WIERTNICTWO NAFTA GAZ • TOM 24 • ZESZYT 1 • 2007

Ján Pinka*, Gabriel Wittenberger*, Marína Sidorová*, Ladislav Vizi*

UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER**

1. INTRODUCTION

This paper provides a general background on utility-scale geothermal power and seeks o teach the readers a basic understanding of geothermal power, as well as build a solid foundation for further understanding of the technical, economic, and policy dimensions of geothermal power worldwide. Economic data and current U.S. geothermal policy help illustrate the concepts of this paper. Readers may refer to the extensive references to reports and Web links to well-established geothermal energy sources, at the end of this brief to learn the latest developments in geothermal power's role in clean energy generation.

Geothermal energy is energy derived from the heat of the earth's core. It is clean, abundant, and reliable. If properly developed, it can offer a renewable and sustainable energy source. There are three primary applications of geothermal energy: electricity generation, direct use of heat, and ground-source heat pumps. Direct use includes applications such as heating buildings or greenhouses and drying foods, whereas ground source heat pumps are used to heat and cool buildings using surface soils as a heat reservoir. This paper covers the use of geothermal resources for production of utilityscale electricity and provides an overview of the history, technologies, economics, environmental impacts, and policies related to geothermal power [1].

2. GEOTHERMAL RESOURCES

Understanding geothermal energy begins with an understanding of the source of this energy – the earth's internal heat. The Earth's temperature increases with depth, with the temperature at the center reaching more than 4,200°C (7,600°F). A portion of this heat is

---

* Katedra Ropného Inžinierstva, BERG Faculty TU, Košice, Slovak Republic

** This paper was prepared with support of the Grant Agency of Slovak Republic number 1/2164/05

a relic of the planet's formation about 4.5 billion years ago, and a portion is generated by the continuing decay of radioactive isotopes.

Heat naturally moves from hotter to cooler regions, so Earth's heat flows from its interior toward the surface.

Because the geologic processes known as **plate tectonics**, the Earth's crust has been broken into 12 huge plates that move apart or push together at a rate of millimeters per year. Where two plates collide, one plate can thrust below the other, producing extraordinary phenomena such as ocean trenches or strong earthquakes. At great depth, just above the down going plate, temperatures become high enough to melt rock, forming magma. Because magma is less dense than surrounding rocks, it moves up toward the earth's crust and carries heat from below. Sometimes magma rises to the surface through thin or fractured crust as lava.

However, most magma remains below earth's crust and heats the surrounding rocks and subterranean water. Some of this water comes all the way up to the surface through faults and cracks in the earth as hot springs or geysers. When this rising hot water and steam is trapped in permeable rocks under a layer of impermeable rocks, it is called a **geothermal reservoir**. These reservoirs are sources of geothermal energy that can potentially be tapped for electricity generation or direct use.

Figure 1 is a schematic of a typical geothermal power plant showing the location of magma and a geothermal reservoir. Here, the production well withdraws heated geothermal fluid, and the injection well returns cooled fluids to the reservoir [1, 2].

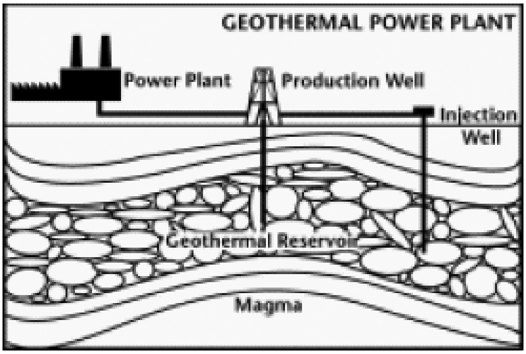

Fig. 1. Schematic of geothermal power plant production and injection wells
Source: U.S. Department of Energy

Resource Identification

Geological, hydrogeological, geophysical, and geochemical techniques are used to identify and quantify geothermal resources. Geological and hydrogeological studies involve mapping any hot springs or other surface thermal features and the identification of favorable geological structures. These studies are used to recommend where production wells can be drilled with the highest probability of tapping into the geothermal resource. Geophysical surveys are implemented to figure the shape, size, depth and other important characteristics of the deep geological structures by using the following parameters: temperature (thermal survey), electrical conductivity (electrical and electromagnetic methods), propagation velocity of elastic waves (seismic survey), density (gravity survey), and magnetic susceptibility (magnetic survey).

