Geothermal energy is not a new type of energy. It is the third most important renewable energy source after hydroelectric and biomass, and has been used industrially in some parts of the world for more than a century. It has attracted increased interest in recent years, and has become a serious rival of solar energy.

GEOTHERMAL MODESTY

Enormous quantities of heat are stored in the depths of our planet, originating from the natural radioactivity of rocks in the earth's crust from the disintegration of radioactive elements such as uranium and thorium.

The temperature of more than 99% of the earth's mass is higher than 1,000°C, while only 0.1% of this mass (essentially the earth's crust) is at a temperature of less than 100°C.

The flow of heat that reaches the surface of the globe is significant. To give an image, it equals a radiator of approximately 40 million MWe, or 30,000 standard nuclear units! The comparison is impressive, but it is important to realize that this flow of energy is very widely distributed and is too weak to be felt directly.

We cannot use the geothermal flow in itself, but we can use heat accumulated in some underground structures – usually ground water. This heat flow occasionally bursts out spectacularly on the earth's surface in geysers, for example in Iceland, New Zealand and Yellowstone (United States).

TRUE OR FALSE

The geothermal heat stream equals the heat from the sun's rays.

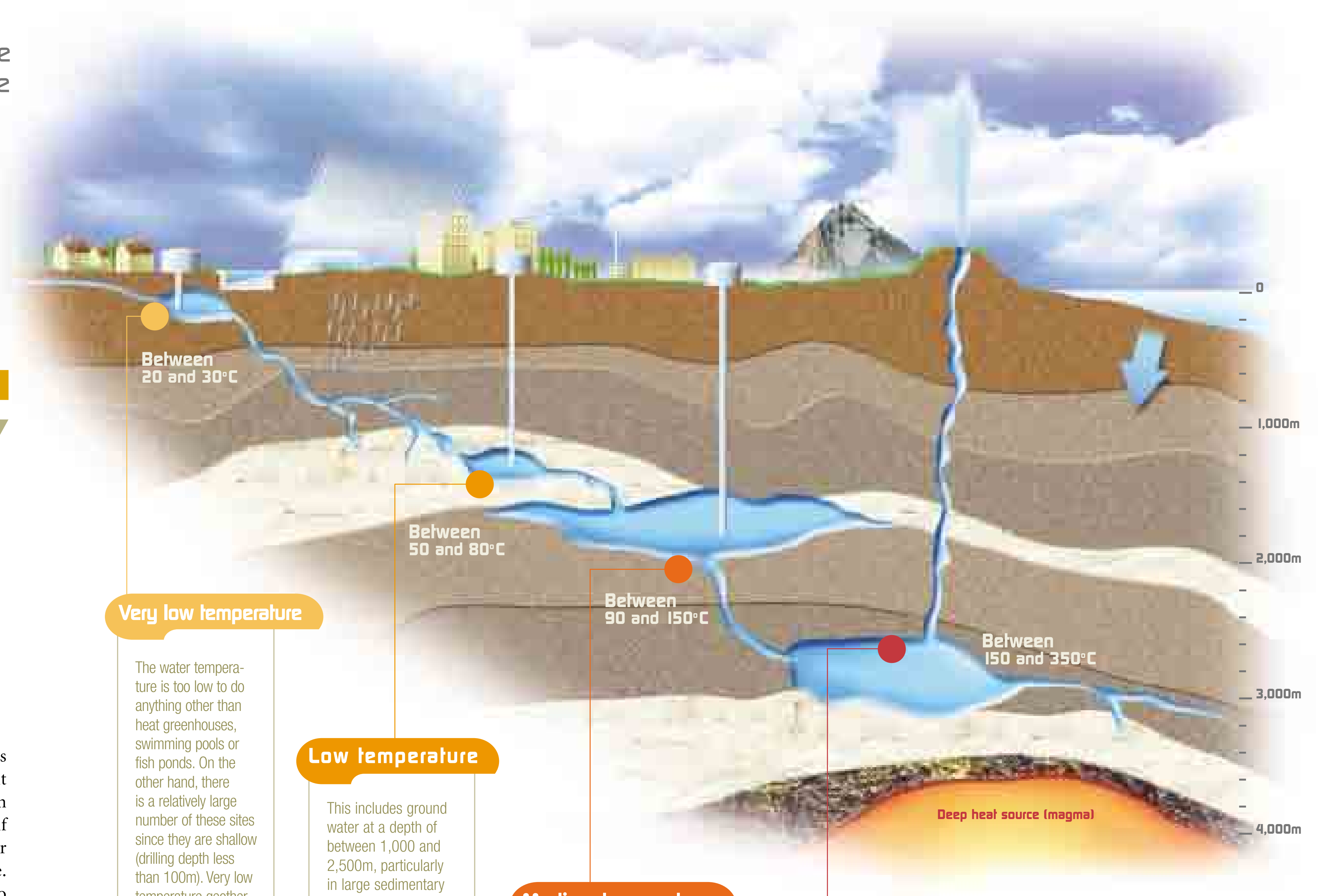
FALSE

On average, 0.06 Watts per m^2 of heat is generated in the heart of the earth, which is 23,000 times less than the sun's direct rays! However, the heat in some aquifers is sufficient for use.

Using the heat of the earth

