9

Geothermal

Contents

Strategic insight

1. Introduction

Geothermal Resources Potential

Geothermal energy comes from the natural heat of the Earth primarily due to the decay of the naturally radioactive isotopes of uranium, thorium and potassium. Because of the internal heat, the Earth's surface heat flow averages 82 mW/m^2 which amounts to a total heat of about 42 million megawatts. The total heat content of the Earth is of the order of 12.6×10^{24} MJ, and that of the crust, the order of 5.4×10^{21} MJ (Dickson and Fanelli, 2004). This huge number can be compared to the world electricity generation in 2007 of 7.1×10^{13} MJ (IEA, 2009). The thermal energy of the Earth is immense, but only a fraction of it can be utilised. So far utilisation of this energy has been limited to areas where geological conditions permit a carrier (water in the liquid or vapour phases) to 'transfer' the heat from deep hot zones to or near the surface, thus creating geothermal resources.

On average, the temperature of the Earth increases with depth, about 25–30˚C/km above the surface ambient temperature (called the geothermal gradient). Thus, assuming a conductive gradient, the temperature of the earth at 10 km would be over 300˚C. However, most geothermal exploration and use occurs where the gradient is higher, and thus where drilling is shallower and less costly. These shallow depth geothermal resources occur due to: 1) intrusion of molten rock (magma) from depth, bringing up great quantities of heat; 2) high surface heat flow, due to a thin crust and high temperature gradient; 3) ascent of groundwater that has circulated to depths of several kilometres and been heated due to the normal temperature gradient; 4) thermal blanketing or insulation of deep rocks by thick formation of such rocks as shale whose thermal conductivity is low; and 5) anomalous heating of shallow rock by decay of radioactive elements, perhaps augmented by thermal blanketing (Wright, 1998).

At the base of the continental crust, temperatures are believed to range from 200 to 1 000°C, and at the centre of the earth the temperatures may be in the range of 3 500 to 4 500°C. The heat is transferred from the interior towards the surface mostly by conduction. Geothermal production wells are commonly more than 2 km deep, but rarely much more than 3 km. With the average geothermal thermal gradient, a 1 km well in dry rock formations would have a bottom temperature near 40–45°C in many parts of the world (assuming a mean annual air temperature of 15°C) and a 3 km well one of 90–100°C.

Bertani (2003) found that, based on a compilation of estimates produced by a number of experts, the expected geothermal electricity potential ranges from a minimum of 35–70 GW_e to a maximum of 140 GW_e. The potential may be orders of magnitude higher, based on enhanced geothermal systems (EGS) technology. Stefansson (2005) concluded that the most likely value for the technical potential of geothermal resources suitable for electricity generation is 210 GW_e. Theoretical examinations indicate that the magnitude of hidden resource can be 5–10 times larger than the estimate of identified resources.

The magnitude of low-temperature geothermal resources in the world is about 140 EJ/yr of heat. For comparison, the world energy consumption is now about 420 EJ/yr.

It is considered possible to produce up to 8.3% of the total world electricity with geothermal resources, supplying 17% of the world population. Thirty nine countries (located mostly in Africa, Central/South America and the Pacific) can potentially produce 100% of their electricity using geothermal resources (Dauncey, 2001).

Types of Geothermal Resource

Geothermal resources are usually classified as shown in Fig. 9.1, modelled after White and Williams (1975) and ranging from the mean annual ambient temperature of around 20˚C to over 300˚C. In general, resources above 150˚C are used for electric power generation, although power has recently been generated at Chena Hot Springs Resort in Alaska using a 74˚C geothermal resource (Lund, 2006). Resources below 150˚C are usually used in direct-use projects for heating and cooling. Ambient temperatures in the 5–30˚C range can be used with geothermal (ground-source) heat pumps which provide both heating and cooling.

Figure 9.1

Geothermal resource types (Source: White and Williams, 1975)

Resource type	Temperature range (oC)
Convective hydrothermal resources	
Vapour dominated	≈240o
Hot-water dominated	20o-350o+
Other hydrothermal resources	
Sedimentary basin	20o-150o
Geopressured	90o-200o
Radiogenic	30o-150o
Hot rock resources	
Solidified (hot dry rock)	90o-650o
Part still molten (magma)	>600o

Convective hydrothermal resources can be found where the Earth's heat is carried upward by convective circulation of naturally-occurring hot water or steam. Underlying some high-temperature convective hydrothermal resources are temperatures of 500º-1 000˚C from molten intrusions of recently solidified rocks. The lower temperature resources result from deep circulation of water along fractures.

Vapour dominated systems ('dry steam') produce steam from boiling of deep, saline waters in low permeability rocks. These reservoirs – few in number – The Geysers in northern California, Larderello in Italy and Matsukawa in Japan are being used to produce electricity.

Water-dominated systems ('wet steam') are based on ground water circulating at depth and ascending from permeable reservoirs with the same temperature over large volumes. There is typically an upflow zone at the centre of each convection cell, an outflow zone or plume of heated water moving laterally away from the centre of the system, and a down-flow zone where recharge is taking place. On the surface they can appear as hot springs, fumaroles, geysers, travertine deposits, chemically altered rocks, or sometimes they are not noticeable at all (a blind resource).

Hot dry rock resources are defined as heat stored in rocks within about 10 km from the surface from where energy cannot be economically extracted by natural hot water or steam.

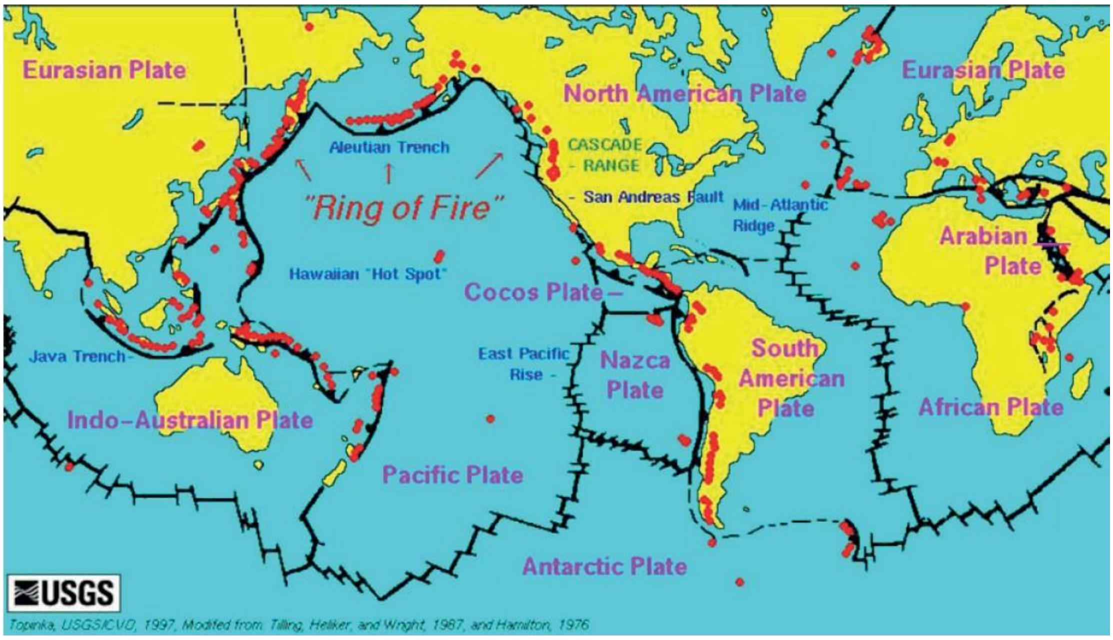
These hot rocks have few pores or fractures, and therefore, contain little water and little or no interconnected permeability. To extract the heat, new experimental technologies are being tested, including hydraulic fracturing under pressure, followed by cold water circulating down one well and producing hot water from a second well in a closed system.

Exploitable geothermal systems can be found in a number of geological environments. They can be broadly divided into two groups depending on whether they are related to young volcanoes and magmatic activity. High-temperature fields used for conventional power production are mostly confined to the former group, but geothermal fields utilised for direct application of the thermal energy can be found in both groups. The temperature of the geothermal reservoirs varies from place to place depending on the geological conditions:

High-temperature fields (>180°C) are the fields where volcanic activity takes place mainly along so-called plate boundaries (Fig. 9.2). According to the plate tectonics theory, the Earth's crust is divided into a few large and rigid plates which float on the mantle and move relative to each other at average rates counted in centimetres per year (the actual movements are highly erratic). The plate boundaries are characterised by intense faulting and seismic and in many cases volcanic activity. Geothermal fields are very common on plate boundaries, as the crust is highly fractured and thus permeable to water, and other sources of heat. In such areas magmatic intrusions, sometimes with partly molten rock at temperatures above 1 000°C, situated at a few kilometres below the surface, heat the groundwater. The hot water has lower density than the surrounding cold groundwater and therefore it flows up towards the surface along fractures and other permeable structures;

Most of the plate boundaries are below sea level, but in cases where the volcanic activity has been intensive enough to build islands or where active plate boundaries transect continents, high-temperature geothermal fields are scattered along the boundaries. A spectacular example of this is the 'ring of fire' that surrounds the Pacific Ocean (the Pacific Plate) with intense volcanism and geothermal activity. Other examples are Iceland, which is located on the Mid-Atlantic Ridge plate boundary, the East African Rift Valley and 'hot spots' such as Hawaii and Yellowstone.

Figure 9.2
World map showing the lithospheric plate boundaries, dots = active volcanoes
Source: U.S. Geological Survey



Low-temperature fields (< 180°C) – geothermal resources unrelated to volcanoes can be divided into four types:

a. resources related to deep circulation of meteoric water along faults and fractures;
b. resources in deep high-permeability rocks at hydrostatic pressure;
c. resources in high-porosity rocks at pressures greatly in excess of hydrostatic (i.e. 'geopressured');
d. resources in hot but dry (low-porosity) rock formations.

All these, with the exception of type c), can also be associated with volcanic activity. Types c) and d) are not commercially exploited as yet.

Type a) is probably the most common for warm springs in the world. These can occur in most rock types of all ages, but are most frequent in mountainous regions where warm springs appear along faults in valleys. Warm springs of this type are of course more numerous in areas with a high regional conductive heat flow (with or without volcanic activity), but are also found in areas of normal and low heat flow. The important factor here is a path for the meteoric water to circulate deep into the ground and up again. Areas of young tectonic activity are commonly rich in this type.

Type b) is probably the most important type of geothermal resources not associated with young volcanic activity. Many regions throughout the world are characterised by deep basins filled with sedimentary rocks of high porosity and permeability. If these are properly isolated from surface ground water by impermeable strata, the water in the sediments is heated by the regional heat flow. The age of the sediments makes no difference, so long as they are permeable. The geothermal reservoirs in the sedimentary basins can be very extensive, as the basins themselves are commonly hundreds of kilometres in diameter. The temperature of the thermal water depends on the depth of the individual aquifers and the geothermal gradient in the area concerned, but is commonly in the range of 50–100°C (in wells less than 3 km deep) in areas that have been exploited. Geothermal resources of this type are rarely seen on the surface, but are commonly detected during deep drilling for oil and gas.

Enhanced Geothermal Systems (EGS) – the principle of EGS is simple: in the deep subsurface where temperatures are high enough for power generation (150–200°C) an extended fracture network is created and/or enlarged to act as new paths. Water from the deep wells and/or cold water from the surface is transported through this deep reservoir using injection and production wells, and recovered as steam/hot water. Injection and production wells as well as further surface installations complete the circulation system. The extracted heat can be used for district heating and/or for power generation.

A number of basic problems need to be solved for successful deployment of EGS systems, mainly that techniques need to be developed for creating, profiling, and operating the deep fracture system (by some means of remote sensing and control) that can be tailored to site-specific subsurface conditions. Some environmental issues, such as the chance of triggering seismicity and the availability of surface water, also need detailed investigation. There are several projects where targeted EGS demonstration is under way.

New developments: drilling for higher temperatures – production wells in high-temperature fields are commonly 1.5–2.5 km deep and the production temperature 250–340°C. The energy output from individual wells is highly variable, depending on the flow rate and the enthalpy (heat content) of the fluid, but is commonly in the range of 5–10 MW_e and rarely over 15 MW_e per well. It is well known from research on eroded high-temperature fields that much higher temperatures are found in the roots of the high-temperature systems. The international Iceland Deep Drilling Project (IDDP) is a long-term programme to improve the efficiency and economics of geothermal energy by harnessing deep unconventional geothermal resources (Fridleifsson et al., 2007). Its aim is to produce electricity from natural supercritical hydrous fluids from drillable depths. Producing supercritical fluids will require drilling wells and sampling fluids and rocks to depths of 3.5–5 km, and at temperatures of 450–600°C.

Geothermal Utilisation and Characteristics

Electric Power Generation

Geothermal power is generated by using steam or a hydrocarbon vapour to turn a turbine-generator set to produce electricity. A vapour-dominated (dry steam) resource can be used directly, whereas a hot-water resource needs to be flashed by reducing the pressure to produce steam, normally in the 15–20% range. Some plants use double and triple flash to improve the efficiency, however in the case of triple flash it may be more efficient to use a bottoming cycle (a small binary plant using the waste water from the main plant). Low-temperature resources generally require the use of a secondary low boiling-point fluid (hydrocarbon) to generate the vapour, in a binary or Organic Rankine Cycle (ORC) plant.

Usually a wet or dry cooling tower is used to condense the vapour after it leaves the turbine to maximise the temperature and pressure drop between the incoming and outgoing vapour and thus increase the efficiency of the operation. However, dry cooling is often used in arid areas.

Binary plant technology is playing a very important role in the modern geothermal electricity market. The economics of electricity production are influenced by the drilling costs and resource development (a typical capital expenditure or Capex quota is 30% for reservoir and 70% plant). The electricity productivity per well is a function of reservoir fluid thermodynamic characteristics (phase and temperature).The higher the energy content of the reservoir fluid, the lesser the number of required wells and as a consequence the reservoir Capex quota is reduced. Single geothermal wells can produce from 1–5 MW_e, however, some producing as high as 30 MW_e have been reported. Binary plants on the reinjection stream could be a very effective way of producing cheap energy, because there would not be any additional pumping costs.

Direct Utilisation

The main advantage of using geothermal energy for direct use projects in the low- to intermediate-temperature range is that such resources are more widespread and exist in at least 80 countries at economic drilling depths. In addition, there are no conversion efficiency losses and projects can use conventional water-well drilling and off-the-shelf heating and cooling equipment (allowing for the temperature and chemistry of the fluid). Most projects can be on line in less than a year. Projects can be on a small scale, such as for an individual home, greenhouse or aquaculture pond, but can also be a large-scale commercial operation such as for district heating/cooling, or food and lumber drying.

It is often necessary to isolate the geothermal fluid from the user side to prevent corrosion and scaling. Care must be taken to prevent oxygen from entering the system (geothermal water is normally oxygen-free), and dissolved gases and minerals such as boron and arsenic must be removed or isolated, as they are harmful to plants and animals. Hydrogen sulphide, even in low concentrations, will cause problems with copper and solder and is harmful to humans. On the other hand carbon dioxide, which often occurs in geothermal water, can be extracted and used for carbonated beverages or to enhance growth in greenhouses. The typical equipment for a direct-use system includes downhole and circulation pumps, heat exchangers (normally the plate type), transmission and distribution lines (normally insulated pipes), heat extraction equipment, peaking or back-up plants (usually fossil-fuel fired) to reduce the number of geothermal wells required, and fluid disposal systems (injection wells). Geothermal energy can usually meet 80–90% of the annual heating or cooling demand, yet only be sized for 50% of the peak load.

Geothermal Heat Pumps

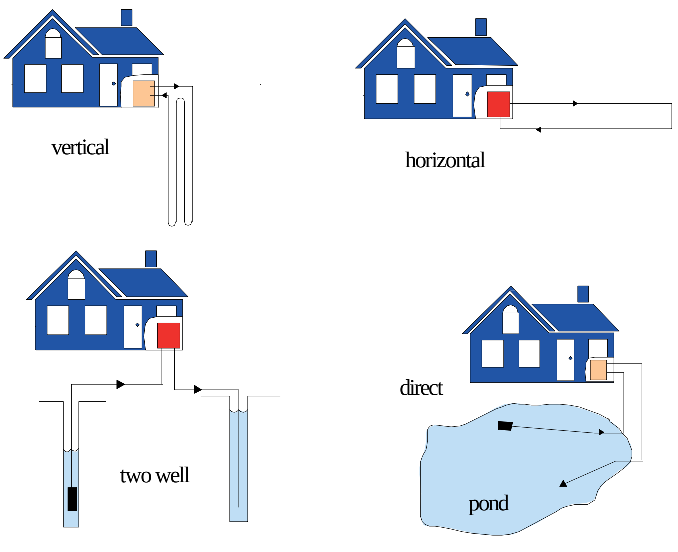
Ground-source heat pumps (GHPs) use the relatively constant temperature of the earth to provide heating, cooling and domestic hot water for homes, schools, governmental and commercial buildings. A small amount of electricity input is required to run a compressor, however the energy output is in the order of four times this input. The technology is not new: Lord Kelvin developed the concept in 1852, which was then modified as a GHP by Robert Webber in Indianapolis in 1945. GHPs gained commercial recognition in the 1960s and 1970s. Europe began using this technology around 1970 and it now popular in the USA, Canada, Germany, Sweden, Switzerland, France and other western European countries.

