EUSUSTEL

European Sustainable Electricity
Comprehensive Analysis of Future European Demand and
Generation of European Electricity and its Security of Supply

WP3:
Electricity generation technology and integration system

Geothermal conversion

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1. Introduction: European situation

A huge quantity of heat is present inside the earth and large temperatures exist. Its origin is partly from the primitive energy of the earth formation and from the nuclear disintegration of natural radioactive nuclei (^{238}U, ^{235}U, ^{232}Th and ^{40}K). At the human time scale, this energy may be considered as renewable although, in some situations, one can exhaust the quantity of heat contained in given region.

In this study, only the power generation will be developed (see graph below)

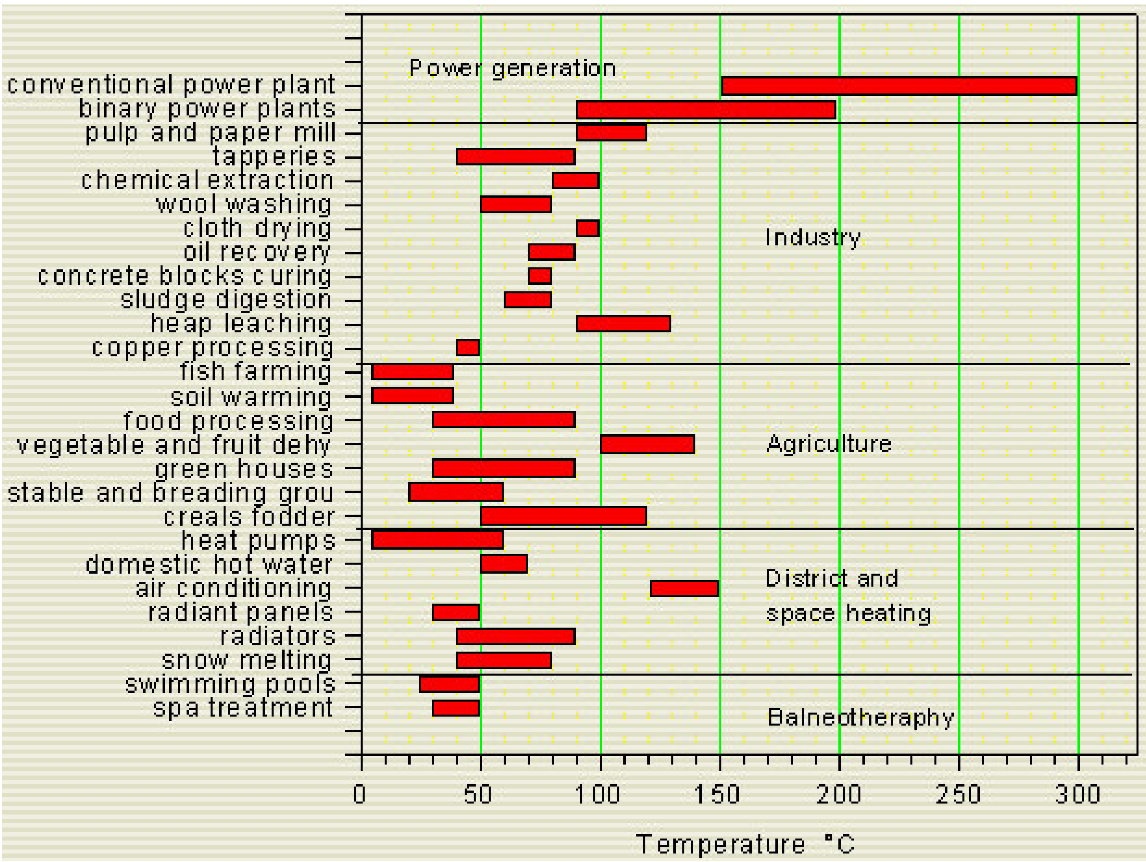


Figure 1: Lindal diagram

Geothermal electricity is exploited by relatively few countries in the European Union. These countries have geologically active areas. Only 5 countries possess the natural resources with a quality able to produce electricity.