The purpose of a geothermal facility is to extract this energy stored in the heart of the earth, and to use it for heating or to produce electricity from the steam generated. However, this heat can only be extracted if underground geological formations are permeable or cracked, so that hot water can rise to the surface. In some cases, rock discontinuities enable hot water to surge through cracks at tens of thousands of liters per hour in a thermal spring. There are many sites of this type in France, particularly in Chaudes-Aiges, Southern Auvergne (in the Cantal Department), where water surges out at 82°C. It is the hottest spring in Europe.

Clearly, the difficulties in harnessing geothermal heat vary depending on the geological context and depth. Some regions are more favorable than others, and it is no exaggeration to say that there are deposits of geothermal energy in the same way as there are oil deposits. Hot water can be found almost everywhere, provided that we drill far enough. But it is obviously better to search for the best sites, where hot water is



Very low temperature

The water temperature is too low to do anything other than heat greenhouses, swimming pools or fish ponds. On the other hand, there is a relatively large number of these sites since they are shallow (drilling depth less than 100m). Very low temperature geothermal calories are attractive for the use of heat pumps, a system that is now very popular in Western countries.

Low temperature

This includes ground water at a depth of between 1,000 and 2,500m, particularly in large sedimentary basins, and is suitable for urban heating. This use is cost effective starting from 2,000 houses. In France, the most favorable regions are the Paris Basin (the largest geothermal basin in Europe), the Aquitaine Basin and the Rhone Valley.

Medium temperature

These deposits are frequently located in sedimentary basins at depths of between 2,000 and 4,000m. In France, there are medium temperature deposits in the Alsace Plain and in Auvergne (Limagne). A temperature of 100°C is sufficient to produce electricity under some conditions.