GHPs come in two basic configurations: ground-coupled (closed loop) which are installed either horizontally or vertically, and groundwater (open loop) systems, which are installed in wells and lakes. The type chosen depends upon the soil and rock type at the installation, the land available and/or if a water well can be drilled economically or is already on site (Fig. 9.3)

Figure 9.3

Examples of common geothermal heat pump installations

Source: Lund, et al., 2004



In the ground-coupled system, a closed loop of high-density polyethylene pipe is placed either horizontally (1–2 m deep) or vertically (50–70 m deep) in the ground, and a water-antifreeze solution circulated through the pipe to either collect heat from the ground in the winter or reject heat to the ground in the summer (Rafferty, 2008). The open-loop system uses ground water or lake water directly in the heat exchanger and then discharges it into another well, into a stream or lake, or on the ground (say for irrigation), depending upon local regulations.

Figs. 9.4 and 9.5 show the operation of a typical geothermal heat pump in either heating or cooling mode. A desuperheater can be provided to use reject heat in the summer and some input heat in the winter for domestic hot water heating.

Figure 9.4

GHP in the cooling cycle

Source: Oklahoma State University

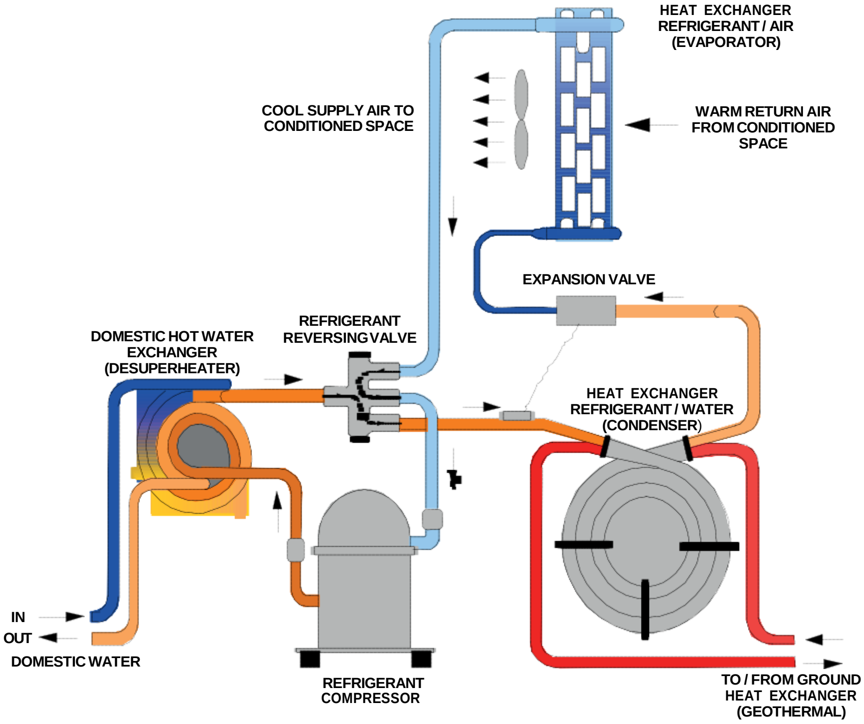
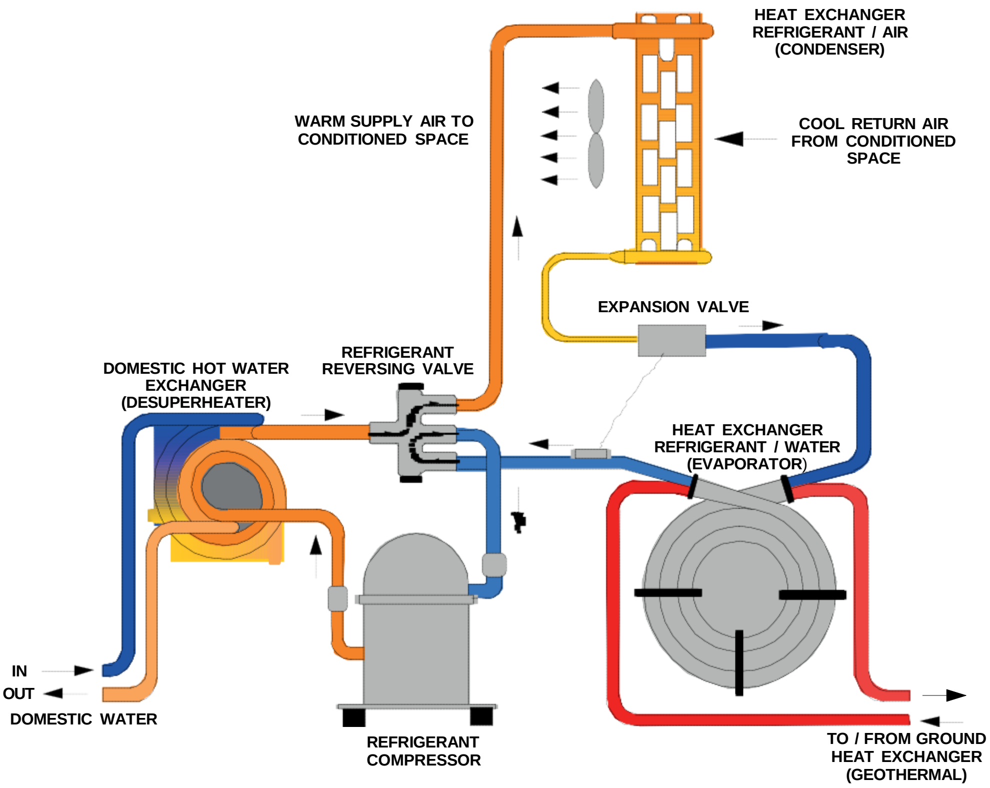


Figure 9.5
GHP in the heating cycle
Source: Oklahoma State University



Technical Potential

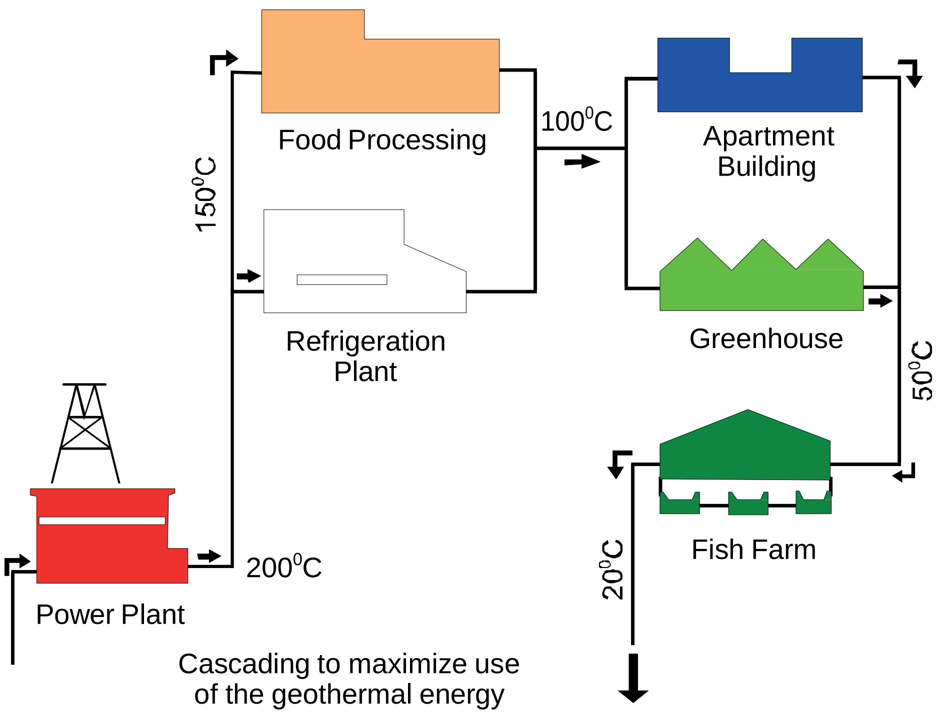
The main advantage of geothermal heating and power generation systems is that they are available 24 hours per day, 365 days a year and are only shut down for maintenance. Power generation systems typically have capacity factors of 95% (i.e. operate at nearly full capacity year round), whereas direct-use systems have a capacity factor around 25 to 30%, owing to heating not being required year round. Heat pump systems have operating capacities of around 10–20% in the heating mode and double this if the cooling mode is also included.

Within the direct utilisation sector of geothermal energy, geothermal heat pumps have world-wide application, as the shallow ground temperature is within their range anywhere in the world. Traditional direct use heating is limited to where the resource is available in economic depths and where climate justifies the demand.

Power generation in the past has been limited by resources above 180°C. However, with recent advances in binary (Organic Rankine) cycle technology, lower-temperature fluids at around 100°C are being utilised, thus increasing the number of potential locations. Drilling depth, fluid quantity and quality, and temperature of the resource determine the economic viability of the project.

More recently, the use of combined heat and power plants has made low-temperature resources and deep drilling more economic. District heating using the spent water from a binary power plant can make a marginal project economic as has been done in Germany, Austria and Iceland. This is a form of cascading (Fig. 9.6), where the geothermal fluid is utilised at progressively lower temperature, thus maximising the energy extracted.

Figure 9.6
Example of cascaded geothermal resource for multiple uses
Source: Geo-Heat Centre



Summary of Current Geothermal Use

Table 9.1 is based on data for 2008 reported by WEC Member Committees for the present *Survey*, supplemented by information submitted to the World Geothermal Congress 2010.

Of the countries utilising their geothermal resource, almost all use it directly but only 24 use it for electricity generation.

At end-2008, approximately 10 700 MW_e of geothermal electricity generating capacity was installed, producing over 63 000 GWh/yr. Installed capacity for direct heat utilisation amounted to about 50 000 MW_t, with an annual output of around 430 000 TJ (equivalent to about 120 000 GWh). The annual growth in energy output over the past five years has been 3.8% for electricity production and around 10% for direct use (including geothermal heat pumps). Energy produced by ground-source heat pumps alone has increased by 20% per annum over the same period. The low growth rate for electric power generation is primarily due to the low price for natural gas, the main competitor.

The data show that with electric power generation, each major continent has approximately the same percentage share of the installed capacity and energy produced, with the America's and Asia having over 75% of the total. Whereas, with the direct-use figures, the percentages drop significantly from installed capacity to energy use for the Americas (26.8 to 13.9%) due to the high percentage of geothermal heat pumps with low capacity factor for these units in the U.S. On the other hand, the percentages increased for the remainder of the world due to a lesser reliance on geothermal heat pumps and the greater number of operating hours per year for these units.

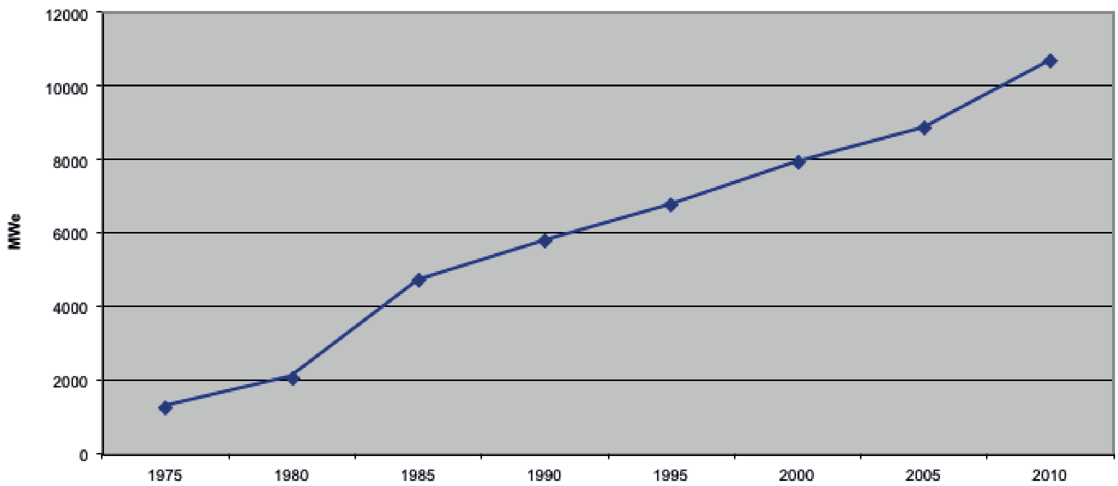
Geothermal Electric Power

Electric power has been produced from geothermal energy in 27 countries; however, Greece, Taiwan and Argentina have shut down their plants due to environmental and economic reasons. The worldwide installed capacity has the following distribution: 27% dry steam, 41% single flash, 20% double flash, 11% binary/combined cycle/hybrid, and 1% backpressure (Bertani, 2010).

Figure 9.7

Worldwide growth of installed geothermal generating capacity

Source: International Geothermal Association

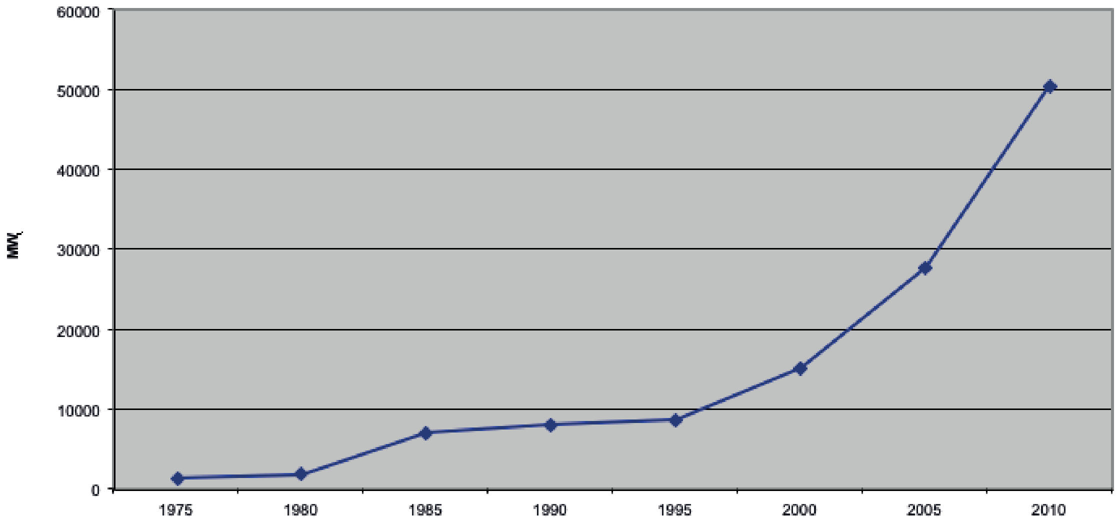


Direct Utilisation (including geothermal heat pumps)

The world direct utilisation of geothermal energy is difficult to determine, as there are many diverse uses of the energy and these are sometimes small and located in remote areas. Finding someone or even a group of people in a country who are knowledgeable on all the direct uses is difficult. In addition, even if the use can be determined, the flow rates and temperatures are usually not known or reported, thus the capacity and energy use can only be estimated. This is especially true of geothermal waters used for swimming pools, bathing and balneology.

The total installed capacity, reported at the end of 2009, for the world's geothermal direct utilisation is 50 583 MW_t, almost a two-fold increase over the 2005 data, growing at a total rate of 12.3% annually. The total annual energy use is 438 071 TJ (121 696 GWh), a 60% increase over 2005, growing at a compound rate of 11.0% annually. Compared to ten years ago the capacity had been increasing by 12.8%/yr and the use by 8.7%/yr. Thus, it appears that the growth rate has increased slightly in recent years, despite the low cost of fossil fuels, economic downturns and other factors. It should, however, be noted that part of the growth from 2000 to the present is due, to a certain extent, to better reporting, and includes some geothermal countries that were missed in previous reports. The capacity factor is an indication of the amount of use during the year (i.e. a factor of 1.00 would indicate the system is used at a maximum the entire year, and 0.5 would indicate using the system for 4 380 equivalent full-load hours per year). The worldwide average for the capacity factor is 0.27, down from 0.31 five years ago and 0.40 ten years ago. This decrease is due to the increased used of geothermal heat pumps that have a worldwide capacity factor of 0.19 in the heating mode.

Figure 9.8
Worldwide growth of installed geothermal direct use capacity
Source: International Geothermal Association



The growing awareness and popularity of geothermal (ground-source) heat pumps had the most significant impact on the data. The annual energy use for these grew at a compound rate of 19.7% per year compared to five years ago, and 24.9% compared to ten years ago. The installed capacity grew 18.0% and 20.9% respectively. This is due, in part, to the ability of geothermal heat pumps to utilise groundwater or ground-coupled temperatures anywhere in the world.

The countries with the largest installed capacity were the USA, China, Sweden, Norway and Germany, accounting for about 63% of the installed capacity and the five countries with the largest annual energy use were: China, USA, Sweden, Turkey and Japan, accounting for 55% of the world use. Sweden, a new member of the 'top-five' obtained its position due to the country's increased use of geothermal heat pumps. However, if considered in terms of the country's land area or population, then the smaller countries dominate. The 'top-five' then include Netherlands, Switzerland, Iceland, Norway and Sweden (TJ/area), and Iceland, Norway, Sweden, Denmark and Switzerland (TJ/population). The largest increases in geothermal energy use (TJ/yr) over the past five years are in the United Kingdom, Netherlands, Korea (Republic), Norway and Iceland; and the largest increases in installed capacity (MW_t) are in the United Kingdom, Korea (Republic), Ireland, Spain and Netherlands, due mostly to the increased use of geothermal heat pumps.

In 1985, there were only 11 countries reporting an installed capacity of over 100 MW_t. By 1990, this number had increased to 14, by 1995 to 15, by 2000 to 23 and by 2005 to 33. At present there are 36 countries reporting 100 MW_t or more. In addition, six new countries, compared to 2005, now report some geothermal direct utilisation.

