ETH
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Geothermal Energy: Role in future energy needs

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Energy Economics and Policy - Term Paper

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Abstract

Alternative energy is a matter of utmost concern in the present day world. Fossil fuels have been the major contributor to global energy demands, but will no longer be the case for the decades to come. Excessive carbon emissions produced by combustion of fossil fuels have serious repercussions, upsetting the normal course of nature. There has been a rising demand for energy across all sectors owing to rapid economic growth and globalization. Petroleum geologists might promise the availability of oil for the next 100 years but at current production rates, there is more likely to be a shortage of supply rather than oil just ceasing to exist as a source. In this report, the technological, economic and environmental aspects of geothermal energy are discussed in an effort to understand its contribution as a promising fuel for a clean and sustainable future.

Contents

1 Technology

The word geothermal originates from the Greek words *'geo'* (earth) and *'therme'* (heat). Geothermal energy involves the extraction of heat from earthś interior in the form of steam or hot water which is used to generate electricity. It is a renewable source as heat is continuously produced inside the earth.

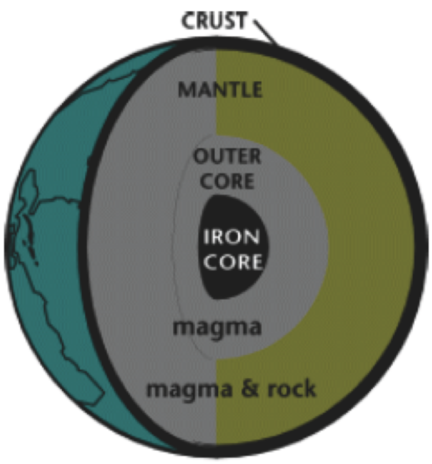
1.1 Earth's inner structure

Temperatures inside the core are high due to slow decay of radioactive particles, a process which happens in all rocks. The layers inside earth are divided into three main layers - core, mantle and crust (shallow outer portion).

Core: Comprises of a solid inner part surrounded by molten matter (outer core).

Mantle: About 2,900 km thick, surrounds the core and is made up of rock and magma.

Crust: Land that forms continents and ocean beds, around 25-50 km in thickness.

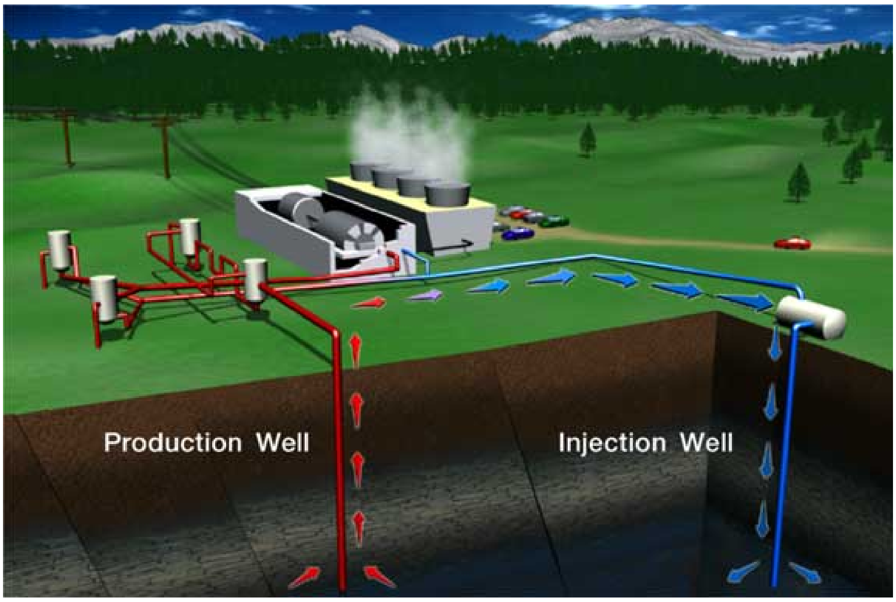


THE EARTH'S INTERIOR

1.2 Working

Earthś crust is made up of broken pieces called plates. When two plates collide, one plate can thrust below the other resulting in a phenomenon known as subduction. At great depths, 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 earthś crust and carries heat from below. Magma which rises to the surface through fractures is known as **lava**. Mostly magma remains below earth's crust and heats ground water trapped in porous rock.