High temperature

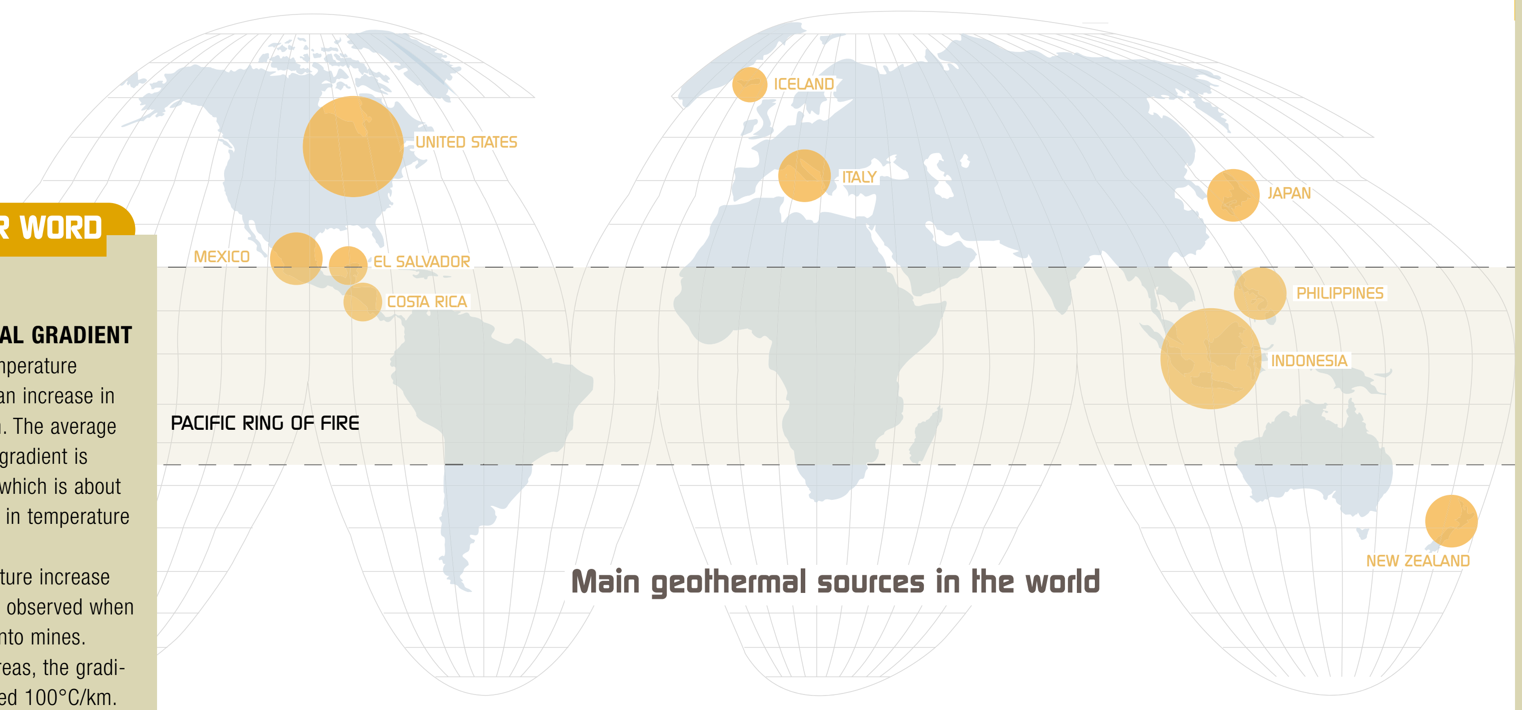
Steam from high temperature deposits can be used to generate electricity. Steam deposits are found at depths varying from 1,500 to 3,000m in volcanic areas in which the temperature increases quickly with the depth. The largest power stations are at "The Geysers" (1,000MWe, about 100km north of San Francisco), Larderello (40MWe) and Monte Amiata in Tuscany, Italy, and in Wairakei (150MWe) and Broadlands (New Zealand). There are a few other power stations in different places around the world, and particularly in Iceland, Mexico and Japan. France has a power station at the Bouillante site in Guadeloupe, but it is only a low power site (5MWe, to generate 22GWh/year); a 15MWe extension is under construction.

WORD FOR WORD

GEOTHERMAL GRADIENT
Recorded temperature increase for an increase in depth of 1km. The average value of this gradient is about 33°C, which is about 1°C increase in temperature every 30m.
This temperature increase can easily be observed when going down into mines.
In volcanic areas, the gradient can exceed 100°C/km.