Figure 9.9

Worldwide geothermal energy direct use

Source: International Geothermal Association

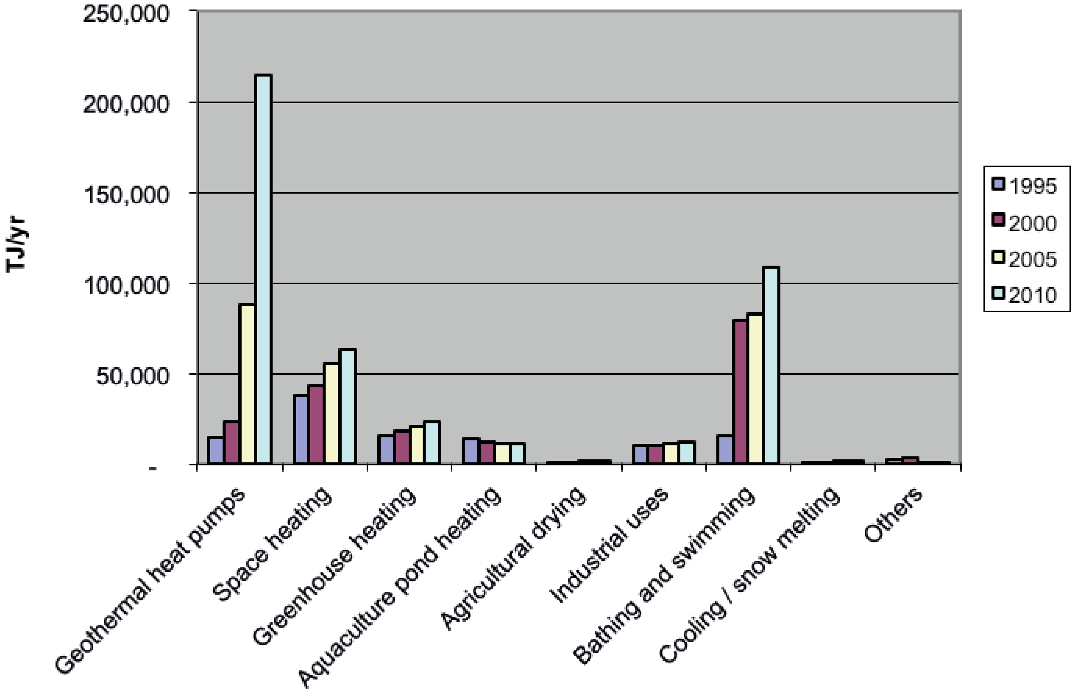
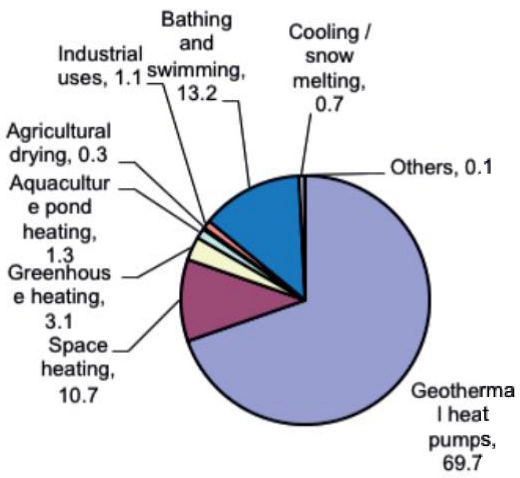
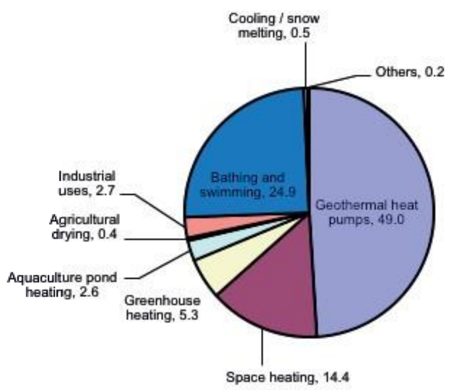


Figure 9.10

Categories of geothermal energy direct use in 2010: capacity (a), utilisation (b)

Source: International Geothermal Association





In Fig. 9.10 district heating is estimated at 78% of total space heating energy use and 82% of the installed capacity. Snow melting represents the majority of the cooling/snow melting figure.

Market Development

The factors that must be considered when assessing the viability of a geothermal project will vary from project to project (i.e. it is site-specific), especially between electricity generation and direct use. The economic factors that are common to all projects include supplying the fuel (energy) from the geothermal resource; the design and construction of the conversion facility and related surface equipment such as transformers and transmission lines for electricity generation plants, and pipelines and heat exchangers for district heating projects; and the operation and maintenance (O&M) of the equipment. Finally the market penetration and revenues generated from the sale of electricity or products produced from greenhouses, aquaculture facilities or industrial operations, minus the O&M costs, must be sufficient to meet or exceed the requirements of the financing package.

Financing is a critical factor in the economics of any project, and thus the potential for market penetration and development. For many new projects, the largest annual operating cost is the amortisation of the cost of capital, which can be as high as 75% of the annual operating expense for new geothermal district energy projects, with O&M at 15%, and ancillary energy provisions at 10% making up the balance (Bloomquist and Knapp, 2003). Unfortunately, geothermal projects, especially in the resource development stage, have a high risk of failure. Thus obtaining financing at reasonable rates (or even at all) can be difficult in the early stages of a project. Once the resource is proven, then financing is more certain and investors become easier to find..

Market development is highly dependent upon competition from other sources of electricity or from direct-use product supply (fish, vegetables, flowers, minerals, etc.). Remote areas, often off-grid, are excellent candidates for electrical energy. The availability of transmission lines can be critical and these are often lacking and expensive to construct over large distances. Direct-use projects must have a market and a transportation system to get the products to consumers economically. Unfortunately, geothermal resources that can be utilised are often remote, which may limit their development for commercial operations. However, on the positive side, with increasing fossil fuel prices and limitations on the production of greenhouse gases, development of geothermal energy has become more competitive as a renewable and 'green' energy resource.

Sustainability Issues

Geothermal energy is generally classified as a renewable resource, where 'renewable' describes a characteristic of the resource: the energy removed from the resource is continuously replaced by more energy on time scales similar to those required for energy removal (Stefansson, 2000). Consequently, geothermal production is not a 'mining' process. Geothermal energy can be used in a 'sustainable' manner, which means that the production system is able to sustain the production levels over long periods. The longevity of production can be secured and sustainable production achieved by using moderate production rates, which take into account the local resource characteristics (field size, natural recharge rate, etc.).

The production of geothermal fluid/heat continuously creates a hydraulic/heat sink in the reservoir. This leads to pressure and temperature gradients, which in turn – after end of production – generate fluid/heat inflow to re-establish the pre-production state. The regeneration of geothermal resources is a process which occurs over various time scales, depending on the type and size of the production system, the rate of extraction, and on the attributes of the resource.

Environmental Issues

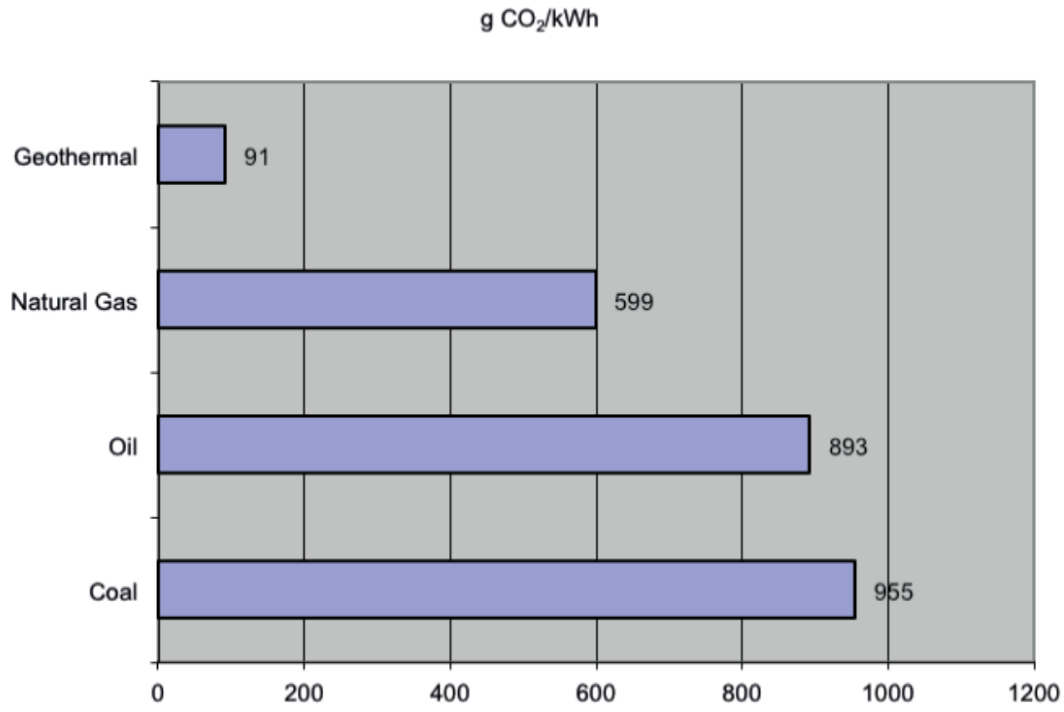
Geothermal fluids contain a variable quantity of gases, largely nitrogen and carbon dioxide, with some hydrogen sulphide and smaller proportions of ammonia, mercury, radon and boron. The amounts depend on the geological conditions of different fields. Most of the chemicals are concentrated in the disposal water which is routinely re-injected into drill holes and thus not released into the environment. The concentration of the gases is usually not harmful and they can be vented to the atmosphere. Removal of hydrogen sulphide released from geothermal power plants is mandatory in the USA and Italy.

The range of CO_2 emissions from high-temperature geothermal fields used for electricity production is variable, but much lower than that for fossil fuel plants.

Figure 9.11

Comparison of CO_2 emissions from electricity generation in the USA

Source: Bloomfield, et al., 2003



The gas emissions from low-temperature geothermal resources are normally only a fraction of the emissions from the high-temperature fields used for electricity production. The gas content of low-temperature water is in many cases minute, as in Reykjavik, where the CO_2 content is lower than that of the cold groundwater. In sedimentary basins, such as the Paris Basin, the gas content may cause scaling if it is released. In such cases the geothermal fluid is kept under pressure within a closed circuit (the geothermal doublet) and re-injected into the reservoir without any de-gassing taking place. Conventional geothermal schemes in sedimentary basins commonly produce brines which are generally re-injected into the reservoir and thus never released into the environment (zero CO_2 emission). GHP are environmentally benign and represent a large potential for reduction of CO_2 emissions.

2. Technical and economic considerations

Summary of Current Geothermal Use

Table 11.1 is based on electricity data for 2013 for the EGC Conference, supplemented by information submitted to the World Geothermal Congress 2010 for the Direct Heat utilization.

Of the countries utilising their geothermal resource, almost all use it directly but only 24 use it for electricity generation. At end-2012, approximately 11490 MWe of geothermal electricity generating capacity was installed, producing over 68630 GWh/yr. Installed capacity for direct heat utilisation amounted to about 50 000 MWt, with an annual output of around 430 000 TJ (equivalent to about 120 000 GWh).

The annual growth in energy output over the past five years has been 3.8% for electricity production and around 10% for direct use (including geothermal heat pumps). Energy produced by ground-source heat pumps alone has increased by 20% per annum over the same period. The low growth rate for electric power generation is primarily due to the low price for natural gas, the main competitor.

The data show that with electric power generation, each major continent has approximately the same percentage share of the installed capacity and energy produced, with the Americas and Asia having over 75% of the total. Whereas, with the direct-use figures, the percentages drop significantly from installed capacity to energy use for the Americas (26.8 to 13.9%) due to the high percentage of geothermal heat pumps with low capacity factor for these units in the U.S. On the other hand, the percentages increased for the remainder of the world due to a lesser reliance on geothermal heat pumps and the greater number of operating hours per year for these units.

Geothermal Electric Power

The worldwide installed capacity has the following distribution: 27% dry steam, 41% single flash, 20% double flash, 11% binary/combined cycle/hybrid, and 1% backpressure (Bertani, 2010).

Implementation Issues

The challenges to geothermal development are varied and include the following issues:

- resource identification and characterisation;
- economics, financial risks;
- development risks (i.e. proving the resource, drilling);
- competition by other forms of energy;
- environmental misconceptions;
- siting and permitting delays;
- transactional costs (i.e. high capital costs);
- transmission capacity (power) or market penetration (direct use);
- local population concerns;
- public perceptions and support;
- lack of knowledge of the benefits of development and utilisation.

Technical and Market Barriers

The major barrier to the exploitation of geothermal energy is the high financial risk in comparison not only with the use of natural gas but also with most other forms of renewable energy.

Development risks are high and prediction of the quality of a resource requires capital investment in drilling and well tests. A resource must also be close to an area of high demand. Those countries, e.g. France and Iceland, who have underwritten the risks at both the reservoir assessment and drilling stage, have been able to develop the resource more readily. Other countries, where geothermal energy plays a significant role in the total energy supply, such as Kenya, Philippines and several central American countries, have governmental support for development.

There is a lack of published technical, financial and legislative information for developers, particularly in comparing the experiences gained by others through various individual schemes.

Environmentally, geothermal schemes are relatively benign, but they generally produce a highly corrosive brine which may need special treatment and discharge consents. There is also a possibility of noxious gases, e.g. hydrogen sulphide, being emitted and developers must meet local environmental and planning requirements.

A combination of approaches can be used to overcome these barriers, including:

- educational, including training and outreach;
- technical improvements;
- economic incentives;
- government support.

Ruggero Bertani, John Lund
International Geothermal Association

References

Bertani, R., 2010. Geothermal Power Generation in the World 2005–2010 Update Report, Proceedings, World Geothermal Congress 2010, Bali, Indonesia, paper no. 0008.

Bloomfield, K.K., Moore, J.N. and Nelson, R.N., 2003. Geothermal Energy Reduces Greenhouse Gases, Geothermal Resources Council Bulletin, 32, Davis, CA, USA, pp. 77–79.

Bloomquist, R.G., and Knapp, G., 2003. Economics and Financing (Chapter 9), In: Geothermal Energy Utilization and Technology, ed. by M. H. Dickson and M. Fanelli, UNESCO, pp. 175–199.

Dauncey, G., with Mazza, P., 2001. Stormy Weather: 101 Solutions to Global Climate Change, New Society Publishers, Ltd., P.O. Box 189, Gabriola Island, British Columbia, V0R 1X0, Canada, 271 pp.

Dickson, M.H., and Fanelli, M., 2004. What is Geothermal Energy? Home page: http://iga.igg.cnr.it/geo/geoenergy.php visited 2008.

Fridleifsson, G.O., Albertsson, A., Stefansson, B., Gunnlaugsson, E., and Adalsteinsson, H., 2007. Deep Unconventional Geothermal Resources: a Major Opportunity to Harness New Sources of Sustainable Energy, 20th World Energy Conference, Rome, November, World Energy Council, (www.worldenergy.org).

International Energy Agency, 2009. Energy Statistics of Non-OECD Countries, 2009 Edition.

Lund, J.W., 2006. 'Chena Hot Springs', Geo-Heat Center Quarterly Bulletin, Vol. 27, No. 3 (September), Klamath Falls, OR, USA, pp. 2–4.

Rafferty, K., 2008. An Information Survival Kit for the Prospective Geothermal Heat Pump Owner, HeatSpring Energy, Cambridge, MA, USA, 32 p.

Stefansson, V., 2000. The Renewability of Geothermal Energy, Proceedings of the World Geothermal Congress 2000, Kyushu-Tohoku, Japan, May-June, p. 883–888.

Stefansson, V., 2005. World Geothermal Assessment, Proceedings of the World Geothermal Congress 2005, Antalya, Turkey http://iga.igg.cnr.it

White, D.E. and Williams, D.L., Eds., 1975. Assessment of Geothermal Resources of the United States – 1975, U.S.

Geological Survey Circular 727, U.S. Government Printing Office, 155 p.

Wright, M., 1998. Nature of Geothermal Resources, in Geothermal Direct-Use Engineering and Design Guidebook, edited by John W. Lund, Geo-Heat Center, Klamath Falls, OR, USA, pp. 27–69.

Global tables

Table 9.1
Geothermal energy: electricity generation and direct use at end-2011

	Electricity generation			Direct use		
	Installed capacity	Annual Output	Annual Capacity Factor	Installed capacity	Annual Output	Annual Capacity Factor
Country	MW	GWh	%	MW	TJ	%
Albania	8123.0	43.3	53.2	2.0	43.0	0.3
Algeria	0.0					
Argentina	30.0			149.9	609.4	
Australia	1.1	0.7	53.2	129.0	1314.3	
Austria	0.9	1.1		662.0	8107.0	
Brazil				360.0		
Bulgaria				98.3	1370.1	
Canada	0.0			1045.0	5112.0	
Chile	0.0			9.1	131.8	
China	24.2	125.0		8898.0	75348.3	
Costa Rica	166.0	1131.0				
Croatia				114.0	557.0	
Czech Republic	0.0			4.5	90.0	
Denmark				200.0	2500.0	
Ecuador				5.0		
El Salvador	204.0	1422.0				
Ethiopia	7.3	10.0				
France	18.3	14.0		1345.0	12949.0	
Germany	7.3	18.8		3485.4	12764.5	
Greece	0.0			134.6	937.8	
Guatemala	52.0	289.0		2.3	56.5	
Hong Kong	24.0					
Hungary	0.0			654.6	9767.0	
Iceland	665.0	4465.0		2002.9	24621.4	
Indonesia	1197.0	9321.0				
Israel				23.4	692.0	
Italy	772.0	5754.0		1000.0	12599.5	
Japan	537.7	2632.0		2099.5	25697.9	
Kenya	169.0	1430.0		16.0	126.6	
Korea (Republic)				105.4	43.0	
Lithuania				48.1	411.5	
Mexico	886.6	6502.0		155.8	4022.7	
Netherlands	0.0			1410.3	10699.4	

New Zealand	792.0	5550.0	393.0	9552.0
Nicaragua	82.0	289.8		
Norway			1000.0	
Philippines	1904.0	10311.0	3.3	39.6
Poland	0.0		281.0	1501.0
Portugal	30.0	210.0	28.1	420.0
Romania	0.0		173.6	1520.2
Russian Federation	82.0	441.0	308.2	6143.5
Serbia			119.0	3244.0
Slovakia			132.2	3067.2
Spain	0.0		120.0	
Sweden			4460.0	45301.0
Switzerland	0.0		1060.6	8799.0
Thailand	0.3	2.0	2.5	79.1
Turkey	114.2	616.7	2084.0	36885.9
United Kingdom	0.0		186.6	849.7
United States of America	3101.6	15009.0	12611.5	56551.8

Country notes

The Country Notes on Geothermal Energy have been compiled by the Editors with input from the WEC Member Committees. A wide range of sources have been consulted, including national, international and governmental publications/web sites and other publicly available information. Use has also been made of direct personal contacts.