By the end of 2003, the installed capacity in the European Union for electricity production was 883 MW_e. More than 98% of this installed capacity is in a single country, Italy (862 MWe), which is the principal European stock. Italy has, however, closed some of its oldest wells, and its installed capacity has decreased. The other countries involved in geothermal origin electrical production are Portugal with 16 MW_e, France with 15 MW_e (in Guadeloupe), and to a lesser extend in Austria (1,25 MW_e and Germany (0,23 MW_e). The production associated to this capacity was 5,152.2 GWh in 2003. This figure shows an increase of 7.2% compared to 2002.

Unlike the other renewable energy sectors, 2010 objectives of the White Paper of the European Commission should be met as far as geothermal electricity production is concerned.

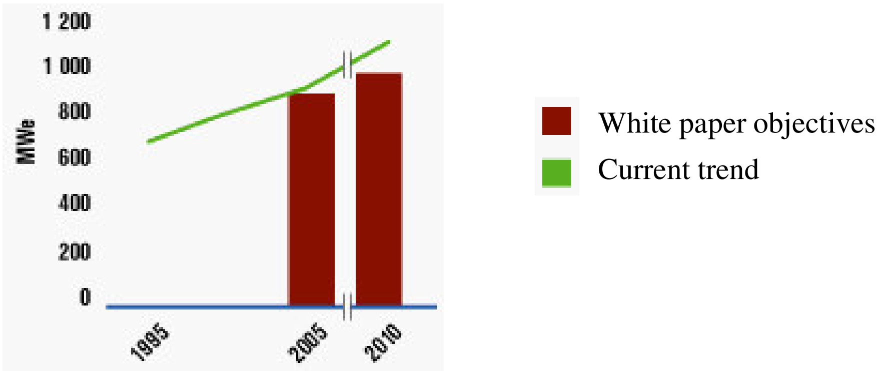


Figure 2 : European geothermal production of electricity current trend and White Paper objectives (in MWe), Eurobserv'ER

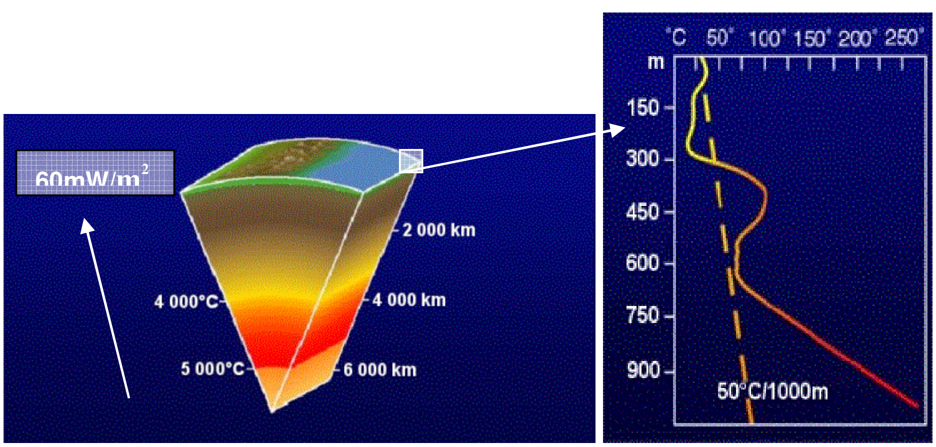
No target was set for the sector in the scope of the Campaign for Take-Off. The European Union has just an objective concerning the electricity production sector.

Future efforts announced by committed countries should make it possible to reach the targeted threshold of 1 000 MW. In that respect, Italy plans to have a total capacity of 950 MW_e by the year 2010. Portugal and France are respectively targeting 45 MW_e and 21 MW_e, respectively, at the same date. These efforts, added to the new small-size binary power plants that could be developed for example in Austria, should bring the European total capacity up to around 1 010 MWe. Moreover, a 250 MW power plant project is currently under construction in Germany.

1.1. Principle of geothermic electricity production

More than 99% of the planet has a temperature larger than 200°C. The aim is to capture the energy contained in the 5 first kilometers of the earth's crust. The graph below shows the global evolution as a function of the depth. The second graph represents the temperature variation close to a geothermal source. If the temperature is high enough, heat can be transformed in electricity, or directly used.

The most important advantage of geothermal energy is that it ensures a continuous production: the availability is about 90% all over the year, and the generated power is independent of climatic conditions (geothermal plants can operate 24 hours-a-day).