Emergence of heated water through cracks in earth results in **hot springs** or **geysers**. When the heated water/steam gets trapped in a layer of permeable rocks under a layer of impermeable rocks, a **geothermal reservoir** is formed. These reservoirs are sources of geothermal energy and can be harnessed for generating electricity. As shown in the following figure, a typical geothermal power plant has a production well which withdraws heated geothermal fluid from the reservoir and an injection well which returns cooled fluids back to the reservoir.



1.3 Occurance

Indicators of geothermal reservoirs include volcanoes, fumaroles (holes where volcanic gases are released), hot springs and geysers. Most of the resources are found near major plate-ocean boundaries represented as red dots in the following figure.

1.4 Exploration techniques

Geological, hydrogeological, geophysical and geochemical techniques are required for the identification of geothermal resources.

- Geological and hydrogeological studies involve mapping of surface thermal features and identification of favorable geological structures.
- Geophysical surveys throw light upon the shape, size, depth and other important characteristics of deep geological structures by using the following parameters:
  Temperature (thermal surveys)
  Electrical conductivity (electrical and electromagnetic methods)
  Propagation velocity of elastic waves (seismic survey)
  Density (gravity survey) and
  Magnetic susceptibility (magnetic survey).
- Geochemical surveys determine whether the system is water / vapor dominated.

1.5 Applications

Near-surface heat is utilized for heating purposes and the energy from deep reservoirs is exploited for electricity generation. The main applications of geothermal energy are as follows.

Direct use / District heating systems: Use of hot water (low temperatures) from springs or near surface reservoirs for cooking, bathing was common in ancient times (Roman civilization). In more recent times, it is being used for heating buildings (district heating systems) where hot water is piped directly into buildings and industries for heat. This system provides heat for 95% of buildings in Reykjavik, Iceland.

Power plants for electricity generation: Require water/steam at very high temperatures (150^o - 380^o). Power plants are usually built in close vicinity to the geothermal reservoirs.

1.6 Types of geothermal power plants

Dry steam plants: Uses steam piped directly from a reservoir to run the generator turbines. The first geothermal plant was built in Italy.

Flash steam plants: When water is pumped out, it is released from the pressure of the deep reservoir. This pressure drop causes some of the water to vaporize to steam, which spins the turbines to generate electricity. When the steam cools, it condenses to water and is injected back into the ground to be used again. Most geothermal plants are flash steam plants.

Binary cycle power plants: Transfers heat from geothermal water to another liquid (usually an organic compound with a low boiling point). This heat causes the second liquid to turn to steam which drives the generator turbines.

Both dry steam and flash steam power plants emit small amounts of carbon dioxide, nitric oxide and sulphur, generally 50 times less than traditional fossil- fuel power plants.

In binary cycle systems, the working fluid boils at a lower temperature than water does, so electricity can be generated from reservoirs with lower temperatures. The binary cycle system is self-contained and hence produces virtually no emissions. For these reasons, binary cycle systems could be the dominant geothermal power plants of the future.

1.7 Power generation

After the Second World War many countries started using geothermal energy, considering it to be economically competitive with other forms of energy. It did not have to be imported and in some cases, it was the only energy source available locally.

Utilization of geothermal energy in developing countries increased from 75 to 462 MW between 1975 - 1979 and reached a value of 1495 MW by the end of 1984, showing a rapid increase over the specified periods. An increase of almost 150% was observed from 1984 to 2000. It plays a significant role in the energy equation in some areas like the Philippines, Kenya, Costa Rica and El Salvador as seen from the table below.

