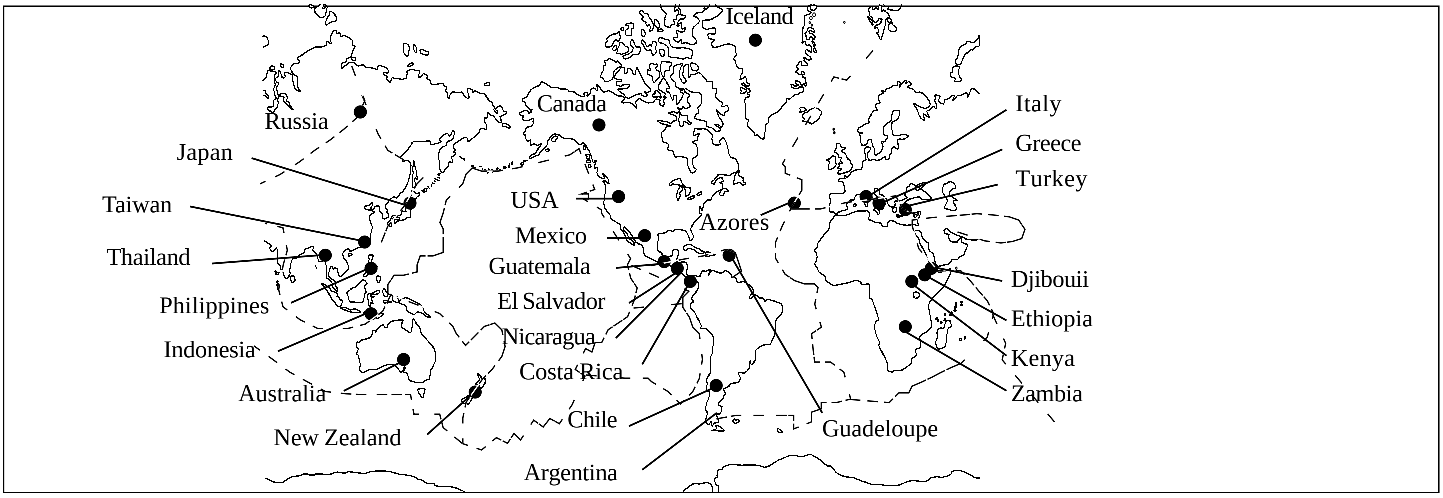
Geo Factsheet

Number 76

Geothermal Energy

This Factsheet will explain the uses of geothermal energy, examine the conditions required for its use and assess its advantages and disadvantages.

Fig 1. Geothermal power sites.



What is geothermal energy?

Geothermal energy comes from the heat stored in rocks inside the earth. Currently, all functioning geothermal plants are **hydrothermal**; they exploit the heating of groundwater. The heated groundwater is pumped to the surface; its heat energy is used to generate power or for heating purposes, then the now cooled water is either returned to the aquifer directly or pumped into the sea.

Recent research, however, has focused on **Hot Dry Rock** (HDR) technology. The "hot dry rock" refers to the heat stored in impermeable rock strata. To utilise this, it would be necessary to create an artificial fracture zone and circulate water through it. The technical feasibility of this has not been completely demonstrated, and work is still underway.

In the longer term, it might also be possible to drill through the earth's crust in regions where it is relatively thin to extract heat from magma directly. However, new materials would need to be developed to cope with the high temperatures and harsh conditions involved; this is unlikely to be developed in the near future.

Where can it be produced?

Usable hydrothermal resources will have three key features:

- an aquifer which can be accessed by drilling
- a cap rock to retain the liquid
- a heat source

Aquifers require **porous**, **permeable** rocks, such as volcanic ashes or rocks such as limestones and sandstones (and occasionally granite) with high fracture permeability.

Caprocks must be impermeable; mudrocks, clays and unfractured lavas are obvious candidates.