Geochemical surveys (including isotope geochemistry) are a useful means of determining whether the geothermal system is water or vapor-dominated, of estimating the minimum temperature expected at depth, of estimating the homogeneity of the water supply and, of determining the source of recharge water [1].

Geothermal exploration addresses at least nine objectives:

1) Identification of geothermal phenomena.
2) Ascertaining that a useful geothermal production field exists.
3) Estimation of the size of the resource.
4) Classification of the geothermal field.
5) Location of productive zones.
6) Determination of the heat content of the fluids that will be discharged by the wells in the geothermal field.
7) Compilation of a body of data against which the results of future monitoring can be viewed.
8) Assessment of the pre-exploitation values of environmentally sensitive parameters.
9) Determination of any characteristics that might cause problems during field development.

3. DRILLING

Once potential geothermal resources have been identified, exploratory drilling is carried out to further quantify the resource. Because of the high temperature and corrosive nature of geothermal fluids, as well as the hard and abrasive nature of reservoir rocks found in geothermal environments, geothermal drilling is much more difficult and expensive than conventional petroleum drilling [4].

Each geothermal well costs \$ 1–4 million to drill, and a geothermal field may consist of 10–100 wells. Drilling can account for 30–50% of a geothermal project’s total cost. Typically, geothermal wells are drilled to depths ranging from 200 to 1,500 meters depth for low- and medium-temperature systems, and from 700 to 3,000 meters depth for high-temperature systems [1, 2].

Wells can be drilled vertically or at an angle. Wells are drilled in a series of stages, with each stage being of smaller diameter than the previous stage, and each being secured by steel casings, which are cemented in place before drilling the subsequent stage. The final production sections of the well use an uncemented perforated liner, allowing the geothermal fluid to pass into the pipe. The objectives of this phase are to prove the existence of an exploitable resource and to delineate the extent and the characteristics of the resource.

An exploratory drilling program may include shallow temperature-gradient wells, “slim-hole” exploration wells, and production-sized exploration/production wells. Temperature-gradient wells are often drilled from 2–200 meters in depth with diameters of 50–150 mm.

Slim-hole exploration wells are usually drilled from 200 to 3,000 meters in depth with bottom-hole diameters of 100 to 220 mm. The size and objective of the development will determine the number and type of wells to be included in exploratory drilling programs [1].

4. GEOTHERMAL POWER TECHNOLOGY

Utility-scale geothermal power production employs three main technologies. These are known as dry steam, flash steam and binary cycle systems. The technology employed depends on the temperature and pressure of the geothermal reservoir. Unlike solar, wind, and hydro-based renewable power, geothermal power plant operation is independent of fluctuations in daily and seasonal weather.

Dry steam

Dry steam power plants use very hot (> 455°F, or > 235°C) steam and little water from the geothermal reservoir. The steam goes directly through a pipe to a turbine to spin a generator that produces electricity. This type of geothermal power plant is the oldest, first being used at Lardarello, Italy, in 1904.

Figure 2 is a schematic of a typical dry steam power plant [1].

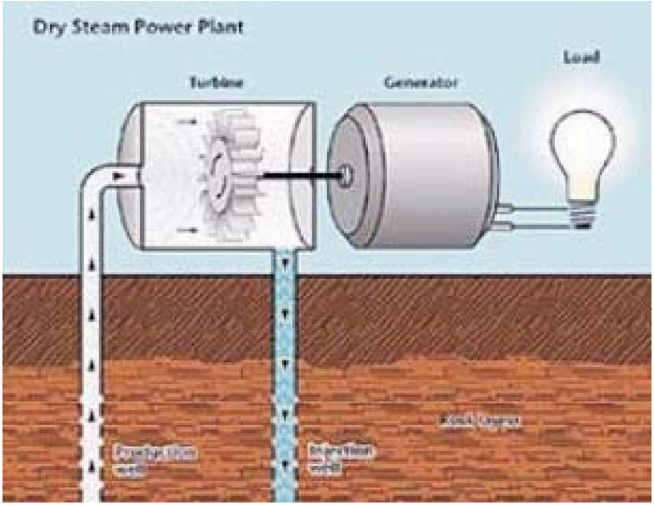

Fig. 2. Dry steam power plant schematic
Source: National Renewable Energy Laboratory (NREL)