Table 1: Installed capacities in MW

Country	1995	2000	1995-2000 (%inc)	2003
China	28.8	29.2	1.4	28.2
Costa Rica	55	142.5	159	162.5
El Salvador	105	161	53.3	161
Indonesia	309.8	589.5	90.3	807
Italy	631.7	785	24.3	790.5
Japan	413.7	546.9	32.2	560.9
Kenya	45	45	-	121
Mexico	753	755	0.3	953
New Zealand	286	437	52.8	421.3
Philippines	1227	1909	55.8	1931
Russia	11	23	1109	73
USA	2816.7	2228	-	2020

Source: International Geothermal Association

2 Economics

Commercial viability of any kind of fuel/energy source depends on capital costs, operating costs, amount of power generated and its market value. As geothermal energy incurs a high initial cost it is at an economic disadvantage when compared to conventional fossil fueled power plants. Conversely, the fuel cost is far less and is in the range of the maintenance cost. High capital costs can thus be recovered by savings in fuel costs if the plant is planned for a long duration.

2.1 Capital cost

Capital costs include cost of land, drilling, plant and the equipment required. Drilling a geothermal well costs $1 - 4 million and it can account for 30 - 50% of the project's total cost. Capital cost varies from $1150 - $3000 per installed kW depending on the technology implemented. New technologies can decrease the initial costs incurred. Typical lifetime of the plant is 30-40 years.

Geothermal fluids can be transported over long distances in thermally insulated pipelines (as long as 50 km). Since pipelines are expensive, distance between reservoir and the plant has to be kept to a minimum.

Table 2: Capital cost comparison

Type	(US$/kW)
Geothermal	1150 - 3000
Hydropower	735 - 4778
Coal	1070 - 1410
Nuclear	1500 - 4000

2.2 Operating and maintenance cost

Geothermal operating costs range between 0.4 and 1.4 UScent/kWh which is around the same value when compared to conventional power plants. Large plants have lower operating costs due to economies of scale. In order to reduce maintenance costs, the technical intricacy of the plant should be on a level such that local expertise can be utilized when necessary.

Table 3: Operating and maintenance cost comparison

Type	(UScents/kWh)
Geothermal	0.4 - 1.4
Hydropower	0.7
Coal	0.5
Nuclear	1.9

2.3 Levelized cost

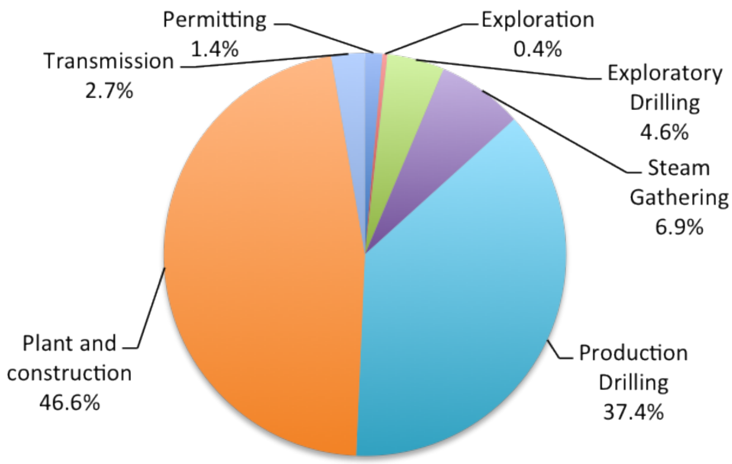
The average cost of production over the life of a plant is known as levelized cost (includes capital, operating and fuel costs). Levelized costs for geothermal electricity generation are \$0.045 - \$0.07 per KWh, more or less close to the fossil fuel costs. Main factors which affect the cost of geothermal plants are depth of wells, temperature of reservoir, environmental compliance and project financing.

Table 4: Levelized cost comparison

Type	(UScents/kWh)
Geothermal	1.5 - 7.0
Hydropower	0.5 - 2.4
Coal	2.0 - 5.0
Nuclear	1.5 - 3.0

2.4 Total cost

Typical cost of a geothermal plant is about 3000 - 4000 US\$ per installed kW. Though geothermal power production is very capital-intensive with high first-cost and risk, it boasts of low operating costs, making it one of the most economical baseload power generation options available.