Earth temperatures repartition, BRGM

In a geothermal stock, 95% of thermal energy is stored in the rocks; only 5% is in fluids (water or steam). There is one well for injection, and one for production. The water goes up because of the difference of pressure between the stock and the surface. At the same time, water is re-injected in the second drilling, to maintain this difference of pressure. Most part of the geothermal fluid is re-injected at the end of the production cycle, to minimize environmental impacts, and extend the resource exploitation. The improvements of exploitation methods would permit to increase a lot the available power.

In fact, the plants and equipment, such as pipes, require high maintenance, and the hot ground water contains dissolved materials. When the water cools, some of these materials deposit on the pipes as solids and may stop the flow. Furthermore, because water is acid, pipes corrode.

Taking water from underground can cause the surface land to cave in or subside. Pumping water back into the ground can reduce this risk. Taking geothermal energy from rocks too quickly might cool them down. The temperature of the rocks must be monitored to ensure that the use does not exceed the reheating capacity of the area. This re-heating is slow: it can take about 10,000 year for heat to be transported over a distance of 300m.

The binary cycle technology

Developed at the beginning of the 1980s, the principle of binary production of geothermal electricity is on the way to becoming one of the most widespread system in use in the world.

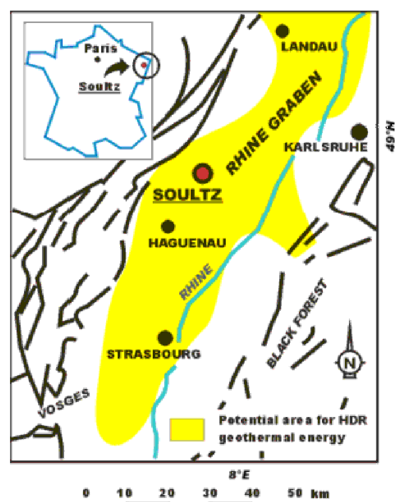
The principle is to use underground water to heat an intermediate fluid which has the property of vaporizing at a temperature lower than that of water. It is therefore possible to produce electricity from hot underground water with temperatures in the neighborhood of 100°C.

1.2. Hot dry rock, example of the Soultz-sous-Forêts program

The potential of hot dry rocks technology is very important: about 110TW_e in Europe so a non negligeable part of the French electricity consumption.

In France, the Soultz-sous-Forêts deep geothermal experimental program runs researches about heat and electrical power generation, within a European collaboration.

A 6 MW pilot installation dedicated to electricity production should be achieved by the year 2006. This experience will make it possible to improve techniques for exploiting the heat of deep rocks.