GEOTHERMAL COUPLE
Assembly composed of a "rising" main well (through which ground water is pumped up) and a "descending" well at a distance from the main well through which water is reinjected. These couples are necessary when the geothermal hot water is not pure, to transfer heat from geothermal water to water in a secondary heating circuit without any mixing between the two circuits. Another advantage of the couple technique is that it maintains the pressure in the deposit, thus avoiding settlement of geological layers.

HEAT PUMP
Technique used when the temperature is too low for direct use in heating. Principle: heat is transferred to a fluid with a low boiling point (for example ammonia) that acts as an intermediary. It warms up, and transfers its heat to a water circuit.



Main geothermal sources in the world

close to the surface. Steam or this water can then be used in geothermal power stations to generate electricity or supply a heating network for buildings.

Unequal distribution throughout the world

Uses depend on the temperature and the depth of deposits. If the water reservoir is in a zone with a medium gradient (see "Word for word"), this water can be used for heating. It is called low temperature geothermal. But the water temperature can exceed 150°C, or even reach 350°C, if the reservoir is in a zone with a high gradient close to some volcanoes. This high temperature geothermy is the only means of generating electricity. A clear distinction needs to be made between these two applications (heat and electricity), which account for 45 and 55% respectively of geothermal energy harnessed around the world. There are about 350 "high temperature" geothermal facilities in the world. They are distributed in 18 different countries and their total power is almost 10GWe, after almost doubling during the last ten years (from 5,836MWe to 7,974MWe during the 1990s). However, note that three quarters of the world generation of geothermal electricity is installed in only four countries (United States, Philippines, Mexico and Italy). In other words, different countries are far from being equally endowed with this form of energy. Apart from Italy and Iceland, most sites are located on the famous Pacific "Ring of Fire", the most active volcanic area in the world. Thus, a large proportion of Nicaragua's electrical capacity is generated from geothermal energy. But the most spectacular increase has been in the Philippines, where the accumulated power is now more than 5,000MWe (6.2TWh generated annually), equal to 19% of national consumption; and their objective is to reach 50% in 2005! New projects are under way to achieve this, particularly on the Luzon and Leyte islands. Other islands in the archipelago must be connected to the network through submarine cables.

Geothermal heating in France

Geothermy is used in France for heating and cooling. But all the projects are pilot projects, and France is considered a pioneer in Europe. The only European country that makes greater use of geothermal energy is Iceland, where the capital, Reykjavik, is 82% heated by geothermal.
The contribution of geothermy to French energy production is far greater than solar and wind generated energy, and production is now at 200,000 tons of oil equivalent per year. Geothermy accounts for 10% of the energy supplied through urban heat generation networks and 0.4% of the global energy consumption. Geothermy in France increased dramatically between 1980 and 1985, after the first project that was built in 1969. It supplied heating for 3,000 dwellings in a district of Melun (large town in the Seine-et-Marne department) from a water table at 30°C.

GEOTHERMY
Etymologically: from ancient Greek "Geo" (the Earth) and "therme" (Heat). Geothermy is heat from deep in the earth.

EXPERT OPINION

Prospecting and drilling The difficulties

It is not enough to drill a well anywhere and hope to find a layer of hot water. Sedimentary basins are the best areas, but precise prospecting is necessary even within these areas. Considering the high cost of wells, it is important not to get it wrong, or at least to make the fewest possible mistakes.

Alternatives: How do you choose the site for a geothermal well?
Alain Desplan: There are two main difficulties in drilling a geothermal well; the first is to find the best site within the chosen area, and the second is to prevent corrosion of the tubing. For the first point, maps are available to help choose the optimum location for a well, using the geothermal inventory made by the BRGM at the beginning of the 1980s. These maps were produced from oil prospecting data in sedimentary basins. If we drill far enough, we will find either oil or hot water. A failure for oil companies is a success for us! Like oil, geothermal water does not exist in a "reservoir" in a free state. It impregnates sand or friable rock and the fluid is driven to the surface under the effect of pressure, by drilling to expose the layer to the open air.
Therefore, any geothermal operation must be preceded by exploration for a site. Note that a second inventory was made in the early 1990s at the request of EDF (Electricité de France), this time concentrating on surface geothermy (about 100m deep), as part of a program to install heat pumps. All these maps will be updated starting this year, with the assistance of the ADEME (French Agency for the Environment and Energy Control) and will be more easily accessible using new computer and communication storage technologies.

