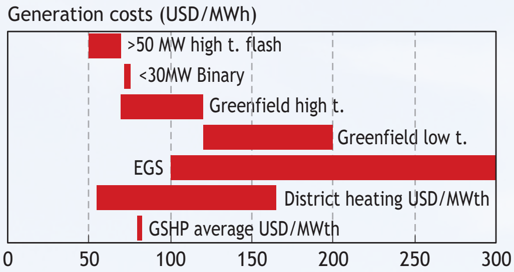
1. Source: IEA Heat Pump Implementing Agreement, Navigant Consulting, Ecodesign Hot Water Task 4.
2. Under the condition of a 15-year debt, 6.5% interest rate.

Direct use: Direct use of geothermal energy for heating purposes can be currently competitive with conventional energy sources. In Europe, geothermal district heating costs are about USD 55-165/MWh_{th}, averaging USD 68/MWh_{th}. The average cost for GSHP operation is about USD 79/MWh_{th}.

Cost reductions

Figure 2. Generation costs

Data source: IEA Geothermal Implementing Agreement.



Electricity generation: Opportunities for cost reductions include reduced well drilling costs; more reliable high temperature and pressure (HTHP) downhole pumps and logging tools; more accurate estimates of resource potential prior to well drilling; and better methods of creating deep hot reservoirs and for control/mitigation of induced seismicity. In Europe, 2030 target costs are: USD 29/MWh for conventional geothermal; USD 74/MWh for low-temperature and EGS production.

Direct use: GSHP cost reductions will be driven by economies of scale related to the rapid global deployment. In Europe, by 2030, cost is expected to decrease by 10%, to USD 74/ MWh_{th}. District heating costs are expected to decrease by 5%, to USD 65/MWh_{th}.

New investment

Investment in geothermal development grew significantly in the past few years, reaching USD 2 507 million in 2008, a several fold increase over 2005, and sustained 40% growth in 2007-2008.

Outlook

Growth drivers

Climate change and other negative environmental impacts of conventional power and heat production have raised awareness of the need to use renewable energies, including geothermal. Several countries in Europe have developed incentive schemes, *e.g.* feed-in tariffs and Renewable Portfolio Standards or quota obligations, that make geothermal power generation and GSHPs economic. Other drivers include the desire for energy independence and security; increasing fossil fuel costs; and rapidly growing energy demand.

Barriers

The main barriers to geothermal development are high initial capital costs and resource development risk, *e.g.* failure of drilling wells, significant depth requirements, insufficient productivity and accessibility of the reservoir. Other barriers to geothermal development include: low awareness and limited information about geothermal energy, related technology and the various options and advantages for both power generation and direct use; lack of incentive schemes and uncertainty about the future of such schemes; a shortage of trained geothermal scientists and engineers; and perceived environmental issues (induced seismicity, subsidence, etc.). For GSHPs, technical (standards, quality control) and legal security (licensing, regulation) issues are important.

Long term scenarios

The Baseline scenario in *IEA Energy Technology Perspectives (ETP) 2010* suggests that geothermal technology could provide 1% (approximately 300 TWh) of global electricity in 2050 (Figure 3). Furthermore, the ETP BLUE scenario, which targets a 50% CO_2 reduction by 2050, suggests that geothermal electricity generation could increase up to 1 060TWh/yr in 2050. A forecast presented in the World Geothermal Congress 2010, indicates that the 2050 electricity installed capacity could go up to 160 GW_e (including EGS), with an associated production of about 1 261 TWh/yr. In the same forecast, the expected total direct use capacity deployment in 2050 is estimated at 815 GW_{th} (Figure 4).[3]

Environmental impacts

External effects

Geothermal developments have minor environmental impacts. The disposal of waste water containing small quantities of chemicals (boron and arsenic) and gases (H_2S and CO_2) is an important issue, but various methods are used for dealing with it, including total reinjection of separated water, condensate and gases; chemical treatment; and mineral extraction. Costs can amount to 1-2% of generation cost. CO_2 emissions from low temperature resources are negligible (0-1 g/kWh). Most binary systems, district heating and CHP schemes typically operate in a closed-loop, hence have nearly zero emissions, as will EGS developments. GSHPs reduce CO_2 emissions by at least 50% compared to an oil boiler, depending on the source of the electricity used.

Local impact

Induced seismicity (felt earthquakes) has become an environmental/social issue at some EGS R&D projects. Small seismic tremors have sometimes been felt, though on a minor scale. An international protocol has been developed to address this concern, and proper management methods are being investigated. Subsidence (land sinking) has occurred and caused concern at a few high temperature developments; however, monitoring is standard, and targeted injection is used to minimise it.