N.B. All direct-use data for Geothermal includes figures for heat pump technology.

Albania

	Electricity generation
Installed capacity MWe	812
Annual output GWh	43
Annual capacity factor	53
	Direct use
Installed capacity, MWt	2
Annual output TJ	43
Annual capacity factor	

Albania possesses a large low-enthalpy geothermal resource located in three zones. The largest, Kruja, extends from the Adriatic Sea in the north southwards into northwestern Greece. Of the other two zones, Peshkopia lies in the northeast of the country and Ardenica in the coastal area. The direct use of the available resource has been recognised and utilised for many centuries. Hot springs, often for recreational purposes, have also been incorporated into spa clinics, many as balneological centres. However, possibilities exist for the resource to be used for space heating and heat pumps.

Geothermal resources are widely available in Albania. Similar to neighbouring countries, the potential of geothermal heat is vast. There are many thermal springs of low enthalpy with a maximal temperature of up to 80ºC as well as many wells (abandoned gas or oil) in Albania, which represent a potential for geothermal energy.

The geothermal field is characterized by relatively low values of temperature. The temperature at a depth of 100 meters varies from 8 to 20ºC. The highest temperatures (up to 68ºC) at 3000 meters depth have been measured in the plane regions of western Albania. The temperature is 105.8ºC at 6000 meters depths. The lowest temperature values have been found in the mountainous regions. There are many thermal springs and wells of low enthalpy. Their water have temperatures up to 65.5ºC. The thermal springs and wells are located in three areas: the geothermic area of Kruje, Ardenica and Peshkopii.

Algeria

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	56
Annual output TJ	1723
Annual capacity factor	

With abundant fossil fuel resources, there has historically been little development of the geothermal resource in Algeria. However the New and Renewable Energy Policy of the Ministry of Mines and Energy will help to utilise the resource, which research has shown to exist in the zone to the north of the Tellian Atlas mountains and to the south in the Saharan platform.

Although the area around Biskra has been found to have high-temperature springs, the more than two hundred springs that have been recorded in the northern part of the country are low-temperature. They are used mainly for balneological purposes, although a small amount of greenhouse heating also exists.

The most widely recognised use of geothermal springs is for balneotherapy. These hot springs are mainly located in the northern part of the country, used by about ten public resorts.

During the last few years, a significant interest has been shown for alternative uses of geothermal energy. Three sites have been selected for geothermal aquaculture projects. Currently, fish farms in Ghardaia and Ouargla are using the Albian geothermal water of the Sahara to produce about 1,500 tonnes/yr of Tilapia fish. A third site at Ain Skhouna, located near Saida produced 200 tonnes of Tilapia during 2008.

A small geothermal heat pump project has also been started in this region. The heat pump is a reverse one, used for heating and cooling 12 classrooms, the library and the restaurant of a primary school. Hammam Sidi Aissa geothermal water (46°C) is used for this purpose. A similar project is planned to be opened at Khenchla (North East of Algeria). These various applications of geothermal water are: 1.4 MWt and 45.1 TJ/yr for individual space heating; 9.8 MWt and 308 TJ/yr for fish farming; 44.27 MWt and 1,368.65 TJ/yr for bathing and swimming; 0.17 MWT and 1.38 TJ/yr for geothermal heat pumps.

Argentina

	Direct use
Installed capacity, MWt	149
Annual output TJ	609
Annual capacity factor	

Argentina is in the forefront of South American utilisation of geothermal resources and in recent years there has been much progress in the knowledge of, and direct use of, the resource. High-temperature geothermal heat exists in the western region, along the Andes range and moderate to low-temperature thermal fields have been identified in other parts of the country.

Direct use of geothermal heat is widespread in Argentina. The total capacity of 150 MW_t – installed at 70 different locations – was mainly used for bathing and swimming but also with some applications in fish farming, greenhouse and soil heating, individual space heating and snow melting.

Australia

Within the last five years 11 new projects were started and are now being explored for direct-use. These projects are being considered for recreational therapeutic facilities and to supply drinking water to nearby towns.

	Electricity generation
Installed capacity MWe	1.1
Annual output GWh	0.7
Annual capacity factor	53.2
	Direct use
Installed capacity, MWt	129
Annual output TJ	1314.3

As a result of the Federal Government's ongoing promotion of renewable energy and the introduction in 2001 of the Mandatory Renewable Electricity Target (MRET), the development of the Australian geothermal resource continues.

The Australian geothermal resource can be classified into three categories: Hot Sedimentary Aquifers (HSA); Hot Rock (HR), including Hot Dry Rocks (HDR), and Hot Fractured Rocks and Direct Use (HFR). The first two categories have the potential for electricity generation. However, the sole use of geothermal power for electricity generation in Australia is the 120 kW (gross) Birdsville plant in Queensland. For the past decade it has supplied the town's night time electricity requirements and generally during the winter. When the geothermal plant is able to satisfy demand, an automatic switching system shuts down the fossil-fuel generated electricity system.

It has been estimated that Australia's very significant HDR resource is sufficient to generate the country's electricity requirement for centuries to come.

The total expected geothermal EGS installed capacity for 2020 is about 100 MW.

Austria

	Electricity generation
Installed capacity MWe	0.9
Annual output GWh	1

	Direct use
Installed capacity, MWt	662
Annual output TJ	8 107

The balneological importance attached to the country's spas together with the restrictions imposed by the Austrian Water Law, have somewhat impeded the progress of development of the geothermal resource. Generally, there has been a lack of public interest and support; the management of spas have expressed concern for the quality of water supplied which could possibly be affected by further and diversified use of the resource and the difficulty of combining different uses at new sites have all contributed to this lack of progress. In the case of the Water Law, it is stated that the groundwater below the land belongs to the land-owner and this can be highly problematical when deviated drilling is necessary.

In the late 1990s the European Union's THERMIE programme provided support for the Simbach-Braunau scheme, a cross-border joint venture between South Germany and Upper Austria – one of the largest district heating schemes in Europe. An installed capacity of over 30 MW serves five hundred people with some 9.3 MW of power.

Seven deep boreholes were drilled in the country recently, all of which were used to supply heat for balneological purposes. No other geothermal projects were undertaken in Austria since 2005 due to lack of public support and low feed-in tariffs for electric power. However, the number of ground source heat pumps has shown a steady increase with the estimated number of units at 50,000 having a capacity of 600 MWt and producing 800 GWh/yr. As in most countries the data on geothermal heat pumps are hard to obtain as only groundwater wells are documented with the authorities. Future projects are expected in the Vienna basin near the capital and in the Austrian Molasse Basin. Geothermal heat pumps are expected to increase with more than 50% of the new family houses to have units installed.

Brazil

	Electricity generation
	Direct use
Installed capacity, MWt	360
Annual output TJ	
Annual capacity factor	

The utilisation of Brazil's huge low-temperature geothermal resource has until now been extremely small. Much research has been undertaken by the Geothermal Laboratory of the National Observatory since the 1970s and it is thought that high-temperature geothermal heat exists only in the offshore Atlantic islands.

In 2005 it was reported that the installed capacity (some 360 MW_t) was used directly, largely for bathing and swimming, with just 4 MW_t used for agricultural drying/industrial process heat. The 12 or so systems in place (mostly located in the western-central area and the south) could be classified as BRT (bathing, recreation and tourism), PIS (potential for industrial use and space heating) and TDB (therapeutic, drinking and bathing). The BRT systems totaled 16 MW_t, the PIS, 343 MW_t and the TDB, 3 MW_t, although the PIS element was not being used industrially, but for recreational purposes.

Bulgaria

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
Direct use	
Installed capacity, MWt	98.3
Annual output TJ	1370.1
Annual capacity factor	

The number of hydrothermal sources in Bulgaria has been estimated at around 150 with about 50 of them having a total of 469 MW_t of proven potential for extraction of geothermal energy. The majority of the waters have been found to be low-temperature at intervals of 20–90°C. Only about 4% of the total capacity has been found to have water hotter than 90°C. The theoretical potential of Bulgaria's geothermal energy amounts to 13 856 TJ/yr with the technical potential put at 10 964 TJ/yr.

There are in the region of 100 MW_t geothermal systems installed in the country, representing some 23% of the currently discovered thermal potential. The annual average production is around 428 GWh.

Bulgaria has a rich geothermal water supply within the temperature range of 20 to 100oC with the main geothermal activity concentrated in the southern part of the country due to the higher water temperature and low water salinity. The main geothermal direct-use in the country is for balneology (prevention, treatment and rehabilitation, bathing and swimming pools), space heating and air-conditioning, greenhouse heating, geothermal heat pumps, direct thermal water supply, bottling of potable water and soft drinks and for unspecified industrial use. The cultivation of microalgae and production of iodine paste and methane extraction are some of the processes no longer in place.

Canada

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	1045
Annual output TJ	5112
Annual capacity factor	

The geography of Canada does not easily lend itself to electricity generated from geothermal resources. However, since the late 1970s exploratory work has been ongoing at a volcanic complex, Mt. Meager in British Columbia. The site may have potential development capacity of 100 MW or greater, but this has not yet been verified.

Ground source heat pumps can be installed almost anywhere in Canada and in total could theoretically meet the entire heating and cooling need of the country's building stock.

Since 2005 Canada has experienced a major transformation of the ground source heat pump industry. Led by the Canadian GeoExchange Coalition (CGC) and supported by

Natural Resources Canada, more than 3 000 industry professionals have been trained to Canadian standards and more than 800 have received their installer or residential designer accreditation. The CGC has also certified thousands of residential installations.

In recent years Canada has progressively increased the usage of heat pump technology. It is estimated that up to 50,000 residential and 5,000 commercial systems are currently installed. The cost of installing these units, especially in building retrofits, is often prohibited for the average consumer; however, federal and local subsidies have contributed towards the costs. The growth rate is estimated at 13% per year, with recent rates being as high as 50%.

Heat pump technology has also been used in abandoned mines, starting as early as 1989 in the Springhill Mine of Nova Scotia where the heating and cooling provides savings estimated C$45,000/yr in energy costs. The City of Yellowknife in the Northwest Territories commissioned a study in 2007 to use water from an abandoned gold mine with a heat pump to provide district heating to the community, saving an estimated C$13 million/yr.

Chile

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	9.1
Annual output TJ	131.8
Annual capacity factor	

There has been interest in geothermal exploration in Chile since the beginning of the 20th century and although in recent years the question of security of energy supply has given the development greater impetus, a higher emphasis on the use of renewable energy generally needs to be instituted prior to further progress.

It has been established that the Chilean Andes has more than 300 hot spring areas, giving the country an estimated high-temperature (over 150^{o}C) potential of some 16 000 MW_t.In the opening years of the 21st century the Geology Department of the University of Chile together with the National Oil Company (ENAP) and various countries with geothermal expertise undertook a research project in the central-southern areas of the country. Additionally, ENAP has worked with CODELCO (the National Copper Corporation) in the northern and southern regions. The intention of the studies was to establish areas that would be suitable for the generation of electricity.

Geothermal energy in Chile is mainly used for recreational purposes. Current use in spa and swimming pools accounts for all the capacity. However, there are many private thermal spas and resorts in the geothermal area, for which quantitative information regarding their use of geothermal resources is not available. In some spas, shallow wells have been drilled to obtain hot water, while in others hot water is collected rudimentary and piped to the buildings pools, through shallow drains and plastic hoses.

China

	Electricity generation
Installed capacity MWe	24.1
Annual output GWh	125
Annual capacity factor	
	Direct use
Installed capacity, MWt	8 898
Annual output TJ	75 348
Annual capacity factor	

With its move to a fast-growing market economy and increasing environmental concerns, the utilisation of geothermal energy in China continues to increase, but not with the same rapidity as other renewable energies.

Studies have identified more than 3 000 hot springs and more than 300 geothermal fields have been investigated and explored. High-temperature resources are mainly concentrated in southern Tibet and western parts of Yunnan and Sichuan Provinces, whereas low-medium temperature resources are widespread over the vast coastal area of the southeast, the North China Basin, Songliao Basin, Jianghan Basin, Weihe Basin, etc.

Historically, the primary development has been in geothermal energy used directly. Approximately half of installed capacity is used for bathing and swimming, with the next largest sector being district heating. Other uses include agricultural drying, fish farming, greenhouse heating and industrial process heat.

The utilisation of geothermal heat pumps (GHP) has grown dramatically in recent years. GHP applications were used extensively in the 2008 Beijing Olympic Games venues. By end-2009 installed capacity of GHP was some 5.2 GW_t, considerably higher than the installed capacity for other direct uses.

The development of geothermal power generation has been, by comparison, relatively slow, owing to the large hydro-electric resources in those provinces with high-temperature geothermal resources (Tibet and Yunnan). At present the only operational power plant is at Yangbajain (Tibet). Capacity is 24.18 MW_e, generating about 125 GWh annually.

Bathing, agriculture, and fish farming have continued to be major uses for geothermal fluids.

Colombia

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	
Annual output TJ	
Annual capacity factor	

Colombia is located on the Pacific Ring of Fire, which provides positive anomalies in respect of the geothermal resource, exemplified by numerous volcanoes and high-temperature hydrothermal systems, associated with magmatic heat sources.

Although exploratory work is being conducted, there has been no actual utilisation yet of the high temperature resource.

Unassociated with magmatic heat, there are low- to medium- temperature hydrothermal sources, evidenced by warm springs throughout the country. Currently, the small use of geothermal heat is confined to bathing and swimming (including balneology).

In the central cordillera of the Andes, is located Nevado del Ruiz volcano, surrounded by a large area of surface and keeping in the ground wealth of an increasingly more important and vital energy.

Costa Rica

	Electricity generation
Installed capacity MWe	166
Annual output GWh	1131
Annual capacity factor	
	Direct use
Installed capacity, MWt	
Annual output TJ	
Annual capacity factor	

The Central American volcanic belt passes through Costa Rica, evidenced by numerous volcanoes and geothermal areas. The fields of Miravalles, Tenorio and Rincón de la Vieja are located in the northwestern part of the country and have been studied in detail.

Exploration work on the slopes of the Rincón de la Vieja volcano at the Las Pailas and Borinquen geothermal fields has resulted in the discovery of high-temperature fields.

Future development of the country’s geothermal resource, for instance the construction of Las Pailas II or Borinquen I will depend on feasibility studies, scheduled for 2011.

In the last 20 years, with the help of the Italian Government and the United Nations Development Fund (UNDP), Costa Rica’s low- and medium-temperature resource has been studied. However, at the present time direct use is confined to hotel swimming pools in areas of ecotourism.

Croatia

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	114
Annual output TJ	557
Annual capacity factor	

The considerable Croatian geothermal resource is located in two large geological formations: the Panonian Basin to the north and east, and the Dinarides Belt in the south of the country. These two geologically different regions have significant differences in potential. At the present time usage of the resource is increasing, but it is still at a very low level.

The direct utilization of geothermal nergy in the Croatia is mainly for heating swimming pools and spas along within recreational centers, as well as space heating. There are 20 spas and five geothermal fields above 100oC that are using geothermal energy. The five high temperature geothermal fields are being considered for combine heat and electrical energy production.

Czech Republic

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	4.5
Annual output TJ	90
Annual capacity factor	

Geothermal energy has been little used, and then only directly (in spas and swimming pools), for over a century. At the present time only one geothermal source is being utilised as a source of power for installed heat pumps. However, in order to meet the EU target of 13% reliance on renewable energy by 2020, utilisation of the resource will likely play a part, albeit small.

Within the Czech Republic about 60 sites have been identified with a theoretical electricity potential of 250 MW_e and a heat supply capacity of about 2 000 MW_t. The resulting electricity generation has been estimated to be some 2 TWh and usable heat, 4 TWh. It is considered that, if successful, further exploration could lead to higher production.

At the beginning of 2009 ČEZ, the country's largest power company, issued a tender for a survey to determine the feasibility of constructing a geothermal power plant in Liberec, north Bohemia.

The direct use of thermal water in spas and swimming pools dates back several hundred years. There are 11 major spas and thermal springs in the Czech Republic, the most famous being Karlovy Vary and Marianske Lazně.

More than 10,000 geothermal heat pumps have been installed, at an average capacity of 20 kW. Using a COP of 3.5 and 2,200 full load operating hours per year, the annual energy use is then estimated at 832 TJ/yr. The estimated capacity for the spas is 4.5 MWt, with an energy use of 90 TJ/yr.

Denmark

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	200
Annual output TJ	2 500
Annual capacity factor	

With the Government's positive attitude towards the utilisation of the country's low-enthalpy resource, there has been an increased usage during the first years of the 21st century, which is expected to continue. It is estimated that there is a sufficient resource to supply heat to several towns for hundreds of years.