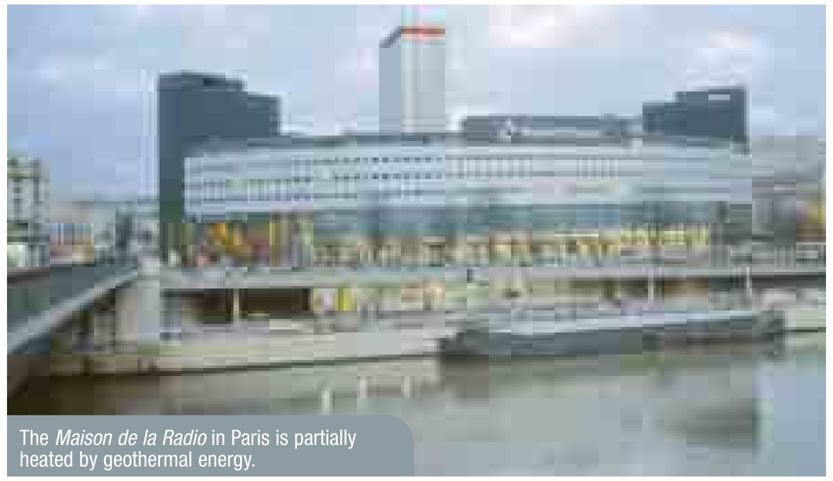
> "If we drill far enough, we will find either oil or hot water."


Alain Desplan, engineer at the BRGM

ZOOM
BRGM
Bureau de Recherches Géologiques et Minières (Geological Mining Research Bureau)
The BRGM is represented in more than 40 different countries, and works on behalf of governments, government-owned companies, industries and international finance organizations. It is involved in all aspects of earth sciences and its activities include studies, institutional support, engineering assistance, training and technology transfer programs.

How do you fight corrosion?
Corrosion was a very serious problem with early projects, but the problem is now perfectly controlled by injecting a chemical that prevents the development of bacteria that create corrosive sulfites. It is an in-depth treatment that needs to be carried out continuously. Provided that the treatment is not interrupted, tubes will not be corroded from the inside and can be used for at least 30 years. All that is necessary is to clean them, like a chimney needs cleaning regularly.

Greenhouse heated by geothermal energy.



The *Maison de la Radio* in Paris is partially heated by geothermal energy.

> WE ARE SITTING ON TOP OF AN ALMOST LIMITLESS STOCK OF ENERGY. ALL WE HAVE TO DO IS TO FIND A WAY TO USE IT."

ADVANTAGES OF GEOTHERMAL ENERGY

- It is a reliable energy and stable with time since it does not depend on atmospheric or climatic conditions.
- It respects the environment, and has little or no effect on it. It generates almost no polluting substances, very little carbon dioxide and only a small quantity of hydrogen sulfide (HS). Most of these products are reinjected into the groundwater and not into the environment.
- Geothermal wells have a very limited visual impact. Once a well has been drilled it is completely invisible, since the wellhead is buried. One was even built in a schoolyard.