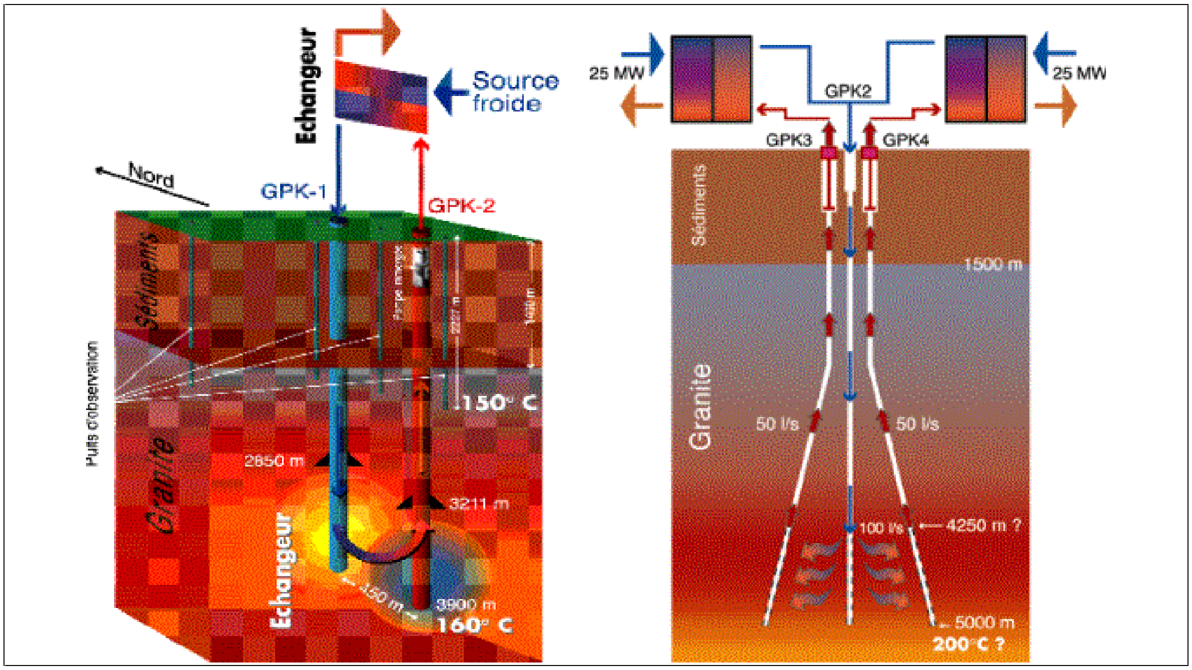


The Hot Dry Rock concept

Different geological systems have called the same concept by different names:
- HDR: Hot Dry Rock
- HWR: Hot Wet Rock
- HFR: Hot Fractured Rock
- EGS: Enhanced Geothermal Systems

The HDR concept is very simple but the development of the associated technology is significantly longer than anticipated.
This concept consists briefly in the following:
- ❖ Using the natural fracture systems in the basement rocks
- ❖ Enlarging its permeability through massive stimulation
- ❖ Installing a multi-well system

- ❖ Through pumping and lifting, forcing the water to migrate through the fracture system of enhanced permeability ("reservoir") and use the heat for power production!
- ❖ Using submersible pumps to increase fluid recovery



Principle of future HDR electricity production of Soultz-sous-Forêts

For such a reservoir to be used as an energy source, the following conditions to be satisfied:

- A substantial mass of hot rock should be available at a reasonable depth
- A fluid flow path and heat exchanger, or a permeable zone, must be created in the rock mass having:

1. A low flow resistance, enabling high fluid throughputs to carry required amounts of thermal energy to the surface power-conversion system.
2. A sufficiently large heat exchange surface between rock and circulating fluid to enable transfer of the thermal energy.

An underground fluid circulation system fulfilling these conditions by enhancement of the natural permeability is the most general definition of an HDR geothermal system. The creation or the enhancement of a natural situation to create the artificial heat exchanger (reservoir) is the heart of HDR technology.

In a HDR exploitation, the water runs in a nearly closed cycle in the underground rocks, and transfers its energy to a fluid in the heat exchanger. This fluid makes the turbine running.

To have an idea of the potential of the heat stored in rocks: 1km^3 of 200℃ hot granite cooled down by 20℃ is able to delivers about 10MW of electric power during a period of 20 years. In Europe, the available resource is about 125 000 km^2 (> 200℃ at 5000m depth).

In terms of costs:
- The sinking costs increase exponentially with the depth
- The production costs decrease linearly when the temperature increases

Progress in drilling technologies will ensure the economic future of enhanced geothermal systems exploitations.

The mains points about Soultz-sous-Forêts

It is a European pilot research program, in 4 phases, with the following aims:

- Integration of all European HDR research activities
- Drilling of 2 wells to 3 600 m, and underground evaluation
- Stimulation and first hydraulic testing
- Successful 4-month circulation test demonstrating the feasibility of the HDR concept
- Industry partnership through the EEIG "Heat Mining"
- Digging a well to 5 000 m, to a temperature of 200℃, with development of a deep heat exchanger
- Successful stimulation experiment at 4 400 – 5 000 m depth
- Building a production pilot plant, based upon the three 5000m sinking
- Test of the heat exchanger, generation of 6,5 MW_e
- Definition of geothermal production plants, from 25 to 30 MW_e

After the success of the two first phases, the third one is engaged which consist on:

Phase 3: 2001-2005

The planned Scientific Pilot Plant module is a 3-well system consisting of one injector and two producers, one on each side of the injector. All wells are started from a single platform using the existing deep well GPK2 as one of the producers.
The predominant operational 4 tasks of the current phase are:

Task 1: Drilling of the deviated well GPK3 starting 6 m from the top of GPK2 down to 5000 m depth into a target zone selected from the stimulation carried out in 2000. The bottom of this new well GPK3 will be separated from the bottom of GPK2 by approximately 600 m.
Task 2: Stimulation of the bottom part of GPK3 to extend the existing reservoir of GPK2 by an overlapping volume of enhanced permeability.