Flash steam

Flash steam power plants use hot water (>360°F, or >182°C) from the geothermal reservoir. When the water is pumped to the generator, it is released from the pressure of the deep reservoir. The sudden drop in pressure causes some of the water to vaporize to steam, which spins a turbine to generate electricity.

Both dry steam and flash steam power plants emit small amounts of carbon dioxide, nitric oxide, and sulfur, but generally 50 times less than traditional fossil- fuel power plants. Hot water not flashed into steam is returned to the geothermal reservoir through injection wells [1].

Figure 3 is a schematic of a typical flash steam power plant.

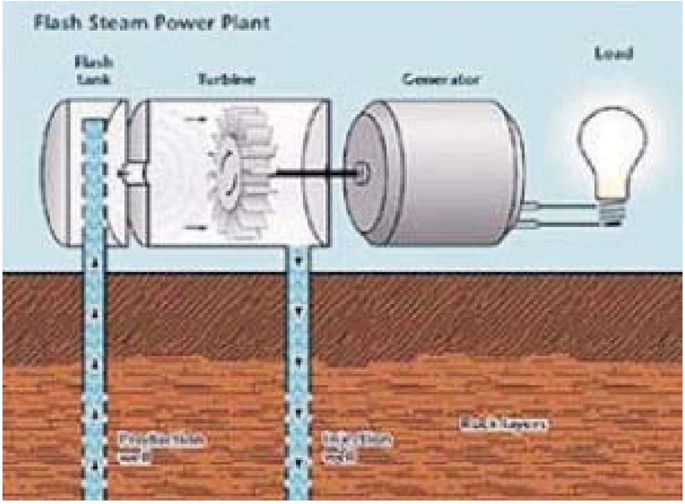

Fig. 3. Flash steam power plant schematic
Source: National Renewable Energy Laboratory (NREL)

Binary-cycle

Binary-cycle power plants use moderate-temperature water (225–360°F, or 107–182°C) from the geothermal reservoir. In binary systems, hot geothermal fluids are passed through one side of a heat exchanger to heat a working fluid in a separate adjacent pipe. The working fluid, usually an organic compound with a low boiling point such as Isobutane or Iso-pentane, is vaporized and passed through a turbine to generate electricity. An ammoniawater working fluid is also used in what is known as the Kalina Cycle.

Makers claim that the Kalina Cycle system boosts geothermal plant efficiency by 20–40 percent and reduces plant construction costs by 20–30 percent, thereby lowering the cost of geothermal power generation.

The advantages of binary cycle systems are that the working fluid boils at a lower temperature than water does, so electricity can be generated from reservoirs with lower temperature, and the binary cycle system is self-contained and therefore, produces virtually no emissions. For these reasons, some geothermal experts believe binary cycle systems could be the dominant geothermal power plants of the future [1].

Figure 4 is a schematic of a typical binary cycle power plant.

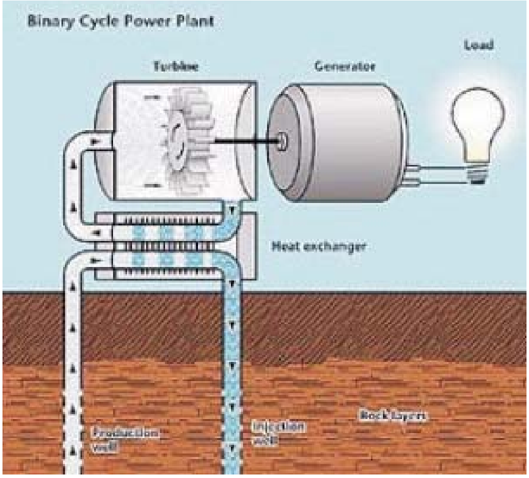

Fig. 4. Binary cycle power plant schematic
Source: National Renewable Energy Laboratory (NREL)

5. GEOTHERMAL POWER GENERATION

As of 2000, approximately 8,000 megawatts (MW) of geothermal electrical generating capacity was present in more than 20 countries, led by the United States, Philippines, Italy, Mexico, and Indonesia (see Tab. 1). This represents 0.25% of worldwide installed electrical generation capacity.