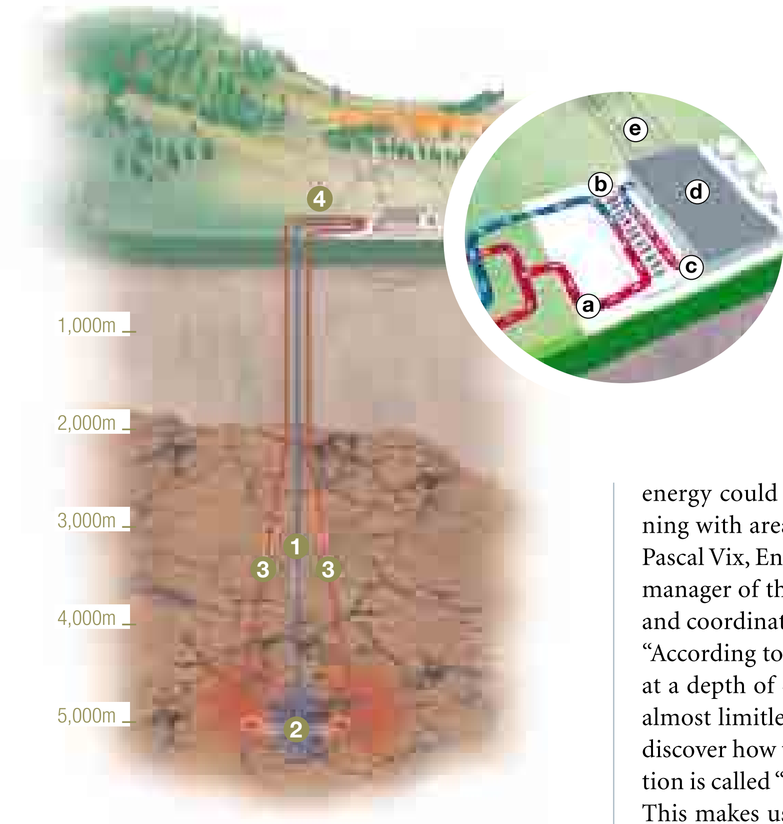
Other large geothermal facilities then flourished in the Paris region, with ground water at a higher temperature (between 70 and 85°C). No fewer than 74 drillings were made in 1986, including 54 in the Paris Basin, 15 in the Aquitaine Basin and 5 in other regions. At the moment, 34 couples (see "Word for word") are still in operation in the Paris region, supplying an energy equivalent to more than 90,000 TOE (tons of oil equivalent), or 10% of the energy distributed in heating networks in the Paris region, sufficient to heat 150,000 homes. One large French project is the *Maison de la Radio* in Paris. This building comprises 100,000m^2 of offices and studios that have partially been heated by water at 27°C drawn from a depth of slightly less than 600 meters, ever since 1963. This water is then disposed off in the city sewers, after being cooled to 7°C. It is estimated that there are 6 MTOE per year of usable "geothermal reserves" in France, but the energy drawn from existing facilities in the year 2000 was no more than 0.117 MTOE, which is only 2% of the country's potential. In other words, there is room for a great deal of expansion in this sector. However so far, geothermal heat has only been used in locations in which hot water was found, which is a severe limitation. If we want to develop geothermal energy in the future, we need to find ways to increase the number of attractive areas.

MTOE
1 MTOE is equal to a 1,000,000 TOE. One ton of oil equivalent (TOE) is the quantity of energy obtained by burning one metric ton of oil.