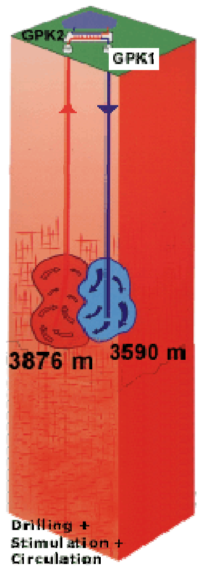
Task 3: Drilling of the deviated well GPK4 from the same platform as GPK2 and GPK3 to 5000 m depth into a target zone selected from the stimulation of GPK3. The bottom of this new well GPK4 will be separated from the bottom of GPK3 also by about 600 m.

Task 4: Stimulation of the bottom part of GPK4 to extend the existing reservoir of GPK2 and GPK3 by an overlapping volume of enhanced permeability.

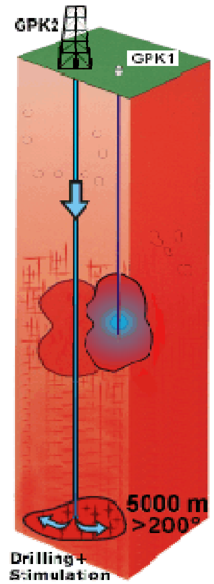
Phase 4: 2005-2008 The surface system: power generation

- Short-term circulation (50l/s)
- Medium term circulation (100l/s) / Power plant installation (1,5 MWe), developing and testing high temperature production pumps (200℃)
- Long term circulation / Power plant Preparation and basic design/ installation (6 MWe)

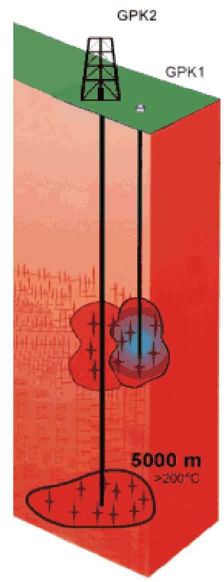
Illustrations



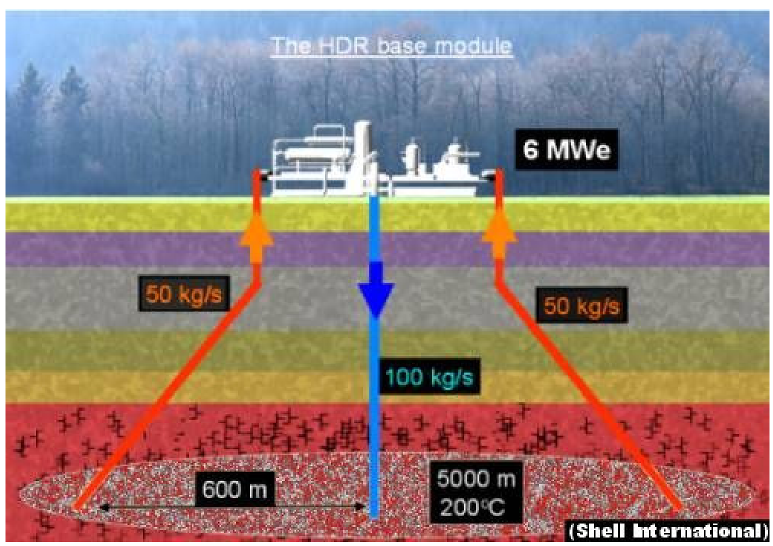
Phase 1



Phase 2



Phase 3



Phase 4

2. Economy

The construction cost of a geothermal power station depends on the size of the generator. The International Geothermal Association point out a cost of 1400€/kW for a 55MW station and 2400€/kW for a 15MW station. The electricity cost is 37€/kWh for a 55MW station and 55€/kWh for a 15MW station.

A large part of the global cost of the project is associated with the drilling cost. It represents an important part of the investment cost and a large risk. In order to decrease the geological risk, the construction of the station can be split in phases done at different time.

The important availability of the energy (about 80% to 90%) for a renewable resource, independent of the weather conditions and the low maintenance cost make geothermal energy one of the cheapest and most interesting renewable energy source for a base production.

Large power is available (100kW to hundreds MW) for this local energy. Some pollution (noise, smell) can be emitted by the installation.

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