Heat is brought near to the surface of the earth by thermal conduction and intrusions of molten magma into the earth's crust. This energy is only usable if the temperature is high enough sufficiently close to the surface of the earth. Due to limitations in drilling technology, usually only the top six kilometers of the earth's crust is considered "sufficiently close".

Suitability can be assessed by examining the **temperature gradient** - that is, the rate at which the temperature changes with distance below the surface. A high temperature gradient shows that high temperatures will be reached relatively close to the surface.

Accordingly, two types of sites are suitable for hydrothermal use:

1. Regions at volcanically active plate margins, where there is a high heat content due to magma intrusions. However, the most recent volcanic areas may not be ideal, since a suitable cap-rock may not have developed. Attempts in the early eighties to develop geothermal resources near the volcano Vesuvius failed for this reason; the volcanic ash forming the sides of the volcano were permeable throughout.

2. Sedimentary basins with shallow rock strata that conduct a low amount of heat energy. Rocks that are not very conductive, such as clays and shales, result in a relatively high rock temperature close to the surface.

If HDR technology is developed, then a third type is added:

3. Granite areas which have a high heat flow. As granite is crystallised from magmas with a naturally high concentration of long-lived radioactive isotopes, it produces heat itself, as well as conducting it from deep heat sources. This can result in a temperature rise of 30^{0}C per kilometre.

Table 1. Geothermal power produced (MW) in 1998

Country	Power
Australia	0.4
China	32
Costa Rica	120
El Salvador	105
France (Guadeloupe)	4.2
Guatemala	5
Iceland	140
Indonesia	589.5
Italy	768.5
Japan	530
Kenya	45
Mexico	743
New Zealand	345
Nicaragua	70
Philippines	1848
Portugal (Azores)	11
Russia	11
Thailand	0.3
Turkey	20.4
USA	2850

Use of geothermal energy

The uses to which geothermal energy may be put depend on the temperature of the fluid obtained. Electrical power can only be generated if the temperature is above 140^{0}C, which is in volcanic areas.

Lower temperature water can be used for heating of various types (Fig 2). Often, the relatively high temperature water produced as "waste" after power generation can also be used for heating purposes.

Fig 2. Uses of geothermal energy

Temp (°C)	Use
180	evaporation of highly concentrated solutions. digestion in paper pulp.
170	drying of diatomaceous earth.
160	drying of timber
150	production of alumina.
140	food canning
130	evaporation in sugar refining extraction of salts by evaporation and crystallisation
120	distillation of fresh water
110	refrigeration using medium temperatures
100	washing and drying of wool
90	intensive de-icing operations
80	space heating for homes and greenhouses
70	refrigeration using low temperatures
60	animal husbandry
50	mushroom growing
40	soil warming
30	swimming pools fermentation
20	fish farming

Electrical power production (180–140)

Case Study: Iceland

Iceland's high level of volcanic activity suggests it is an ideal site for the development of geothermal power. However, the cheap, abundant hydropower available in Iceland has made it uneconomic to develop all the possible geothermal resources. Supply of electricity actually exceeds demand.

Just 22% of Iceland's total geothermal energy production is used to generate electricity. Currently electricity is generated from geothermal energy in only four locations - Bjarnarflag, Krafla, Svartsengi and Reykjanes. Krafla is shut down for four months each year because it is not needed. Reykjanes does not contribute to the National Grid; its 500kW output is dedicated solely to processing sea salt for export.

Other sites could also be used for electricity production, should the need arise; there are plans to use the high-temperature geothermal site at Nesjavellir, which is currently used for heating purposes, to generate 80 MW electricity should it become necessary.

The principal use for geothermal energy in Iceland is space heating; 85% of all houses are heated with geothermal water. This is mainly in the form of district heating schemes. The largest such scheme is in Reykjavik; it serves 145 000 people and delivers water at 80^{0}C.