The hot dry rocks technique

Specialists are expecting a great deal from the new "hot dry rocks" technique. Its advantage is that it can use heat from rocks without the presence of a hot aquifer. The method consists of fracturing rocks between two boreholes and pumping in cold water from the surface, to heat it as it comes into contact with deep rocks. The largest full-scale experiment carried out in the world so far is at Soultz-sous-Forêts in Northern Alsace, which was built in 1987 (there is one equivalent Swiss project under way close to Basel, and another in El Salvador). Water is pumped through an injection well into the network of granite fractures at a depth of 3,600m, and recovered through a second well 450m from the first well with zero losses after being heated at 142°C.
The results of the Soultz experiment are so good that an industrial consortium has been created composed of EDF (Electricité de France), EDS (Electricité de Strasbourg), the electricity generating companies Pfalzwerke (Germany) and Enel Green Power (Italy), and Shell International (Netherlands). The German company Bestec is responsible for management. The research stage is now complete. The French and German authorities that financed the project have begun the industrial electricity production phase by giving the green light to drill the wells for a first power station with a power of 6MWe, sufficient for the consumption of a town with 25,000 inhabitants. This industrial prototype should be commissioned by 2006 at an estimated cost of 44 million euros. Eighty percent of this amount will be provided by French, German and European public financing for the first phase. In France, other sites with a calorific potential of more than 180°C at a depth of 5,000m have been identified in the Languedoc-Roussillon region and in the Massif Central. Similar energy reserves have also been identified in the Balkans and in Turkey.

THE SOULTZ-SOUS-FORÊTS PILOT SITE (ALSACE, FRANCE)



4 On the surface, the hot water in the primary circuit (a) passes through a heat exchanger (b) and is transformed to steam in the secondary circuit (c) to drive a turbine (d) that generates electricity (e).

1 Cold water injected at a depth of 5,000m through the central well.

2 Water circulates in the rock fractures and is heated in contact with the hot rock (200°C).

3 Heated water extracted from the ground through two production wells.

A high potential for development

The worldwide geothermal potential available using this "hot dry rocks" technique is large and is estimated at 15 million TOE per km^2, to a depth of 10 km. The Soultz experiment suggests that this new type of geothermal energy could be developed starting from 2030, beginning with areas with a high geothermal gradient. Pascal Vix, Engineer at Electricité de Strasbourg and co-manager of the European Joint Venture that supervised and coordinated the Soultz project, is firmly optimistic. "According to expert estimates, the Earth's temperature at a depth of 40km is 1,000°C. Therefore we live on an almost limitless stock of energy. All we need to do is to discover how to harness it". Another expanding application is called "surface geothermy", and uses heat pumps. This makes use of the least visible fraction of geothermal energy, and can be used to heat or air condition small buildings. These heat pumps open up new possibilities, and are feasible almost anywhere. The technique consists of drilling a pair of wells to a depth of about 150m, so that a heat exchanger composed of polyethylene tubes can be inserted. The fluid that circulates in these tubes collects heat from the rock to supply a heat pump on the surface. This system has been widely developed in Switzerland, where there are not less than 60,000 installations that now generate 440GWh. There are 40,000 in Germany and Austria, 300,000 in Sweden and the United States is planning to build 400,000! The next objective is to evaluate the political intentions of other countries in this respect, at a time when the trend is toward an "energy mix", and to increase the percentage of renewable energies in the world energy bank. The Franco-German experiment carried out in Alsace is opening up new prospects for geothermal energy, which had been expected to remain restricted to very local areas considering the geophysical conditions necessary for the production of electricity (use at high temperature). However, we will have to wait until the pilot plant is commissioned before we can make a good evaluation of the possibilities of worldwide construction of this new technology, and particularly the economic conditions for this type of use. ■

DISADVANTAGES OF GEOTHERMAL ENERGY

- Geothermal water is often saline, with a very high content of mineral salts – up to 100g/l, which is three times more than seawater! It can only be used through a heat exchanger, in other words a device through which it transfers its heat to a parallel heating circuit containing fresh water. The two liquids never come into contact resulting in a loss of efficiency.
- Geothermal water is almost always corrosive. This corrosion (due to salt, but sometimes also bacteria) increases maintenance costs.
- There is a risk of pollution when the extracted water contains heavy metals. This water has to be reinjected into the ground water.
- Although the extracted energy is free, investment and maintenance costs are very high.
- Depletion of the resource is possible. Underground hot water stocks are considered renewable since they are continuously heated by the internal heat in the earth, but the rate of use must not exceed the rate of renewal.
- The use of geothermal energy remains limited to very specific regions, particularly close to volcanic areas.