Research has shown that the estimated geothermal resource in the area surrounding Copenhagen represents an output of 60 000 PJ.

Temperatures in Denmark are of low-enthalpy with no pronounced temperature anomalies, with normal gradients of 25 to 30oC/km. Two large district heating plants using heat pumps have been built in the country.

The first was established in 1984 at Thisted producing 44oC saline water at 200 m3/h from 1,250 m depth resulting in 7 MWt of installed capacity. The second in Copenhagen started in 2005, uses 73oC saline water at 235 m3/h from 2,560 m depth resulting in an installed capacity of 14 MWt. A number of small heat pump projects have been installed, estimated at 20,000 units in a vertical configuration with a capacity and annual energy use of 160 MWt and 1,700 TJ/yr. Ground water is also being used for cooling and industrial locations.

Ecuador

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	5
Annual output TJ	
Annual capacity factor	

Exploration of the Ecuadorean geothermal potential was begun during the 1970s in order to establish the extent of both high-temperature and low-temperature resources. Despite follow-up prefeasibility studies on the former and prefeasibility studies on the latter, plans for industrial and direct uses were found to be uneconomic.

Ecuador has a very large geothermal potential (it is estimated that it could arrive up to 500 MW) but it has not yet been exploited. It is estimated that the direct usage of geothermal heat can contribute to the development of rural areas and highly contribute to a diminution of poverty.

Geographical Areas With Major Potential: Since the first investigations were conducted, the following areas, that present excellent potential for geothermal usage, were individuated. Tufiño-Chiles Cerro Negro (binational project Ecuador-Colombia), Chachimbiro (Imbabura Province), Chalupas (Cotopaxi Province), in addition to 17 other individuated areas with potential such as Napo-Pichincha, Cuenca, Chalpatan, Pululahua. From these areas, the potential is estimated at approximately 534 MW of energy. Several regions in the country remain un-explored for geothermal resources, namely in the sedimentary basins in the Costa, in the Oriental sedimentary basins and in the Galapagos archipelago. The Andes form the backbone of the country. In the Northern half of the two mountain ranges that constitute the Andes (the Western and Eastern Cordilleras) there exists a well developed arch from Quaternary age that consists of more than 50 volcanoes, of which 30 are active. Recently, in November 2011, the Volcano Tungurahua, situated in the Eastern Cordillera, erupted. The

Southern part of the Andes, according to a study from the Department of Geothermal Power of the Escuela Politécnica Nacional, reports only extinct volcanic activity. The strongest volcanic activity can be witnessed in the Western-most islands, Fernandina, Isabela and Roca Redonda.

El Salvador

	Electricity generation
Installed capacity MWe	204
Annual output GWh	1422
Annual capacity factor	
	Direct use
Installed capacity, MWt	
Annual output TJ	
Annual capacity factor	

Like Costa Rica, El Salvador lies on the Central American volcanic belt and there is thus a plentiful geothermal resource. The main emphasis has been on using the resource for power generation although a potential exists for the direct use of geothermal in drying grains and fruit.

Of the 204.4 MW_e of geothermal capacity currently installed in El Salvador (95 MW_e at Ahuachapán, and 109.4 MW_e at Berlín), 183.8 MW_e is reported to be actually available (80 MW_e at Ahuachapán and 103.8 MW_e at Berlín).

Ethiopia

	Electricity generation
Installed capacity MWe	7.3
Annual output GWh	10
Annual capacity factor	
	Direct use
Installed capacity, MWt	
Annual output TJ	
Annual capacity factor	

Ethiopia is one of a minority of African countries possessing geothermal potential. Considerable resources of both high- and low-enthalpy geothermal have been located in the Ethiopian Rift Valley – in the Main Ethiopian Rift and in the Afar depression. Exploration that began in 1969 has, to date, revealed a potential that could possibly generate more than 5 000 MW_e of electricity. Of the approximately 120 localities that are believed to have independent heating and circulation systems, about two dozen are judged to have potential for high enthalpy resource development, including for electricity generation. A much larger number are capable of being used directly for horticulture, animal breeding, aquaculture, agro-industry, health and recreation, mineral water bottling, mineral extraction, space cooling and heating etc.

The country is heavily dependent on petroleum fuels for transport and some electricity generation, biomass for household cooking and lighting and an erratic hydro supply for the remaining electricity generation. Although geothermal is similar to, for example, hydro in that an installation requires a high initial investment cost, it has the advantage of having a possibly greater than 90% availability factor, perhaps double that of others of similar installed capacity. Recognising this, the Government has taken steps to implement changes to the legal and institutional framework in order for geothermal resources to compete with conventional energy systems and is committed to investigate and develop the country's geothermal potential.

Geothermal exploration work in Ethiopia started in 1969 and continues up to now. Possible resource areas have been defined within the Ethiopian sector of the East African Rift system and the Afar triangle.

France

	Electricity generation
Installed capacity MWe	18.3
Annual output GWh	14.0
Annual capacity factor	
	Direct use
Installed capacity, MWt	1 345
Annual output TJ	12 949
Annual capacity factor	

Low-enthalpy geothermal resources in metropolitan France are found in two major sedimentary basins: the Paris Basin and the Aquitaine Basin in the southwest. Other areas (Alsace and Limagne) have geothermal potential but it cannot be so readily utilised.

The French WEC Member Committee reports the plan includes a 2020 objective of producing 2.4 Mtoe of geothermal heat and equipping 2 million households with heat pumps.

The development of geothermal resources in the country has seen several phases: after a major development phase based on low enthalpy resources from sedimentary basins at the beginning of the 1980s; followed by a period of withdrawal during the 1990s with very little new activity; then more recently by a revival of activity of all kinds, based on a policy by the government for energy management and development, especially of renewable energy (French Energy Law in 2005 and the large consulting process "Grenelle de l'environnement" in 2007).

Germany

	Electricity generation
Installed capacity MWe	7.3
Annual output GWh	18.8
Annual capacity factor	
	Direct use
Installed capacity, MWt	3 485
Annual output TJ	12 764
Annual capacity factor	

Germany's hydrothermal resources, down to a depth of 5 000 m, are located in the North German Basin, the Molasse Basin in the south of the country and the Upper Rheingraben.

The hot dry rock (HDR) resource, at a depth of between 3 000 and 7 000 m, is thought to exist in the Crystalline Basement in the middle and south of the country, the Crystalline Basement in the Upper Rheingraben and the Rotliegend volcanites in the North German Basin.

An evaluation of the maximum recoverable potential for electricity generation from HDR technology has been estimated at 8 620 EJ and 90 EJ from hydrothermal resources.

The first German geothermal power plant (230kW$_e$) was inaugurated at Neustadt-Glewe in November 2003 to provide electricity for 500 households and a second 3 MW$_e$ plant began operating in Landau in 2007. A third 3.4 MW$_e$ plant at Unterhaching first generated heat during 2007 and then electricity in late 2008.

Most of the district heating plants are located in the Northern German Basin, the Molasse Basin in Southern Germany, or along the Upper Rhine Graben. Two geothermal power plants at Neustadt-Glewe and Unterhaching also provide water for district heating.

In addition to these large installations, there are numerous small- and medium-size geothermal heat pump units located throughout the country. Under the prevailing economic and political conditions, multiple or cascaded uses are employed to help improve the economic efficiency of the direct use. For this reason many installations combine district or space heating with greenhouses and thermal spas. No numbers are given for greenhouse heating.

Greece

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	134.6
Annual output TJ	937.8
Annual capacity factor	0.30

Greece possesses both high- and low-enthalpy geothermal fields. The former occurs in the islands of Milos, Santorini, Nisyros, etc. located in the South Aegean volcanic arc. The latter are situated in the plains of Macedonia and Thrace and in association with the country's hot springs. At the present time the geothermal resource is not harnessed for electricity generation.

Low-temperature geothermal fields occurring in structurally active sedimentary basins have a considerable potential. A small proportion of this heat resource is currently utilised, with an installed capacity of about 135 MW$_t$ for space heating, greenhouse and soil heating, bathing and spas, industrial uses, fish farming, cultivation of spiroulina and geothermal heat pumps.

Although the number of heat pump installations in Greece does not equate with some other European countries, nevertheless there has been a strong rate of growth in recent years.

The first half of the present decade was characterized by a diversification of direct applications with new uses such as aquaculture, spirulina production, outdoor pool heating, water desalination and fruit and vegetable dehydration. However, in the past few years there has been a rapid expansion of geothermal heat pumps.

Approximately 21 ha of greenhouses are heated, mainly for vegetable and cut flower growing, with 27 greenhouse units in the country run by 21 operators. Some soil heating, especially for asparagus, has increased significantly and is now 17 ha. There are more than 60 thermal spas and bathing centers in operation. A tomato dehydration unit has been operating since 2001 producing more than 1,000 kg of dehydrated tomatoes per day. Geothermal water is used for frost protection for a number of aquaculture ponds during the winter. Approximately 350 geothermal heat pump applications are located in the country with about 65% being of the open loop configuration.

Guadeloupe

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	16
Annual output TJ	
Annual capacity factor	

The double-flash plant at La Bouillante in the French Overseas Department of Guadeloupe is at present the only example of the island's geothermal energy being utilised for electricity production. The plant was commissioned in 1985 but was closed between 1992 and 1996.

The French Agency for Environment and Energy Management (ADEME) contributed to the development of the Bouillante high-enthalpy field by supporting 20% of the cost of drilling new wells.

Following the rehabilitation of Bouillante 1, a 5 MW_e double-flash unit, in 1996, the plant was able to supply 2% of the island's electricity supply in 1998. Extensive exploration of the Bouillante field ensued and led to the drilling of three new production wells and a plan to construct Bouillante 2, an 11 MW_e unit some 400 m from the original plant. Bouillante 2 was put into service in 2005 and currently some 10% of electricity generation is supplied by the geothermal resource.

Geothermal electricity is not available on the mainland, but only in the Caribbean islands it can reach up to 20% of electricity needs.

The high enthalpy utilization for electricity production in France is only in the French Overseas Department, at Bouillante on Guadeloupe island (Geothermie Bouillante). Its exploitation started in 1984, and a second unit in 2004 has been commissioned. The reservoir temperature is 250°C at shallow depth. The total capacity of 15 MW, not increased since 2005, produces 95 GWh, corresponding to 8% of the local consumption. The activity for the third unit of 20 MW is ongoing. The final target will reach 20% of geothermal contribution to the electricity needs.

Guatemala

	Electricity generation
Installed capacity MWe	52
Annual output GWh	289
Annual capacity factor	
	Direct use
Installed capacity, MWt	2.3
Annual output TJ	56.5
Annual capacity factor	

Guatemala's Instituto Nacional de Electrificación (INDE) has five geothermal areas for development. All five (Zunil, Amatitlán, Tecuamburro, San Marcos and Moyuta) lie in the active volcanic chain in southern Guatemala. INDE has conducted both investigative work and development of geothermal power since 1972. It has been estimated that Guatemala's geothermal resource could supply 20% of the country's electricity supply.

The first geothermal power plant in the country was constructed in the Amatitlán area; electricity was produced from a 5 MW_e back-pressure plant for a period of three years (from October 1998), during which time the field was evaluated.

During 2007, a 20 MW_e binary plant was commissioned at Amatitlán, adding to the existing 5 MW_e back-pressure unit. However, the latter unit is currently out of service and INDE expects to transfer it to the next field – possibly Tecuamburro – to be developed some 2 or 3 years hence.

A second geothermal plant (in the Zunil I field) with a running capacity of 24 MW_e has been operating since July 1999. Following INDE's exploratory drilling work, a contract was signed with Orzunil I for the private installation and operation of the plant. Until 2019 the company will buy steam from INDE and sell power to the national grid.

Direct use of geothermal heat is limited but the 1.6 MW_t Bloteca plant is used in the process of curing concrete construction blocks and in another instance Agro-Industrias La Laguna uses a 0.5 MW_t unit to dehydrate fruit.

The direct-use of geothermal energy in the country in the past has been used for medical purposes, agriculture, and domestic use. The areas of Totonicapan, Quetzaltenango, and Amatitlan are popular tourist attractions known for their thermal bath houses and spas. These are estimated at a total of 0.21 MWt and 3.96 TJ/yr. The construction company, Bloteca, was the first to successfully apply a direct use application of geothermal steam in the curing process of concrete products (Merida, 1999).

In 1999, a fruit dehydration plant, Agroindustrias La Laguan, was built to use hot water from a well in the Amatitlan geothermal field in the drying process.

Hungary

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	654.6
Annual output TJ	9 767
Annual capacity factor	

Hungary possesses very considerable geothermal resources and it has been estimated that the country has the largest underground thermal water reserves and geothermal potential (low and medium enthalpy) in Europe.

The principal applications of geothermal power used directly are for balneological purposes, greenhouse heating, space heating, industrial process heat and other uses.

Surface signs have been known in the country since ancient times, and thermal springs in Budapest have been used during the Roman Empire and also later in the Medieval Hungarian Kingdom. Exploration for thermal waters began in 1877 and during the 1950s and 1960s hundreds of geothermal wells were drilled, mainly for agricultural utilization.

More recently, the use of geothermal energy has decreased substantially due to the global recession; however, promising projects are being investigated for both power production and direct-uses. Balneology was the earliest use of thermal waters, with 289 thermal wells and 120 natural springs presently used for sport and therapeutically purposes. Agricultural use is one of the important applications of geothermal waters in the country with 193 operating wells supplying heat for 67 ha of greenhouses. Animal farms use thermal water in more than 52 cases to raise chickens, turkeys, calves, pigs and snails. At present more than 40 townships with more than 9,000 flats are heated in district heating projects. Thermal waters are also used in secondary oil production with 5,400 m3/s of hot water being injected into oil reservoirs for enhanced oil recovery. In addition, gathering pipes in a heavy oil producing oilfield are heated with geothermal waters.

Iceland

	Electricity generation
Installed capacity MWe	665
Annual output GWh	4465
Annual capacity factor	
	Direct use
Installed capacity, MWt	2002.9
Annual output TJ	24621.4
Annual capacity factor	

Geothermal energy resulting from Iceland's volcanic nature and its location on the Mid-Atlantic Ridge has been utilised on a commercial scale since 1930. The high-temperature resources are sited within the volcanic zone (southwest to northeast), whilst the low-temperature resources lie mostly in the peripheral area. A realistic assessment of Iceland's potential for electricity production has been put at 20 TWh annually, after taking into account economic factors, environmental considerations and technological elements.

The principal use of geothermal energy is for space heating, with about 89% of all houses heated by geothermal resources. There is a total of about 30 municipally-owned geothermal district heating systems located in the country, the largest of which is Reykjavik. Iceland's geothermal capacity for electricity generation has increased dramatically in recent years and is today representing about 30% of total electricity generation. Geothermal accounted for 62% of Iceland's energy supply.

The policy of the Iceland Government is to expand the use of renewable energy to an even greater extent. Direct use of geothermal power has not grown to the same extent as electricity generation but it remains of major importance, especially in the residential sector.

Iceland's economy has been seriously impacted by the global economic situation, which has slowed the pace of geothermal development. Reykjavik Energy has revised its projected drilling plans and although the company will continue with projects, they will take longer to come to fruition.

Due to its location the country has very favourable conditions for geothermal development. The geothermal resources are utilized for both electricity generation and direct heat applications. It provides 62% of the nation's primary energy supply, with space heating the most important direct-use, providing 89% of all space heating in the country.
The largest geothermal district heating system is in Reykjavik where 197,404 people are served with an installed capacity of 1,264 MWt and peak load of 924 MWt.
Two other large district heating systems are located on the Reykjanes peninsula which serves about 20,000 people and the Akureyri system in northern Iceland serving about 23,000 people.

There are 135 swimming pools in the country that use geothermal heat, generally open throughout the year.

Snow melting has been recently increased to where 820,000 m2 are heated throughout the country, with most in Reykjavik. Most of the heat energy comes from the return water from space heating systems.

Industrial uses include the seaweed drying plant at Thorverk; carbon dioxide production at Haedarendi; and fish drying by 18 small companies, producing about 15,000 tonnes of dried cod heads for export. The diatomaceous earth drying plant at Kisilidjan has been closed. Other industrial applications using geothermal heat are salt production, drying of imported hardwood, retreading of car tires, wood washing, curing of cement blocks, and steam baking of bread at several locations.
After space heating, heating of greenhouses is the oldest and most important uses of geothermal energy. Crops produce include vegetables (55%) and flowers (45%), with an estimated 17.5 ha in operation at present. Fish farming has increased to around 10,000 tonnes in 40 plants by 2006, with salmon the main specie; however, arctic char and cod production are increasing rapidly.

India

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	
Annual output TJ	
Annual capacity factor	

It has been estimated by the Geological Survey of India that the geothermal potential is in the region of 10 000 MW_e, widely distributed between seven geothermal provinces. The provinces, although found along the west coast in Gujarat and Rajasthan and along a west-southwest – east-northeast line running from the west coast to the western border of Bangladesh (known as SONATA), are most prolific in a 1 500 km stretch of the Himalayas.

Research has shown that there are 340 hot springs in India, most of which have a low-temperature resource and therefore only suitable for direct use. At the present time direct utilisation is almost entirely for bathing and balneological purposes. However, it is considered that greenhouse cultivation of fruit could be developed extensively in the future.

Investigative studies are being undertaken in order to establish the feasibility of developing the geothermal resource for power generation. The Ministry of New and Renewable Energy is supporting a RD&D programme for such studies. The State Governments of Jammu and Kashmir and Chhattisgarh have indicated their willingness to develop geothermal fields for commercial operation. The Government of Andhra Pradesh has initiated a resource assessment study and has proposed the demonstration and use of heat pumps in Gujarat.

An Action Plan for Indo-Iceland Geothermal Cooperation has been drawn up between the two Governments in order for Iceland's geothermal expertise to assist in developing the Indian resource.