The various uses of geothermal heat in Iceland include:

- *120 public swimming pools of surface area of 23 000 m²*
- *350 000 m² of snow melting systems*
- *175 000 m² of greenhouses*
- *105 000 m² of soil heating*
- *75 fish farms*

However, geothermal technology is not without its dangers; the siting of the power plants near plate margins has inevitable risks. At the Krafla plant alone, there have been, since its construction in 1977, nine volcanic eruptions, many earthquakes, and scaling and corrosion caused by volcanic gases infiltrating the geothermal liquid.

Environmental implications

Although geothermal power is often considered with renewable energy sources, in fact it is not renewable within the scale of human lives, since the rate at which heat is extracted far exceeds the rate at which it is replenished by the earth's heat flow. For example, in Tuscany, Italy, the rate at which heat is being extracted is 24 times greater than the rate at which it is replenished. This is a minor problem in areas with substantial geothermal resources, but where such resources are relatively scarce, the fact that decades or centuries may be required to replenish a geothermal reservoir may well mean that geothermal power is not a long-term solution.

Geothermal energy has a much lower environmental impact than fossil fuels. There is some noise pollution during the construction of a plant, but current technologies have minimal impact afterwards (Table 2). The sulphur emissions from geothermal plants for each kWh generated average only a few percent of those from conventional plants, and the situation for carbon dioxide is similar (Fig 3). Geothermal power also requires very little land.

Fig 3. CO_2 emissions by energy source

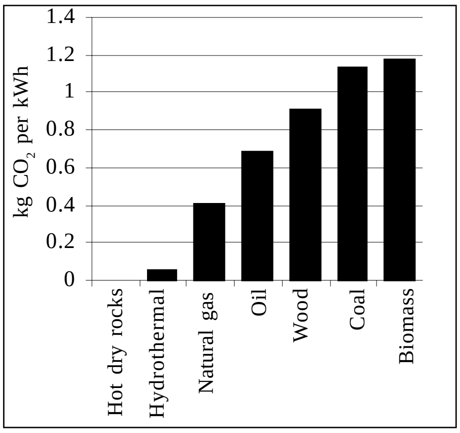


Table 2. Environmental implications of geothermal energy

Type	Environmental Implications
hydrothermal - low temperature (in sedimentary basins)	Minor cooling of ground in winter Use of groundwater which might be needed for water supply Liquid waste will need to be disposed of unless reinjected, since most contain high concentrations of dissolved salts.
hydrothermal - high temperature (in volcanic areas)	Uncondensed gases, including CO_2 H_2S and SO_2 may be contained in water and emitted. The amounts of CO_2 are insignificant, however, and H_2S can be removed.
hot dry rocks	Artificial creation of microseismic activity. Cooling of HDR reservoirs. Minor subsidence of overlying rocks. Large water supply required. Some thermal emissions.
hot magma	Artificial creation of volcanic outbreaks.

Table 3. Advantages and disadvantages of Geothermal Energy

Disadvantages	Advantages
Relatively few sites are suitable for electricity generation using current technology.	Much lower emissions than fossil fuels, hence reducing greenhouse effect, acid rain and low-level atmospheric pollution.
Heating systems have higher initial cost than conventional systems.	Low land use.
Some heating systems require large supplies of clean water for cost-effectiveness.	Reliable; not interrupted by adverse weather conditions (like solar power, wind power) and can be used all year round.
Some heating systems require antifreeze in the cold weather; this often produces greenhouse gases.	For countries with appropriate resources, reduces dependence on imports and allows low-pollution growth for developing countries.
In cooler climates, secondary or back-up heating systems are required.	
The initial drilling is expensive, making it difficult for geothermal electricity to compete economically at current fuel prices.	The cost has decreased by about 25% in the last two decades, and it is anticipated it will decrease further.