Source: US Department of Energy

2.5 Economic benefits

Geothermal power plants are often located in rural areas, which typically have high unemployment rates. Building a 50 megawatt (MW) geothermal power plant might create several 100 temporary (from 2 to 3 years) construction and related development jobs and between 40 - 60 permanent, highly skilled full-time jobs at the facility that pay well above the minimum wage. Because geothermal plants have long operating lifetimes, they can become a reliable part of a communityś economic base.

3 Environmental impact

The primary impacts of geothermal plant construction and energy production are gaseous emissions, land use, noise, ground subsidence and seismic events.

3.1 Gaseous emissions

Geothermal fluids mainly contain carbon dioxide (CO_2) and hydrogen sulphide (H_2S). Geothermal energy scores over fossil fuels as the gases like nitrogen oxides, sulphur dioxides are not released at all and the amount of carbon dioxide emitted is quite low when compared to conventional fuel emissions. H_2S emissions are in the range 0.03 - 6.4 g/kWh and are removed by conversion to sulphur.

Table 5: CO_2 emission comparison

Type	(lb/kWh)
Geothermal	0.2
Natural Gas	1.3
Petroleum	2.0
Coal	2.1

Source: Bloomfield, Moore and Neilson, 2003

3.2 Land use

Geothermal power plants require little land. They do not involve heavy construction or deforestation and also do not cause water pollution. Production and injection wells are lined with steel casing and cemented to isolate fluids from the environment. Spent thermal waters are injected back into the reservoirs from which the fluids were derived. It does not even create waste which needs to be disposed off.

Table 6: Land requirement

Type	Acre/MW
Geothermal	1 - 8
Nuclear	5 - 10
Coal	19

Source: US Department of Energy

3.3 Noise

Noise occurs during exploration, drilling and construction phases. Noise levels vary from 40 - 120 dB. Noise levels in quiet suburban residences are usually in the order of 50 dB and in urban environments are in the range of 80 - 90 dB. Noise levels can be kept as low as 65 dB and construction noise is practically indistinguishable from other background noises at distances of one kilometer.

Table 7: Noise level

Type	dB
Air drilling	85 - 120
Mud drilling	80
Well testing	70 - 110
Diesel engines	45 - 55
Heavy machinery	90

Source: International Energy Agency

3.4 Ground subsidence

Extraction of large quantities of fluids from geothermal reservoirs may give rise to subsidence phenomena (gradual sinking of land surface). It is a slow process distributed over large areas. It should be monitored systematically, as it could damage the stability of geothermal buildings and residential homes in the neighborhood. In most cases subsidence can be prevented or reduced by re-injecting the geothermal waste waters.

3.5 Seismic events

The withdrawal or re-injection of geothermal fluids may trigger or increase frequency of seismic events in certain areas. However, these are microseismic events and can be detected by means of instrumentation. Exploitation of geothermal resources is unlikely to generate major seismic events.

4 Policy

Renewable energy can reduce dependence on fossil fuels and emissions of greenhouse gases. Most renewables have different cost structures from the conventional technologies, with high initial costs and low operating costs. Its the same for geothermal energy, which has high exploration and drilling costs in additional to capital plant expenses. With better technology these costs can be lowered and geothermal energy can become more cost-competitive when compared to other sources of energy.

4.1 Initiatives

In order to spur the widespread use of geothermal energy in the world, the government has to take variety of initiatives. Either in the form of subsidies or tax incentives, it has to develop policies to promote the harness of geothermal energy. Currently, through technology transfer programs, some industrialized nations are helping developing countries make use of their local geothermal energy resources.

4.2 Setting an example: Philippines

The Philippines (second largest user of geothermal energy in the world for power generation) has in place the following incentives to attract geothermal energy development.

- Recovery of operating expenses not exceeding 90% of gross value in any year with carry forward of unrecovered cost
- Service fee of up to 40% of net proceeds
- Exemption from all taxes except income tax
- Income tax obligation paid out of governmentÕs share
- Exemption from payment of tariff duties and compensating tax on the importation of machinery, equipment, share parts and all materials for geothermal operation
- Depreciation of capital equipment over a 10-year period
- Easy repatriation of capital equipment investment and remittance of earnings
- Entry of alien technical and specialized personnel (including members of immediate families)

5 Future developments

Renewable energy technology is continuously evolving with the aim of reducing risk and lowering costs. In order to achieve this, other types of nontraditional resources and experimental systems are being explored. Among these are hot dry rock resources and cheaper heat exchanger materials.