It has been estimated from geological, geochemical, shallow geophysical and shallow drilling data it is estimated that India has about 10,000 MWe of geothermal power potential that can be harnessed for various purposes. Rocks covered on the surface of India ranging in age from more than 4500 million years to the present day and distributed in different geographical units. The rocks comprise of Archean, Proterozoic, the marine and continental Palaeozoic, Mesozoic, Teritary, Quaternary etc., More than 300 hot spring locations have been identified by Geological survey of India (Thussu, 2000). The surface temperature of the hot springs ranges from 35 C to as much as 98 C. These hot springs have been grouped together and termed as different geothermal provinces based on their occurrence in specific geotectonic regions, geological and strutural regions such as occurrence in orogenic belt regions, structural grabens, deep fault zones, active volcanic regions etc., Different orogenic regions are – Himalayan geothermal province, Naga-Lushai geothermal province, Andaman-Nicobar Islands geothermal province and non-orogenic regions are – Cambay graben, Son-Narmada-Tapi graben, west coast, Damodar valley, Mahanadi valley, Godavari valley etc.

Indonesia

	Electricity generation
Installed capacity MWe	1197
Annual output GWh	9321
Annual capacity factor	
	Direct use
Installed capacity, MWt	
Annual output TJ	
Annual capacity factor	

Having become a net oil importer early in the 21st century, Indonesia took the view that it was essential to harness the enormous geothermal resource at its disposal. The Government's National Energy Management Blueprint 2005–2025, contained a target of 9 500 MW_e geothermal capacity by 2025. The national geothermal potential has been estimated at 27.67 GW_e but at the present time only a tiny fraction of this has been realised. The island of Sumatra has in the region of 50% of geothermal potential.

In recent years the Indonesian Government has passed a raft of laws and regulations in order to better regulate both the upstream and downstream side of the sector and to better utilise its geothermal power. Additionally, the Japan International Cooperation Agency, at the request of the Government, was engaged to formulate a Master Plan Study for Geothermal Power Development. A period of 18 months in 2006/2007 was used to assess the fields and formulate a development plan.

By end-2008, a total of 1 054 MW_e geothermal capacity was installed, of which some 95% was based on the island of Jawa-Bali. The remaining 5% was located on Sumatera and Sulawesi. Of the total, Pertamina Geothermal Energy (PGE), a subsidiary of Pertamina, the state-owned oil and gas company, operates 252 MW_e, Chevron, 632 MW_e and other companies, 170 MW_e. Electricity production in 2008 amounted to 8.2 GWh.

A planned programme of construction will gradually increase capacity so that by 2025 about 50% of national electricity demand will be satisfied by geothermal power. It was announced during the World Geothermal Congress 2010 that Indonesia plans to launch a 3 997 MW_e project to expand geothermal power.

A very small amount of geothermal energy is used directly for bathing, balneology and swimming and in the production of mushrooms, tea, silk and coconut sugar drying.

The paper by Darma et al. focuses, as in the past on the development of electricity generation by geothermal energy, however five years ago a group of researchers in government sponsored research and technology agency (BPPT) began to investigate methods to apply geothermal energy to the agriculture sector, particularly to sterilize the growing medium used in mushroom cultivation.

The process is still at the research stage not having yet become commercial.

Other uses of geothermal fluids include palm sugar processing, copra drying, tea drying and pasteurization and some fish farming. These activities are spread over about six areas totaling about 200 – 300 tonnes/hr of fluid.

No heat pump installations are used to date as they appear to be uneconomical at this time due to the availability and abundance of high enthalpy fluids.

Iran

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	
Annual output TJ	
Annual capacity factor	

Iran's geothermal potential is embodied in low- to medium-enthalpy resources found in provinces fairly widely distributed across the country. However, three regions, Damavand in the north-central area, and Maku-Khoy and Sahand in the northwest, are likely to be the most productive.

Traditionally, geothermal heat has been used directly for recreational and balneological purposes.

The country is extremely well-endowed with low-cost fossil fuels and historically this has proved a disincentive to the development of the renewable energies. However, the Government is showing a growing interest in progressing renewable energy in order to meet fast-growing national energy demand. The Renewable Energy Organisation of Iran (SUNA), an affiliate of the Ministry of Energy was established in the 1990s. In recent years SUNA has studied the feasibility of, and given publicity to, using the heat for greenhouses, agriculture, aquaculture and heat pumps for cooling and heating purposes.

Ireland

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	
Annual output TJ	
Annual capacity factor	

There are no high-temperature geothermal resources in Ireland and all instances of low-temperature potential are only suitable for direct utilisation. To date, only one of the 42 warm springs located in the east and south of the country has been exploited, for heating a swimming pool.

The country does however possess an adequate supply of groundwater sources suitable for heat pumps. Since the late 1990s, the market has grown significantly so that now more than 9 500 domestically installed systems (typically, 15 kW) exist. This trend is expected to continue. Additionally, more than 270 large-scale heat pumps have been installed in commercial buildings. In total, heat pumps represent some 164 MW_t of installed capacity.

Italy

	Electricity generation
Installed capacity MWe	772
Annual output GWh	5 754
Annual capacity factor	
	Direct use
Installed capacity, MWt	1000
Annual output TJ	12 600
Annual capacity factor	

Italy is one of the world's leading countries in terms of geothermal resources, lying fifth in terms of production of electricity from geothermal. The high-temperature steam-dominated reservoirs lie in a belt running through the western part of the country from Tuscany to Campania (near Naples). Commercial power generation from geothermal resources began in Italy in 1913 with a 250 kW_e unit. Subsequently the main emphasis has been on the production of power rather than on direct use of the heat.

The main geothermal fields in Italy are Larderello, the oldest and one of the most powerful in the world, with 200 production wells at depths of less than 1 000 to over 4 000 m, the Travale-Radicondoli, with 25 production wells at depths of between 1 500 and 3 500 m, and Bagnore and Piancastagnaio, with 16 production wells at depths of 2 500 – 4 000 m.

Following the limited development of resources during the first half of the 20th century, it was the second half of that century that saw rapid growth. 31 plants are in operation with a total installed capacity of 810 MW_e (711 MW_e operating capacity). All plants in operation are located in the region of Tuscany and over 45% in the Province of Pisa. Electricity generation during the year amounts to 6.3 TWh, Although installed geothermal capacity represented only 3% of total renewable energy capacity, output accounted for 9.5% and Enel, the main Italian power company, already plans to increase capacity by installing a further 112 MW_e in the coming years. Expansion of capacity began in November 2009 when an additional highly-efficient facility was brought into operation.

Government and State support available for both geothermal plants and direct use of heat includes national mandatory quotas, tradable green certificates and financial incentives.

Although the country also utilises its low-enthalpy resources for direct purposes, it is considered that the market is still under-developed. Main applications for direct uses are thermal spas, space and district heating, fish farming, greenhouse heating, heat pumps and industrial process heat.

Heat pumps are being installed at a rate of some 500 per annum, most being groundwater types, with a smaller amount of closed-loop types. The growth potential of the direct use market is seen as greater than that of power generation. The Italian Position Paper foresees a potential capacity of 1 300 MW_e by 2020, while total use of geothermal heat might grow to 6 000 MW_t by 2020.

Geothermal direct-use has increased by a factor of 1.2 in the past five years to 867 MWt and 9,941 TJ/yr. This larger contribution, in terms of installed power, is mainly due to the wide development, mainly in the northern areas of Italy, of geothermal district heating and in the number of single household installations.

Both heating and cooling have been developed using geothermal energy, mainly by a large increase in geothermal heat pumps, both open and closed systems. Much of the growth has been due to interest from the designer's community, as well as the decrease in the cost of systems.

For centuries Italian people have largely used thermal waters for bathing, medical cures and relaxation, and the industry is still an important part of geothermal use, accounting for 32% of the annual energy use.

A number of district heating systems using geothermal energy are operating in the country, with Ferrara being the most important. A number of geothermal district heating systems are also operating in the Tuscany region.

Greenhouse heating and fish farming are also important parts of direct use applications, amounting to 13% and 16% respectively of the annual energy use. The largest greenhouse operation uses "waste" water from the Mt. Amiata power plant in Tuscany.
Large geothermal heat pump installations (2–5 MWt) have played an important role in Italy. Installations of geothermal heat pumps has increased 15% in the past year with an about 12,000 units installed.

Japan

	Electricity generation
Installed capacity MWe	538
Annual output GWh	2 632
Annual capacity factor	
	Direct use
Installed capacity, MWt	2 100
Annual output TJ	25 698
Annual capacity factor	

Japan has a long history of geothermal utilisation, both direct and for power generation. It is one of the world leaders in terms of generation of electricity. The first experimental power generation took place in 1925, with the first full-scale commercial plant (23.5 MW_e) coming on-line at Matsukawa, in the north of the main island of Honshu, in 1966. Following each of the two oil crises, development of Japan's geothermal resources was accelerated and technological improvements were made. By end-1996, installed capacity stood at 529 MW_e but in the following years economic constraints were imposed, financial incentives withdrawn and geothermal capacity grew only marginally, reaching 535 MW_e in 2006. The existing plants are located on the southern island of Kyushu, in northern Honshu, at Mori on Hokkaido and on the island of Hachijo, some 300 km south of Tokyo.

The country's geothermal potential is estimated to be in the order of 24.6 GW_e. Only a small fraction of this potential has been used to date and until ways of tapping Japan's deep resources can be developed, this situation will prevail. Geothermal energy was excluded from the Special Measures Law for the Promotion of Utilisation of the New Energy in 1997 and moreover, suffered when the electricity market was deregulated. In 2003 the Renewable Portfolio Standard Law did include geothermal energy but only insofar as binary cycle plants were concerned. The 2008 New Energy Law does include geothermal in the definition of New Energy and in January 2010, the Ministry of Economy, Trade and Industry (METI) presented measures for the promotion of renewable energy. METI is providing support by means of subsidies, tax incentives, an RPS and feed-in tariffs, appropriate to the energy source. However, although 2020 targets for other renewable energies are high, geothermal power generation is only expected to grow minimally.

By far the most important utilisation of geothermal hot water I n Japan is for direct use. It can be classified into three categories: the thermal use of hot water; geo-heat pumps and hot springs for bathing. The last named has never until recently, been accurately quantified. Based on the consideration that there are more than 25 000 hot springs throughout the country, a figure of nearly 1 700 MW_t expressed in terms of fuel alternative energy was thought to represent this use in 2006. This estimate accounts for some 80% of total direct use. When recreational hot-spring bathing is excluded, the estimated 2006 total installed direct use capacity was 400 MW_t. Of this total, snow melting and air conditioning accounted for 38%; hot water supply and swimming pools, 31%; space heating, 19%; greenhouse heating, 9%; fish breeding 2%; and industrial and other uses, negligible. At the end of the year, some 13 MW_t of ground source heat pumps were estimated to be installed.

The direct use of medium- and low-enthalpy geothermal water is mainly located in the areas around the high-enthalpy geothermal area, where hot spring resources are abundant. Otherwise, the use of shallow geothermal heat pump systems is available nationwide. These latter installation account for only 0.3% of the direct-use, and thus have limited use in the country.

Kenya

	Electricity generation
Installed capacity MWe	169
Annual output GWh	1430
Annual capacity factor	
	Direct use
Installed capacity, MWt	16
Annual output TJ	127
Annual capacity factor	

The country has a high dependence on hydropower for electricity generation (approximately 60%), but the unreliability of the water resource poses a problem, particularly for the industrial sector's power supply and also more generally leads to the purchase of expensive and polluting fossil fuels. With its substantial geothermal resource, the Kenyan Government has expressed its commitment to support further development of this potential, but in the past this has been impeded by financial constraints.

Twenty prospects lying in the Rift Valley have been identified as worthy of future study. However, to date wells have been drilled at only two sites: at Olkaria near Lake Naivasha (about 120 km northwest of Nairobi) and Eburru. Only the former has been exploited although there is a planned 2.5 MW_e power station at Eburru.

KenGen's Olkaria I was Africa's first geothermal power station when the first unit came into operation in mid-1981, with an initial installed net capacity of 15 MW_e. Two more 15 MW_e units were added in 1982 and 1985.

The 2 x 35 MW_e units of the Olkaria II plant (Africa's largest geothermal power plant, co-financed by the World Bank, the European Investment Bank, KfW of Germany and KenGen) were commissioned in late-2003.

Kenyan geothermal power output was increased by 12 MW_e in 2000 when the first two stages of Kenya's first private geothermal plant were installed at Olkaria III. The 35 MW_e third stage became operational at the beginning of 2009, bringing the total installed capacity to 48 MW_e.

In December 2009 drilling of new wells began at Olkaria. It is expected that 10 new wells will be drilled at Olkaria IV, increasing total capacity by 140 MW_e.

The use of thermal waters for direct purposes is limited, although hot springs are being utilised by hotels to heat spas and there is some use of steam at Eburru for domestic purposes.

To date there has been one successful instance of a commercial direct-use application. Oserian began as a 5 ha vegetable-growing farm in 1969. Today it has grown to be a 210 ha farm specialising in floriculture with an annual output of 380 million stems. The Geothermal Rose Project covers an area of 84 ha. The greenhouse heating system is powered by a 2 MW_e binary-cycle power plant commissioned in September 2004, making the company self-sufficient in electricity needs.

Korea (Republic)

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	105
Annual output TJ	
Annual capacity factor	

With its heavy reliance on fossil fuels and nuclear power for electricity generation, Korea's energy supply structure has only in recent years come to fully embrace the renewable energies. The 2008 First National Energy Master Plan encompassed the Third Basic Plan on New & Renewable Energy Technology Development, Utilization and Diffusion, 2009–2030. Within the Third Basic Plan, the share of renewable energy aims to satisfy 11% of primary energy supply and 7.7% of electricity generation by 2030. Although the main emphasis of the Plan is directed towards solar PV and hydrogen/fuel cells, development of the geothermal heat pump sector is expected to play its part. Additionally, the Mandatory Public Renewable Energy Use Act which came into force during 2004 states that more than 5% of the budget for any new public building larger than 3 000 m^2 must be used to install renewable energy. This legislation is hastening the growth of geothermal heat pumps.

Lithuania

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	48
Annual output TJ	412
Annual capacity factor	

Lithuania's geothermal resource, lying in the west of the country, has been found to be significant. In 2000 the 41 MW_t (18 MW_t geothermal heat and 23 MW_t heat from absorption heat pump driven boilers) Klaipeda Geothermal Demonstration Plant (KGDP) was commissioned and began producing 25% of the heat required by the city of Klaipeda.

Much work has been undertaken on the thermal waters in Vilkaviskis, a city in the south-western part of the country, with a view to developing balneological uses and also a district heating scheme.

To date, Lithuania's extensive low-temperature resource has been harnessed for an estimated 1 000 ground-source heat pumps, with an installed capacity of 17 MW_t.

Mexico

	Electricity generation
Installed capacity MWe	867
Annual output GWh	6 502
Annual capacity factor	
	Direct use
Installed capacity, MWt	156
Annual output TJ	4 023
Annual capacity factor	

Reflecting the country's location in a tectonically active region, geothermal manifestations are particularly prevalent in the Mexican Volcanic Belt (MVB), as well as in the states of Baja California and Baja California Sur. Development has, in the main, been concentrated on electric power production, although there is a small amount of geothermal power used for direct purposes.

Comision Federal de Electricidad (CFE) has developed some direct uses of geothermal resources at the Los Azufres geothermal field, including a wood-dryer, a fruit and vegetables dehydrator, a greenhouse and a system for heating of its offices and facilities in this field.

The use of geothermal heat pumps is minimal, and underdeveloped with no information available. District and individual space heating is little used in Mexico due to the mild temperatures throughout the year in most of the country.

eothermal heat is obviating the need to use 3 million m^3 of natural gas. A second borehole was started in late-2008 in preparation for a doubling in the size of the greenhouses. It is expected that this application will encourage further use by horticulturists.

TNO, a Dutch research institute under contract to the Ministry of Economic Affairs, is currently mapping the deep heat resource in order to reassess the potential of the Netherlands. Analysis of deeper formations may demonstrate the feasibility of the resource for electricity generation.

Originally the object of drilling energy wells in the country was to store solar energy for space heating in winter. Later, this application broadened to the storage of thermal energy (both heat and cold) from other sources and to include geothermal heat pumps. The R&D of the early applications in the 1980s was focused on large scale applications such as commercial buildings rather than residential houses. Almost all of these early projects used ground water wells to store and extract thermal energy. In the late 1990s, borehole heat exchangers began to pay a more important role with geothermal heat pumps.

At present, most of the geothermal heat pumps projects are using vertical borehole heat exchangers, with over 10,000 of these in operation. Most are small scale applications such as for single family houses or small office and commercial buildings. Systems in family homes are designed for the heating load, whereas in commercial/office building the design is for both heating and cooling. Most projects use aquifer storage for both heating and cooling, with heat pump capacities in the 50 to 100 kWt range, and using ground water flow rates at less than 10 m3/hr (as no permits are need up to this rate). In Amsterdam about 1,200 large systems are installed with heat pump capacities around 1,000 kWt in some cases extracting over 250 m3/hr from a single well. Direct groundwater cooling is also practiced with the larger projects.

Exploitation of geothermal power in the Momotombo area, located at the foot of the volcano of the same name, began when the first 35 MW_e single-flash unit was commissioned in 1983. A second 35 MW_e unit was added in 1989. Thirteen years later following refurbishment by Ormat, the implementation of a new reservoir management plan and the installation of a 7.5 MW_e binary energy converter, the total nominal generation capacity stood at 77.5 MW_e. (at end-2008 effective capacity was 28.5 MW_e)

Nicaragua's net geothermal electricity output has been on a rising trend since 1999 and in 2008 totalled 289.8 GWh, just under 10% of total net generation.