Case Study: HDR technology under development in France and Switzerland

Conditions for constructing and operating a HDR plant are attractive in northern Switzerland, due both to the geological conditions (a temperature of 200^{0}C at a depth of five kilometers or less is required) and the potential for heat consumption. Ten potential sites are being evaluated. The proposed plant would produce an output of 3MW electrical power and 20MW thermal energy.

Site preparation and initial drilling is scheduled to take place in the next two years, with power production planned to start in 2007.

The decreasing trends in the cost of drilling and of the electricity produced by HDR suggest that the planned plant will at least break even. In addition, it will assist the Swiss government in meeting its targets for reduced carbon dioxide emissions.

*This follows on from the development of the HDR programme in **Soultz-sous-Forets, Alsace, France**. Here, a test took place in 1997; water was circulated between two vertical wells separated by 450m drilled within fractured granite. Water at a temperature of 140^{0}C was successfully produced.*

Case Study: Geothermal energy in the UK and Ireland

Table 4. Predicted annual emission savings for a 50MW HDR power station

Emission	Annual Savings (tonnes of oxide)
Carbon dioxide	290 000
Sulphur dioxide	3950
Nitrogen oxides	1340

As shown in Fig 4, the UK has relatively few hydrothermal resources, and their temperature makes them unsuitable for electricity generation. Two granite areas - Southwest England and Weardale - are potentially suitable for HDR technology, which would allow electricity generation. Although this would produce a substantial reduction in emissions (Table 4), it is currently estimated that the cost of power generated in this way would be several times more than for conventional sources. Of course, the economic viability of such development may change in the future as other fuel prices change, and new technologies are developed.

*The main geothermal scheme in the UK at present is the **Southampton geothermal district heating scheme**. This is based around a single 1800m geothermal well in the city centre. The well accesses Sherwood Sandstone, which is a permeable porous rock containing water at 70^{0}C. The pressure of the water within the aquifer enables it to rise to within 100m of the surface unaided; a turbine pump brings it fully to the surface. A heat exchanger is then used to transfer the heat to clean water in the district heating circuit. This is used to provide central heating and hot water to several city centre buildings. The waste geothermal water is discharged into the Southampton estuary*

The Southampton scheme charges consumers just one penny per kWh, but it is not completely self-financing; drilling and testing costs were "written off" and the scheme is still partly EU financed. However, it is saving the equivalent of over a 1000 tonnes of oil per year.

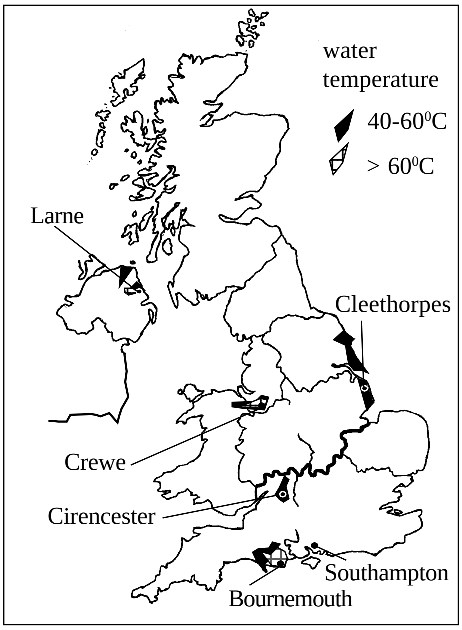
In Ireland, a number of low-temperature thermal springs are utilised. These include:

*The **Mallow geothermal aquifer**, which has a temperature of about 20^{0}C, and is used to heat an adjacent swimming pool and building*

*At **Trinity College, Dublin**, heat is extracted from groundwater at 12^{0}C and used to heat some buildings at the east of the university. The relatively high groundwater temperature is probably due to the urban heat-island effect. The annual energy saving is of the order of 2GWh per year.*

A geothermal heat pump test facility is being developed at Cork Regional Technical College. This will be used to model a number of systems, which will help form the basis of designs for new Irish systems.

Fig 4. Potential UK geothermal fields



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