3. Bromley, C.J., Mongillo, M., Hiriart, G., Goldstein, B., Bertani, R., Huenges, E., Ragnarsson, A., Tester, J. Muraoka, H. and Zui, V. (2010), *Contribution of Geothermal Energy to Climate Change Mitigation: the IPCC Renewable Energy Report*. Proc. World Geothermal Congress 2010, Bali, Indonesia, 25-30 April 2010, 5 pages.

Figure 3. Geothermal electricity generation scenarios

Data source: IEA, 2010.

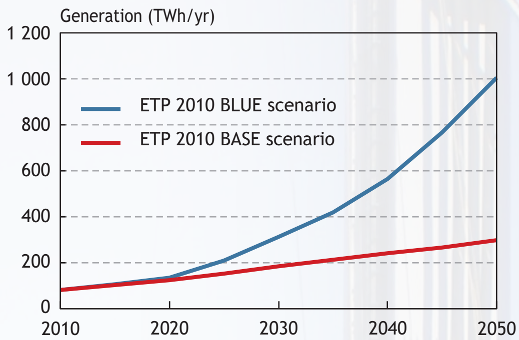
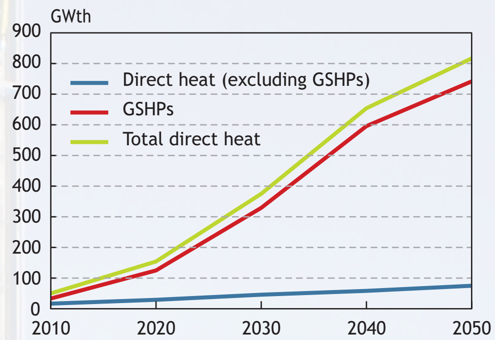


Figure 4. Geothermal direct use and GSHP capacity growth scenarios

Data source: Bromley et al., 2010.



Technology status and development

Geothermal electricity

Conventional plants use steam separated from hot geothermal fluid to drive turbine-generators to produce electricity. Binary plants often use lower temperature (< 180 °C) fluid in a heat exchanger to "boil" a secondary fluid to create a gas that drives the turbine-generators. The emerging technology of EGS, which are underground reservoirs that have been created or improved artificially, circulates water from the surface down wells into deep, enhanced permeable volumes of hot rock, where it heats up, is produced through other wells, sent to binary plants to generate electricity, then circulated back down in a closed loop. Some power developments operate in a *cascade* mode, whereby the hot water exiting the flash or binary plants is used for district heating or other heat applications prior to disposal.

Use of hot supercritical hydrous fluid (400-600 °C) from great depths (4-5 km) will increase the power output/well by a factor of up to 10 (50 MW_e/well), reducing development costs by decreasing the number of wells required.

Geothermal developments have planned (economic) lifetimes of 20-30 years; although ~50% of the current global installed capacity has been in operation for >25 years, and two developments for >50 years. Geothermal plants operate with high capacity (75-95%), load (84-96%) and availability (92-99%) factors. Recovery through natural heat recharge allows depleted resources to be re-used after a rest period.

Ground source heat pumps

GSHPs use the relatively constant temperature of shallow ground (< 300 m deep) to provide space heating, cooling and domestic hot water. GSHPs lift heat from low-temperature ground or groundwater to a higher useful temperature. GSHPs come in two general configurations: vertical borehole heat exchangers and horizontal subsurface loops. Ground source heat pumps are now the fastest growing application of direct geothermal energy use, with about 3 million GSHPs installed at the start of 2010.

Technology advances

Advances in binary plant design have resulted in power production from fluids with temperatures as low as 73 °C. They allow power generation using separated water from steam plants, CHP use of deep sedimentary fluids and they may potentially allow EGS power generation almost anywhere on earth. Better tools for logging High Temperature and Pressure (HTHP) geothermal wells and smaller boreholes produce more reliable and accurate data faster, so reduce logging costs. Modern drill rigs, with better control equipment and drill bits, make it possible to drill more accurately and successfully, sometimes deeper and faster, thus reducing costs. Technology improvements in GSHPs are expected to improve the performance and lower the cost of heat pump technologies. Key components such as compressors and heat exchangers will provide the largest areas for improvement.

R&D priorities

Further technology advances are expected in terms of better methods for more accurate estimates of resource potential prior to drilling, better drilling methods and equipment, more reliable HTHP downhole pumps and logging tools, better methods for creating/enhancing deep hot reservoirs, and better control/mitigation of induced seismicity. Reservoir utilisation/management will be improved with earlier better determination of sustainable production levels and dynamic recovery factors. The main R&D goals for GSHPs aim at reducing investment costs and improving operating efficiency, while expanding the range of products for most of the heating and cooling applications and sub-markets in the building sector.

The IEA wants to thank the Geothermal Implementing Agreement for their substantial contribution in preparing the Geothermal Essentials.