Two of the ten identified areas of geothermal potential are currently being explored. GeoNico, a joint venture between the Italian company Enel and LaGeo of El Salvador, is exploring areas located in El Hoyo-Monte Galáan and Managua-Chiltepe.

Nicaragua will include 36 MW of geothermal energy to the national grid later this month. The 36 megawatts are part of the 72 megawatt geothermal energy field generated by the San Jacinto-Tizate, located in the municipality of Telica, province of León and the Pacific volcanic chain of Nicaragua.

Those 36 megawatts of renewable energy that will come in the next few days to the national grid will mean a decrease in fuel consumption.

In the second phase of the San Jacinto-Tizate geothermal energy project, to be concluded in late 2012 or early 2013, will generate another 36 megawatts, for a total of 72 new megawatts, bringing the energy savings will be up to 80 million dollars annually.

Papua New Guinea

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	
Annual output TJ	
Annual capacity factor	

Positioned as it is in the same tectonic region as Indonesia and the Philippines, exploration has been undertaken to establish the geothermal potential of Papua New Guinea. Since 2002 activity has focused on the island of Lihir, off the northeast coast. In June 2002 a 6 MW_e back-pressure unit was approved by Lihir Gold Ltd (LGL), the owner of the island's gold mine, one of the largest in the world. Commissioning of the plant came just 10 months later and provided the mine with 10% of its power needs.

At end-July 2005 the plant was expanded with the addition of a 30 MW_e unit and in early 2007 a further 20 MW_e were added. The plant currently satisfies approximately 75% of current electricity demand.

During 2008 LGL approved a project to increase the annual processing capacity of its gold mining facility to approximately one million ounces per year, a rise of up to 240 000 ounces. The expansion is expected to be completed during 2012. Drilling is currently being undertaken to ascertain whether there are further reserves of geothermal steam that can be harnessed to supply the expanded facility with power.

Philipines

	Electricity generation
Installed capacity MWe	1904
Annual output GWh	10311
Annual capacity factor	
	Direct use
Installed capacity, MWt	3
Annual output TJ	40
Annual capacity factor	

The Philippines archipelago is exceptionally well-endowed with geothermal resources. Today the country is the world's second largest user of geothermal energy for power generation. With only some 46% of the stated geothermal potential of 4 340 MW harnessed, there is much room for growth.

By end-2008 installed geothermal capacity stood at just under 2 GW_e. Of this figure 1.4 GW_e were considered dependable, representing about 11% of total electric generating capacity. Gross geothermal generation during the year amounted to 10.7 TWh which represented 17.6% of total electricity generation. Plants in the Visayas Islands generated 6.2 GWh; on the island of Luzon, 3.7 GWh and on the island of Mindanao, 0.8 GWh. Gross output in 2008 was 5% higher than in 2007, attributable to both the increased energy transfer from Leyte-Samar to Luzon via the Leyte-Luzon High Voltage Direct Current link – up from 720 GWh to 1 117 GWh and the unavailability of Luzon's coal-fired plants and thus the greater use of geothermal power.

The 2007 Update to the Philippine Energy Plan states the Government's determination to achieve a greater than 60% energy self-sufficiency beyond 2010. In December 2008 the Government legislated for a Renewable Energy Act to come into force at the end of January 2009. The objective of the Act is to accelerate the use of renewable energy so that the country will be able to raise its two-thirds self-sufficiency in electricity generation to possibly as high as 90%. To this end many market development incentives are being put in place. The target for additional geothermal capacity is 790 MW_e.

Direct use of geothermal heat is currently at a low level and is used for agricultural drying and bathing and swimming. The Government plans to further develop direct utilisation.

Direct-use of geothermal energy in the country is very limited. Two agricultural drying plants using geothermal heat are located at Palinpinon and Manito. The Palinpinon project uses steam from the Southern Negros Geothermal Projects (Palinpinon I geothermal power plant) where coconut meat and copra are dried (Chua and Abito, 1994).

The main resorts using geothermal heat are at Laguna and Agco.

The various applications are:

- 1.63 MWt and 26.93 TJ/yr for agricultural draying (the majority at the Palinpinon plant);
- 1.67 MWt and 12.65 TJ/yr for bathing and swimming;

Poland

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	281
Annual output TJ	1501
Annual capacity factor	

Poland has substantial resources of geothermal energy, but not at high temperatures. The available resource ranges from reservoir temperatures of 30ºC to 130ºC at depths of 1 to 4 km.

Although thermal water has been used for balneological purposes for many centuries, development of geothermal power for heating has only taken place during the past 15 years or so. Both the Strategy of Renewable Energy Resources Development which came into effect in 2000 and Polish membership of the European Union in 2004 have helped to encourage the growth of renewable energy use in general, but greater promotion of geothermal energy is needed.

Since 1992 seven geothermal heating plants have been brought on line: three in the Podhale region (Zakopane, Bukowina Tatrzańska and Bańska Niżna), in Stargard Szczeciński and Pyrzyce (both in the northwest) and in Mszczonów and Uniejow (both in central Poland). The plants are utilised for different purposes according to specific characteristics of the water at each location: some are used with gas peaking – the integrated units have a large contribution from gas, others have integrated absorption heat pumps with gas boilers.

Geothermal water is also used at eight balneological installations. It is estimated that there are about 10 000 compression heat pumps – mostly ground source – within the country with an installed capacity of at least 100 MW.

At the present time it is not foreseen that geothermal heat will be utilised for traditional electricity generation. However, there is an interest in studying binary plants which would be based on 90+ºC water.

Poland is characterized by low-enthalpy geothermal resources found mostly in the Mesozoic sedimentary formations. For many centuries warm springs have been used for balneotherapy in several spas. At present five geothermal heating plants are in operation, the largest in the Podhale region in southern Poland with an installed capcity of 41 MW and producing 267 TJ/yr (peak). Seven new bathing centers opened in the past five years.

Other types of geothermal use include greenhouse heating, wood drying, fish farming (these three are at the Podhale Geothermal Laboratory as R&D projects), and salt extraction from geothermal water.

Geothermal heat pumps installations have increased by at least 50% over the past five years with three large units in two major heating plants (water-source units), and over 11,000 units in individual buildings (ground-coupled units, both vertical and horizontal).

The various uses include:

- district heating of 68.0 MWt and 393 TJ/yr;
- greenhouse heating 0.5 MWt and 2.0 TJ/yr;
- fish farming 0.5 MWt and 2.0 TJ/yr;
- bathing and swimming 8.67 MWt and 55.2 TJ/yr;
- geothermal heat pumps at 203.10 MWt and 1,044.5 TJ/yr;
- others (salt extraction and playground heating) 0.28 MWt and 4.4 TJ/yr;

Portugal

	Electricity generation
Installed capacity MWe	30
Annual output GWh	210
Annual capacity factor	
	Direct use
Installed capacity, MWt	28
Annual output TJ	420
Annual capacity factor	

The limited geothermal resources in mainland Portugal have been developed for direct use, whereas geothermal occurrences in the Azores are utilised for the production of electricity as well as being used directly.

Twelve areas with potential for developing geothermal electricity generation have been identified on the islands of Faial, Pico, Graciosa, Terceira and São Miguel in the Azores. Operation of the 3 MW_e Pico Vermelho on São Miguel began in 1981. A second plant came into operation in two phases in 1994 and 1997 and by end-2008 gross geothermal capacity had reached 28.2 MW_e, generating 192 GWh.

Research has shown that the island of Terceira has a high-temperature resource suitable for power generation. Construction of a 12 MW_e plant is planned.

Low-enthalpy occurrences are spread throughout the mainland and have been harnessed for small district heating schemes, greenhouse heating and bathing and swimming (including balneology). Direct use in the Azores excludes district heating. To date there has been little interest in geothermal heat pumps. At end-2009, total installed capacity stood at 27.8 MW_t of which 25.3 MW_t was for bathing and swimming, 1 MW_t for greenhouse heating and 1.5 MW_t for district heating.

High temperature geothermal resources in Portugal are limited to the volcanic islands of the Azores, where electric power has been produced since 1980.

Low-temperature geothermal resources are exploited for direct uses in balneotherapy, small space heating systems and geothermal heat pumps. In 2008, private investors obtained concession rights for exploration of geothermal resources for a total area of 2,655 km2, aiming for future development of small scale EGS generation projects. District heating projects are operating at Chaves in northern Portugal and S. Pedro do Sul, in central Portugal. There is a single greenhouse project in S. Pedro do Sul covering 2 ha, for raising tropic fruit (mainly pineapple). About 30 spas are operating in the country, but most are only open in the summer. Several dozen small geothermal heat pump installations are operating throughout the country, but unfortunately, this application is not recognized as a geothermal resource by the Portuguese administration.

The data on the various geothermal utilizations are:

- 1.5 MWt and 12.9 TJ/yr for district heating;
- 1.0 MWt and 13.8 TJ/yr for greenhouse heating;
- 25.3 MWt and 358.6 TJ/yr for bathing and swimming.

No estimates were made for geothermal heat pumps, thus we estimate 24 installations at 12 kW, a COP of 3.5 and 1,500 full load operating hours per year, gives 0.3 MWt and 1.1 TJ/yr.

Romania

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	174
Annual output TJ	1 520
Annual capacity factor	

Romania's low-enthalpy geothermal potential lies mainly along the western border with Hungary and in the south-central part of the country. Usage of the country's springs has been known since Roman times but it was only during the 1960s that energy-directed exploration began and then as an unexpected result of a hydrocarbon research programme. To date more than 250 exploration wells have been drilled. Completion and experimental exploitation of more than 100 wells during the past 25 years has enabled the evaluation of the heat available from this resource. The geological research programme is continuing, with a few new wells drilled each year, all being usually completed as potential production or injection wells.

The transition to a market economy, together with the run-up to membership of the European Union, have certainly assisted with the development of geothermal energy in Romania but for the full potential of the resource to be realised, access to adequate funding and the latest technology is required.

Currently geothermal heat is used only for direct purposes – there is no use for electricity generation. The installed capacity of 174 MW_t is utilised for space and district heating, bathing and swimming (including balneology), greenhouse heating, industrial process heat, fish farming and animal husbandry.

Near and mid-term plans include drilling of new production and reinjection wells, expansion of existing district heating schemes and development of some new ones, expansion of greenhouse heating and development of health and recreational bathing facilities. There is an evaluated potential in Romania of 20 MW_e for power generation and thus research will be undertaken into the possible use of binary plants.

The main geothermal resources in the country are found in porous and permeable sandstones and siltstones (such as in the western plains), or in the fractured carbonate formations (such as at Oradea and Bors in the western part of the country).

The total capacity of the existing wells is about 480 MWt; however, only about 148 MWt from 80 wells are currently used. 35 of these wells are used for balneology and producing water at temperatures from 40 to 115oC. During the last five years seven geothermal wells have been drilled in the country with National financing, with some to depths of 1,500 to 3,000 m producing up to 90oC water.
There are two main companies in Romania currently exploiting geothermal resources: Transgex S.A. and Foradex S.A., have been given long term concession for practically all known geothermal reservoirs. Transgex, the most active company, is looking at developing district heating projects in a number of communities. The University of Oradea has established a Geothermal Research Center which provides geothermal training and research.

The current direct utilization in the country includes:

- 13.28 MWt and 164.83 TJ/yr for individual space heating;
- 58.95 MWt and 531.72 TJ/yr for district heating;
- 4.18 MWt and 20.78 TJ/yr for greenhouses (8 locations);
- 4.50 MWt and 9.70 TJ/yr for fish farming (one location);
- 1.40 MWt and 12.70 TJ/yr for agricultural drying;
- 0.75 MWt and 6.84 TJ/yr for industrial process heat (4 locations);
- 64.68 MWt and 489.16 TJ/yr for bathing and swimming;
- and an estimated 5.5 MWt and 29.70 TJ/yr for geothermal heat pumps.

Russian Federation

	Electricity generation
Installed capacity MWe	82
Annual output GWh	441
Annual capacity factor	
	Direct use
Installed capacity, MWt	308
Annual output TJ	6 144
Annual capacity factor	

The Russian Federation has a significant geothermal resource, with thermal waters of 50–200°C having been identified in numerous areas from Kaliningrad in the west to the Russian Far East. In the Kamchatka Peninsula and the Kuril Islands the thermal water reaches 300°C. It has been estimated that the high-temperature resources defined to date in the Peninsula could ultimately support generation of 2 000 MW_e. and 3 000 MW_t of heat for district heating. Exploration has shown that the discovered geothermal resource of Kamchatka could provide the peninsula's total demand for both heat and electricity for in excess of 100 years.

The country's energy sector has long been based on fossil fuels and the exploitation of hydroelectric and nuclear power. The contribution from geothermal energy represents a very small percentage. Considering the Federation's vast area and also the logistics of fuel transportation, the use of geothermal heat for power generation could be particularly important in the northern and eastern regions. However, the main thrust of Russian geothermal utilisation has been, and continues to be, for direct purposes.

The first plant using geothermal energy for power generation in Kamchatka was commissioned at Pauzhetka, south of Kamchatka in 1966. Four further plants were installed in 1999, 2002 and 2007 and by end-2008, total installed capacity stood at 81.9 MW_e. A 2.5 MW_e plant in Kamchatka and a 3.2 MW_e plant are currently under construction.

The use of geothermal heat for direct purposes is widespread and has mostly been developed in the Kuril-Kamchatka region, Dagestan and Krasnodar Krai. Many district heating and greenhouse heating schemes already exist, together with use of geothermal heat for industrial processes, cattle and fish farming, drying of agricultural products, and swimming pools and baths. There are plans for greater exploitation in Krasnodar Krai and the regions of Kaliningrad and Kamchatka.

There is much scope for the installation of heat pumps in Russia, but their use is presently at an early stage of development.

In January 2009 the Russian Prime Minister signed an Executive Directive for a greater use of renewable energy in order for the efficiency of the electric power sector to be improved. The targets for the share of renewable energy in electricity generation are 1.5% in 2010, 2.5% in 2015 and 4.5% by 2020. At the beginning of 2010 it was reported that a Ministerial MOU had been signed between Finland and Russia. The stated objective is that cooperation and shared knowledge will lead to greater energy efficiencies and improved utilisation of renewable energies.

Direct use of geothermal resources is mostly developed in the Kuril-Kamchatka region, Dagestan and Drasnodar Krai, mainly for district and greenhouse heating.

To date, 66 thermal water and steam-and hydrothermal fields have been exploited in Russia. Half of them are in operation providing approximately 1.5 million Gkal of heat annually (Povarov and Svalova, 2010). Approximately half of the extracted resource is used for space heating, a third for heating greenhouses, and about 13% for industrial processes. There are also approximately 150 health resorts and 40 factories bottling mineral water.

Heat pumps are at an early stage of development in Russia. An experimental facility was set up in early 1999 in the Philippovo settlement of the Yaroslavl district. Eight heat pumps are used for a 160-pupil school building. There are also some buildings using heat pumps in Moscow (Svalova, 2010).

A district heating project is being proposed for Vilyuchinsk City on Kamchatka (Nikolskiy et al., 2010).

Serbia

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	119
Annual output TJ	3 244
Annual capacity factor	

Exploration for geothermal resources in Serbia began in 1974: four provinces were discovered and preliminary drilling and pilot studies ensued. At the present time the main utilisation is at thermal spas for balneology and recreation. However, the 97 MW_t installed capacity is used for bathing and swimming, space heating, greenhouses, fish and other animal farming, industrial process heat and agricultural drying. In addition, about 22 MW_t of thermal water heat pumps are in use.

The most common use of geothermal energy in the country is for balneology and recreation. Archeological evidence indicates similar uses by the Romans in the locations of the present spas such as Vranjuska, Niska, Vrnjacka and Gamzigradska.

Today there are 59 thermal water spas in the country used for balneology, sports and recreation and as tourist centers. Thermal waters are also bottled by nine mineral water bottling companies. Space heating and electric power generation from geothermal energy is in the exploration stages. There are presently 25 wells in use within the Pannonian Basin, and with uses for heating greenhouses (4 wells), heating pig farms (3 wells), industrial process such as in leather and textile factories (2 wells), space heating (3 wells) and 13 wells for various uses in spas and for sport and recreation facilities. Outside the basin, geothermal water is used for space heating, greenhouse heating (raising flowers), a poultry farm, a textile workshop, a spa rehabilitation center and a hotel. Three other spas and rehabilitation centers also use geothermal heat, including heat pumps of 6 MWt, which uses water at 25oC, and in the carpet industry.
The various applications include:

- 20.9 MWt and 356 TJ/yr for space eating;
- 18.5 MWt and 128 TJ/yr for greenhouse heating;
- 6.4 MWt and 128 TJ/yr for fish and animal farming;
- 0.7 MWt and 10 TJ/yr for agricultural drying;
- 4.6 MWt and 58 TJ/yr for industrial process heating;
- 39.8 MWt and 647 TJ/yr for bathing and swimming;
- 9.9 MWt and 83 TJ/yr for geothermal heat pumps.

Slovakia

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	132
Annual output TJ	3 067
Annual capacity factor	

Slovakia's geothermal resources, first explored during the 1970s, have been located in areas covering 27% of the territory. The country has thermal waters ranging from low temperature (20–100°C) to medium temperature (100–150°C) to high temperature (>150°C). At the present time, utilisation is only for direct purposes: bathing and swimming, district heating, greenhouse heating and fish farming.

Several projects are under development: a greenhouse heating scheme in Podhajska; a district heating scheme in Galanta and a space heating project in Slovakia's second city, Košice. The Košice scheme is in the final stage of preparation, having obtained the necessary permits and awaits the go-ahead prior to implementation.