Table 1
Installed geothermal generating capacities worldwide

Country	1995 (MWe)	2000 (MWe)	Country	1995 (MWe)	2000 (MWe)
United States	2,817	2,228	Kenya	45	45
Philippines	1,227	1,909	Guatemala	33	33
Italy	632	785	China	29	29
Mexico	753	755	Russia	11	23
Indonesia	310	590	Turkey	20	20
Japan	414	547	Portugal	5	16
New Zealand	286	437	Ethiopia	0	8
Iceland	50	170	France	4	4
El Salvador	105	161	Thailand	0.3	0.3
Costa Rica	55	142	Australia	0.2	0.2
Nicaragua	70	70	Argentina	0.7	0
Total (MW)				6,833	7,974

In the United States, geothermal power capacity was 2,228 MW, or approximately 10% of non-hydro renewable generating capacity in 2001 (see Tab. 2). This capacity would meet the electricity needs of approximately 1.7 million U.S. households.

Table 2

U.S. Non-hydro renewable power generating capacity, 2001

Power Source	Construction Employment (jobs/MW)	O&M Employment (jobs/MW)	Total Employment for 500 MW Capacity (person-years)	Factor Increase over Natural Gas
Wind	2.6	0.3	5,635	2.3
Geothermal	4.0	1.7	27,050	11.0
Solar PV	7.1	0.1	5,370	2.2
Solar thermal	5.7	0.2	6,155	2.5
Landfill Methane/ Digester Gas	3.7	2.3	36,055	14.7
Natural Gas	1.0	0.1	2,460	1.0

Current geothermal use is only a fraction of the total potential of geothermal energy. In United States geothermal resources alone are estimated at 70,000,000 quads, equivalent to 750,000-years of total primary energy supply (TPES) for the entire nation at current rates of consumption.

The geothermal energy potential in the uppermost 6 miles of the Earth's crust amounts to 50,000 times the energy of all known oil and gas resources in the world. Not all of these resources are technologically or economically accessible, but tapping into even a fraction of this potential could provide significant renewable resources for years to come. The Geothermal Energy Association reports the potential for developing an additional 23,000 MW of generating capacity in the United States using conventional geothermal energy technology [1, 2].

6. CONCLUSIONS

Our intention has been to provide the reader with a balanced overview of the utility-scale geothermal power industry. We believe clean, reliable power can be developed from renewable resources, with geothermal power making an important contribution. Examples from the U.S. geothermal sector have been used to illustrate the costs, benefits, policies, and trends in geothermal energy today. What follows is a list or further resources available on the world-wide web to allow the reader to gain a deeper understanding of the potential of geothermal power and the issues surrounding its development. We urge the reader to seek further understanding of these issues, and the means to their resolution, in order to support the progress of geothermal energy in providing clean, reliable, and economic power [3].

REFERENCES

[1] Pinka J., Wittenberger G.: *Súčasný stav geotermálnych vrtov GTD 1,2,3 v Ďurkove*. 3. mezinárodní konference „Netradiční metódy využití ložisek", Ostrava 6–7 októbер 2005, Sborník v.deckých prací Vysoké Školy Báňské-Technické Univerzity Ostrava, č. 1, 2005, r. LI, 325–328, ISBN 80-248-0920-6, ISSN 0474-8476

[2] Stryczek S., Gonet A.: *Geoinżynieria*. Kraków, WIGSMiE PAN 2000

[3] Scientific Report: National Renewable Energy Laboratory (NREL), USA, 2004

[4] Wittenberger G., Pinka J.: *Využitie geotermálnej energie na Slovensku*. Acta Montanistica Slovaca, R. 10, 2005, č. 4, 387–391, ISSN 1335-1788