5.1 Hot dry rock

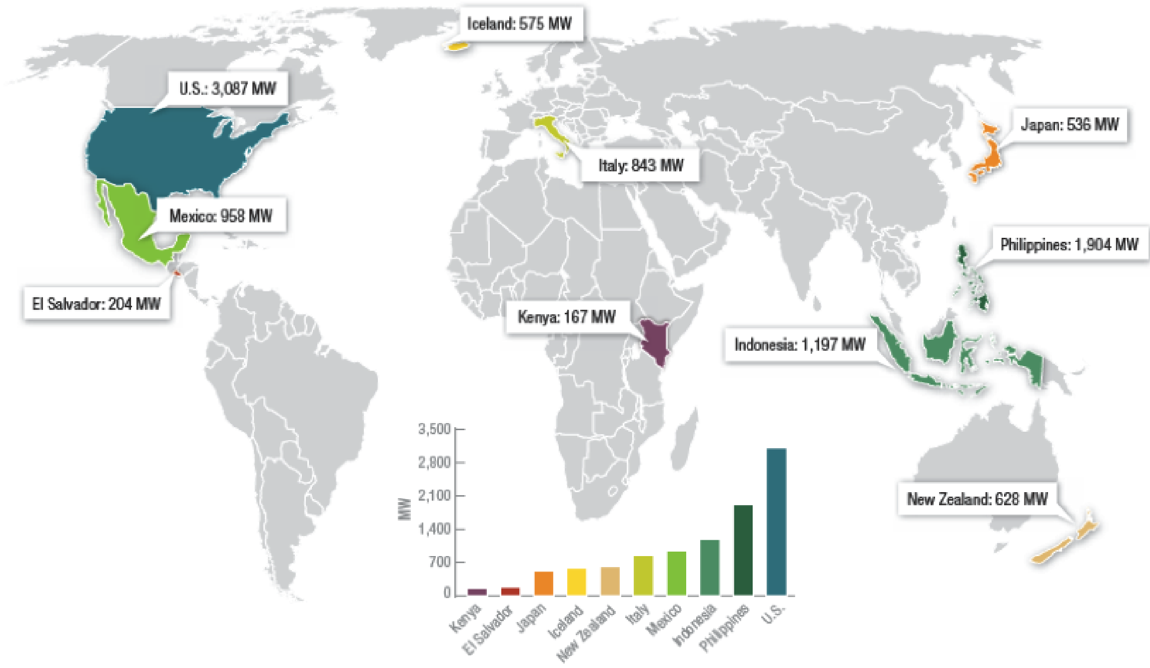
Hot dry rock are resources located much deeper than conventional resources. The energy comes from relatively water free hot rock found at a depth of about 4 km or even deeper. Energy can be extracted by circulating water through man-made fractures in the hot rock. If the technology can evolve to make hot dry rock resources commercially viable, hot dry rock resources are sufficiently large enough to supply a significant fraction of world electric power needs for centuries.

5.2 Heat exchanger materials

Highly corrosive nature of the geothermal fluid poses a challenge to heat exchangers by reducing their thermal conductivity. Research is being done to try to replace these expensive heat exchanger materials (such as stainless steel and titanium) with less expensive polymer-based coated carbon steel.

6 Conclusion

Geothermal energy present inside the earth is enormous. It is generated with domestic resources and hence reduces a country's dependence on foreign resources for energy. Many developing countries are rich in geothermal resources. This can be an important source of revenue to improve the country's infrastructure and its economic situation. Even low-temperature reservoirs can be quite fruitful when considered for small scale implementations. This way local communities can be made self-sufficient as far as their energy needs are concerned, also raising their standard of living.



Generation capacities worldwide - 2009

Source: Geothermal Energy Association

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