Geothermal direct-use is distributed in eight counties in the country with Nitra County (south-west of the center of the country) having the highest number of locations (19), and Trnava Country (western Slovakia) having the highest amount of thermal energy used. The smallest number of uses is in Kosice Country (eastern Slovakia) with five locations reported; however, this area has the highest potential for geothermal use in the country, including the generation of electricity.

Greenhouse heating is reported in 11 locations, two of which receive heat at the end of a cascaded system. Vegetables and cut flowers are the main products grown in these green-houses. There are 19 installation using geothermal energy for individual space heating and two locations for district heating. The main district heating system is for heating of blocks of flats and a hospital in Galanta.

There are 59 locations using geothermal water for swimming pools, both outside and inside. For some, the combined utilization (cascaded use) of the energy is for greenhouse heating, district heating and finally for bathing – in Topolniky and Podhajska. Two locations use geo-thermal energy for fish farming. There are also nine locations using geothermal heat pumps with a total of 16 units installed.

The various direct-uses include:

- 16.7 MWt and 381.1 TJ/yr for individual space heating;
- 10.8 MWt and 232.0 TJ/yr for district heating;
- 17.6 MWt and 461.1 TJ/yr for greenhouse heating;
- 11.9 MWt and 271.0 TJ/yr for fish farming;
- 73.6 MWt and 1,708.5 TJ/yr for bathing and swimming;
- 1.6 MWt and 13.5 TJ/yr for geothermal heat pumps.

Spain

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	120
Annual output TJ	
Annual capacity factor	

Research has shown that a low-enthalpy geothermal resource is widely distributed across the Spanish mainland. The main areas are in the northeast, southeast, northwest and the centre. In the Canary Islands, it has been found that a high-temperature resource exists on Tenerife (but is not commercially viable) and that Lanzarote and La Palma have an HDR resource.

To date the geothermal resource has not had a major role in the Spanish energy economy. However, at the end of 2007, geothermal gained a higher profile within the Institute for the Diversification and Saving of Energy (IDEA) with the creation of the Hydroelectric and Geo-thermal Department, which together with the Instituto Geológico y Minero de España (IGME), will promote the technology and utilisation of geothermal energy. At the end of 2008, the country became a member of the IEA Implementing Agreement for Cooperation in Geother-mal Research and Technology.

There is a limited amount of capacity installed for direct purposes: – some 6 MW_t utilised for individual space heating, greenhouse heating and swimming and bathing.

Geothermal resource exploration, assessment and evaluation started through Spain in the seventies with a general geological and geochemical survey of known thermal springs and areas showing signs of thermal activity.. Over the following decades, each of the selected areas has been investigated utilizing techniques from geology, geophysics, geochemistry and related disciplines, the intensity of the investigation depending on each area's geothermal potential. Lastly, deep drilling has been done, enabling the geothermal potential of the more important areas to be evaluated. These major areas are located in the southeast (Granada, Almería and Murcia), northeast (Barcelona, Gerona and Tarragona), northwest (Orense, Pontevedra and Lugo) and center (Madrid) of the Iberian Peninsula. Other, more minor areas located in Albacete, Lérida, León, Burgos and Mallorca have also been investigated.

The geothermal resources evaluated in all these cases exhibit low temperatures, 50–90 ºC. The only area where high-temperature fluids might possibly exist at depth lies in the volcanic archipelago of the Canary Islands. Hot dry rock resources have been evaluated on the islands of Lanzarote and La Palma. On the island of Tenerife, the presence of high-temperature areas has been investigated, but no commercially viable geothermal reservoirs have been found.

Low-temperature geothermal sites are currently being exploited on a small scale. For example, geothermal fluids are being used for heating and to provide hot water to spa buildings in Lugo, Arnedillo (in La Rioja), Fitero (in Navarra), Montbrió del Camp (in Tarragona), Archena (in Murcia) and Sierra Alhamilla (in Almería). In Orense and Lérida, geothermal waters are being used to heat homes and schools. Greenhouses are being geothermally heated at Montbrió del Camp (Tarragona), Cartagena and Mazarrón (in Murcia), and Zújar (in Granada); these facilities cover a total area of over 100,000 m2.

Sweden

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	4 460
Annual output TJ	45 301
Annual capacity factor	

Sweden's utilisation of deep geothermal heat is on a very limited scale. however, Lund, in the far south of Sweden, has two heat pumps totaling about 47 MW_t providing base-load heat to a district heating network. The plant was connected to the network in 1984 and started heat production in 1985.

There are many small ground-source heat pumps installed in the country. It is reported that more than 350 000 small heat pumps have been installed in residential and official buildings, providing an estimated 10% of heat demand.

The Swedish Deep Drilling Program began in 2007. The purpose of the Program is to 'study fundamental problems of the dynamic Earth system, its natural history and evolution'. In 2009 a grant was awarded for a mobile truck-mounted drillrig that is capable of reaching a depth of 2 500 m. Supported by the International Scientific Drilling Program, drilling is planned to begin in 2011.

The majority of the heat pumps are small and typically used in single houses. There are currently around 230,000 installations with about 25,000 units installed annually. Bed- rock-soil-water is the most common source for heat pumps using geothermal energy with about 12 TWh of energy extracts or about 15% of the national heat demand covered. A number of systems used underground thermal energy storage UTES), either as aquifer thermal energy storage (ATES) orborehole thermal energy storage (BTES). The former was implemented in the mid 1980s and current there are approximately 100 plants using this system, mainly large scale with average capacity of 2.5 MWt.
Water wells are used and serve a dual function, both as production and injections wells, with the flow direction being reversed from summer to winter. The BTES systems consist of a number of closed spaced boreholes, normally 50 to 200 m deep. These are equipped with borehole heat exchanger, with the holes filled with ground water and not grouted. It has been shown that water filled boreholes are more efficient than grouted ones. These are typically used for combined heat and cooling of commercial and institutional buildings. The reported total for UTES is 90 MWt and 504 TJ/yr for heatings and 90 MWt and 612 TJ/yr for cooling.

Switzerland

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	1060
Annual output TJ	8799
Annual capacity factor	

Switzerland's installed geothermal capacity has grown rapidly in recent years and the country now ranks among the world leaders in direct-use applications (there is no geothermal-based electricity at the present time). There are two main components to Switzerland's geothermal energy: the utilisation of shallow resources by the use of horizontal coils, borehole heat exchangers (BHE), foundation piles and groundwater wells, and the utilisation of deep resources by the use of deep BHEs, aquifers by singlet or doublet systems, and tunnel waters. In virtually all instances heat pumps are the key components.

There remains substantial room for growth in Switzerland's geothermal sector. The annual growth-rate for heat pumps is estimated at 15% and the Government is actively supporting research and development into geothermal energy.

The use of geothermal energy for direct-use has increased substantially, mainly with the installations of geothermal heat pumps (GHP). GHP have increased at rates up to 17% per year, with borehole heat exchangers-coupled systems dominating.

The second largest use of geothermal energy is with thermal spas and wellness facilities. The proportion of the various uses in terms of energy use (GWh) is 73.9% for HE and horizontal loops, 13.6% for balneology, 10.4% using shallow groundwater, 1.0% using geostructures (energy piles), 0.6% using deep aquifers which includes using tunnel water. With about one GHP installed on the average every square km, this is the highest concentration in the world.

Tanzania

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	
Annual output TJ	
Annual capacity factor	

Preliminary studies conducted in different parts of Tanzania by surface geological exploration, magnetic and gravity data analyses and reconnaissance exploration have indicated that the country possesses high-temperature (exceeding 200°C) fluids beneath the volcanoes.

Hot springs have provided a positive indication of the country's geothermal potential. Fifty hot springs have been sampled, with the majority having a surface temperature of 86°C and a reservoir temperature of 220–276°C.

Presently the country's geothermal resource is not utilised. However, and especially in the light of the growing energy demand, the National Energy Policy drafted in 2003 showed the need to assess the potential and establish its viability.

Estimates indicate that the geothermal potential of Tanzania is as high as 650 MW. Based on first assessment, the potential was adjusted to be in the order of 140 to 380 MW. This value is based on the natural heat discharge from hot springs. Provided that geothermal reservoirs exist, the potential could be even higher.

There are at least 15 hot springs in Tanzania with water temperatures above 40°C. They have been found in three regions:

Thailand

	Electricity generation
Installed capacity MWe	0.3
Annual output GWh	2
Annual capacity factor	
	Direct use
Installed capacity, MWt	3
Annual output TJ	79
Annual capacity factor	

Investigations of geothermal features in Thailand began in 1946 and subsequently more than 90 hot springs located throughout the country were mapped. However, it was not until 1979 that systematic studies of the resources began.

A small (0.3 MW_e) binary-cycle power plant was installed at Fang, in the far north near the border with Myanmar. Since commissioning in December 1989, this sole Thai geothermal plant has operated successfully, with an 85–90% availability factor. In addition, the Electricity Generating Authority of Thailand (EGAT) is using the 80°C exhaust from the power plant to demonstrate direct heat uses to the local population. The exhaust can be used for crop drying and air conditioning (the latter not currently in use). A further example of utilising the heat directly is a public bathing pond and sauna that have been constructed by the Mae Fang National Park.

Based on communications from Praserdvigai (2005), an estimate of 2.54 MWt and 79.1 TJ/yr are currently installed and being utilized at a 0.3 MWe binary plant at Fang in Chiang-Mai province. A small crop-drying facility and air-conditioning unit are utilizing the exhaust from the power plant.

Turkey

	Electricity generation
Installed capacity Mwe	114
Annual output GWh	617
Annual capacity factor	
	Direct use
Installed capacity, MWt	2 084
Annual output TJ	36 886
Annual capacity factor	

A significant factor in Turkey's high geothermal potential is the fact that the country lies in the Alpine-Himalayan orogenic belt. It has been determined that Western Anatolia, containing the areas of most significance, accounts for about 78% of the 31.5 GW potential.

Geothermal exploration began during the 1960s, since when about 186 fields have been identified. Although some of these are high-enthalpy fields, 95% are low-medium enthalpy resources and thus more suited for direct-use applications.

Turkey has extensive geothermal resources, that have been utilized for heating of residences, district heating, greenhouse heating and for spas.

There are a total of 260 spas in the country using geothermal water for balneological purposes. There is also a liguid carbon dioxide and dry ice production factory integrated with a power plant at Kizildere.

Greenhouse heating has increased substantially in the last three years, with installations in six major areas covering 230 ha.

Tourism is also an important industry with over 12 million local and 10,000 foreign visitors benefiting from the balneological aspects of hot springs and spas.

Uganda

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	
Annual output TJ	
Annual capacity factor	

Uganda's power sector relies heavily on indigenous hydroelectricity. The country is particularly well-endowed with a hydro resource but large losses due to long transmission lines, together with the possible effects of climate change on the supply of water, has ensured that the Government recognises the importance of diversification.

Research has established that three areas in particular, lying in the west of the country near the border with the Democratic Republic of Congo, have considerable geothermal potential. Assessments have shown that the three prospects, Katwe-Kikorongo, Buranga and Kibiro have an estimated potential of 450 MW and if the temperatures of 140–200^{o}C, 120–150^{o}C and 200–220^{o}C respectively are confirmed, then production or electricity and direct use in industry and agriculture could follow. Further investigative work is to be undertaken on these known prospects and in other areas of the country.

The area, which was formerly mined for lead and fluorspar, is known to possess a source of geothermally-heated water (46^{o}C at a depth of 1 000 m). The Weardale Task Force's Master Plan for the eco-friendly village envisages that the heat will be utilised for a public hot-springs spa and fish-breeding ponds. Additionally, the development will include environmentally-friendly commercial and residential property and a range of tourist and leisure activities based on the use of biomass (for a district heating scheme), wind, solar and hydro technologies.

The famous hot springs at Bath have long been a tourist attraction among the Roman architecture of the ancient city. Now the baths, together with four adjacent buildings, have undergone a major refurbishment, and have been reopened in 2008 and are now fully operational.

The ongoing increase in geothermal heat pumps is estimated to be in the range of 3,000 to 5,000 installations per year. A few of these installations are large scale open loop systems (~500 kW to 2 MWt), the majority are closed loop systems in the range of 3.5 kW heating only, with approximately 750 units at commercial/institutional sites and 4,500 units at residential sites with full load operating hours per years of 1,500 and 1,800 respectively. The main driver for the geothermal heat pumps activity in UK has been the understanding that if connected to the UK grid they can offer significant reductions in overall carbon emissions compared to traditional methods of heat delivery.

United Kingdom

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	187
Annual output TJ	850
Annual capacity factor	

There is no recorded high-temperature resource in the UK and although the country possesses a low- and medium-enthalpy resource it is, unlike some of its European neighbours, very under-utilised.

Historically there has been no direct Government support for geothermal energy and the only application of low-enthalpy geothermal energy is the scheme, launched in 1986 in the city of Southampton. The scheme now supplies more than 40 GWh/yr of heat, 26 GWh of electricity from the combined heat and power plant and over 7 GWh of chilled water for air conditioning.

The Government has announced that it will provide GBP 6 million for exploration of the potential for deep geothermal power in the UK. Past research has shown the southwest region of England to be an area particularly rich in this resource.

The area, which was formerly mined for lead and fluorspar, is known to possess a source of geothermally-heated water (46^{o}C at a depth of 1 000 m). The Weardale Task Force's Master Plan for the eco-friendly village envisages that the heat will be utilised for a public hot-springs

The famous hot springs at Bath have long been a tourist attraction among the Roman architecture of the ancient city. Now the baths, together with four adjacent buildings, have undergone a major refurbishment, and have been reopened in 2008 and are now fully operational.

The ongoing increase in geothermal heat pumps is estimated to be in the range of 3,000 to 5,000 installations per year. A few of these installations are large scale open loop systems (~500 kW to 2 MWt), the majority are closed loop systems in the range of 3.5 kW heating only, with approximately 750 units at commercial/institutional sites and 4,500 units at residential sites with full load operating hours per years of 1,500 and 1,800 respectively. The main driver for the geothermal heat pumps activity in UK has been the understanding that if connected to the UK grid they can offer significant reductions in overall carbon emissions compared to traditional methods of heat delivery.

United States of America

	Electricity generation
Installed capacity MWe	3102
Annual output GWh	15 009
Annual capacity factor	
	Direct use
Installed capacity, MWt	12 612
Annual output TJ	56 551
Annual capacity factor	

The USA possesses a huge geothermal resource, located largely in the western half of the country. Research has shown that geothermal energy has been used in North America for many thousands of years but the first documented commercial use was in 1830 in Arkansas. In 1922 an experimental plant began generating electricity in California but, proving to be uneconomic, it soon fell into disuse. Another 38 years were to pass before the first large-scale power plant began operations at The Geysers, north of San Francisco, California. The USA is the world's largest producer of electricity generated from geothermal energy.

Nine States use their geothermal resource for electricity. California accounts for the majority share at 83%. Nevada follows with 14% and at the other end of the spectrum, New Mexico, Oregon and Wyoming each have less than 0.01%.

The DOE states that an additional capacity totaling 80 MW_e is under construction and a further 234 MW_e is planned. Geothermal systems, with a potential capacity of 9 057 MW_e have been identified in 13 western States, approximately 5 800 MW_e more than that currently operating. Based on Geographic Information Systems statistical models, the mean estimated undiscovered resources in the 13 States is more than 30 GW_e.

The DOE's Geothermal Technologies Program is focused on Enhanced Geothermal Systems (EGS) technology, with activities ranging from site selection for future development to site characterisation, reservoir creation and validation, interwell connectivity, reservoir scale-up and reservoir sustainability. On the assumption that this technology is successfully implemented, models yield an estimated mean electric power resource on private and accessible public land of 517 800 MW_e in the 13 States. Development of an EGS R&D demonstration project at Desert Peak, Nevada is under way.

Geothermal heat suitable for direct utilisation is far more widespread, ranging from New York State in the east to Alaska in the west. Bathing and swimming (113 MW_t), district heating (75 MW_t), space heating (140 MW_t), agricultural drying (22 MW_t), industrial process heat (17 MW_t), snow melting (3 MW_t) and air conditioning (2 MW_t) are the main users of geothermal heat.

Most of the direct use applications have remained fairly constant over the past five years; however, geothermal heat pumps have increased significantly. A total of 20 new projects have come on-line in the past five years and a number of projects have closed.

Agricultural drying has decreased the most due to the closing of the onion/garlic dehydration plant at Empire, Nevada. Two district heating projects have also shut down; the Litchfield Correctional Facility in California and the New Mexico State University system.

There has been a slight increase in snow melting, cooling and fish farming, with a major increase in industrial process heating due to two biodiesel plants (Oregon and Nevada), a brewery (Oregon), and a laundry (California) coming on line.

On present estimates, there are at least one million units installed, mainly in the Midwestern and eastern states. Approximately 90% of the units are closed loop (ground-coupled) and the remaining open loop (water-source). It is presently a US$2 to US$3 billion annual industry in the country.

Vietnam

	Electricity generation
Installed capacity MWe	
Annual output GWh	
Annual capacity factor	
	Direct use
Installed capacity, MWt	
Annual output TJ	
Annual capacity factor	

The government-supported exploration and evaluation of the country's geothermal resource has shown that there is a total of 269 prospects of which 30 sites, with a capacity of 340 MW_e have been identified as being capable of power generation. The south-central, north-western and northern regions are the areas of Vietnam with the greatest potential. At the present time there is no geothermal power generation. Direct utilisation is limited to the provision of industrial process heat (iodide salt production) and bathing and swimming. The theoretical capacity of direct use has been estimated at 472 MW_t, of which 200 MW_t could be in operation by 2020.

Presently, there are more than 200 sources of hot water at temperatures of 40–100 degrees centigrade in Vietnam. Thermal reserves in the Red River Delta alone can be utilized to generate 1.16 % of the country's total electricity production output.