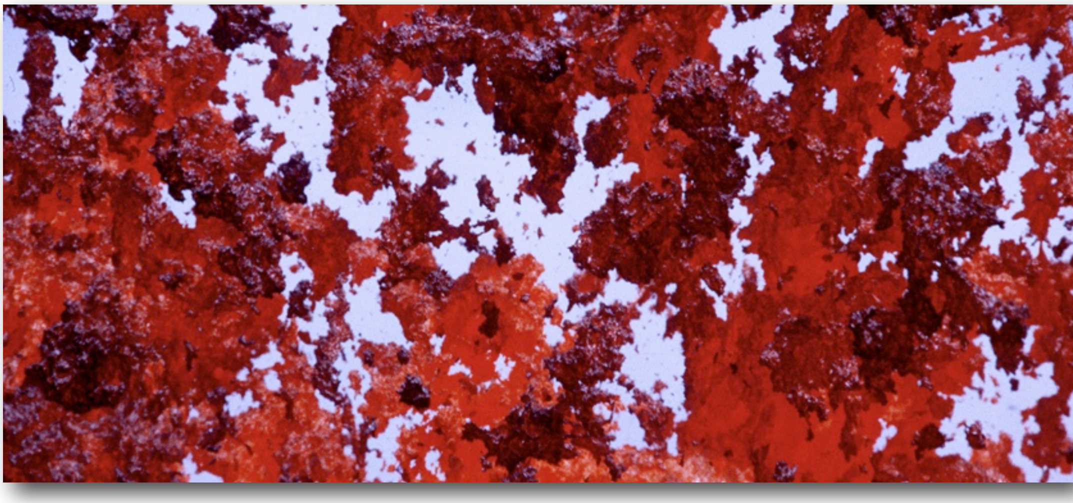
Bassfeld Technology Transfer

GEOTHERMAL POWER GENERATION

ECONOMICALLY VIABLE ELECTRICITY GENERATION THROUGH
ADVANCED GEOTHERMAL ENERGY TECHNOLOGIES

VERSION FEBRUARY 2009

17 ch. des Mollies / 1293 Bellevue / Switzerland • telephone: +41 22 774 2443
www.bassfeld.eu guenther@bassfeld.ch



Magma spatter from a volcano vent

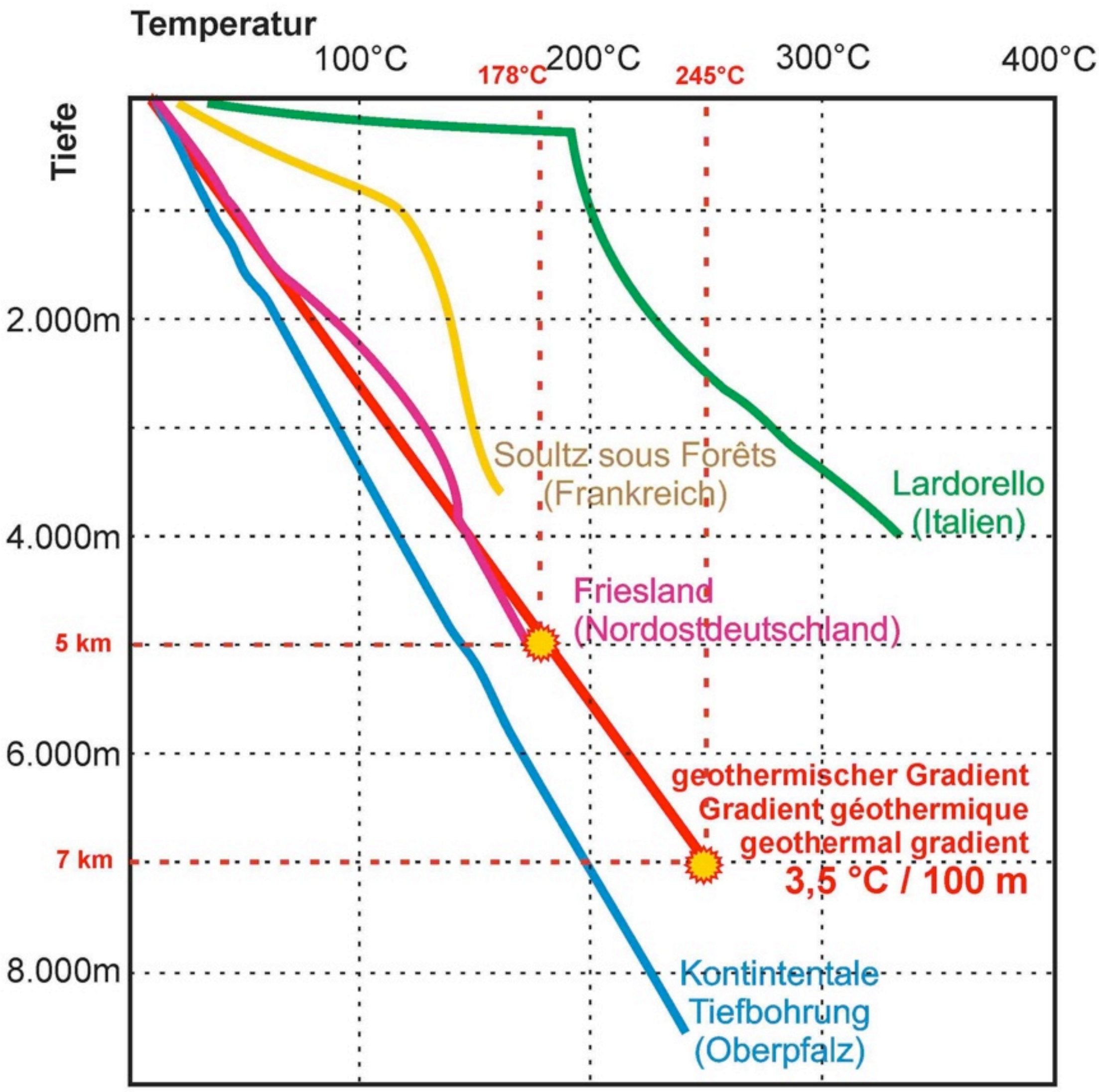
Geothermal Basics

Temperature gradient

Geothermal energy, in the broadest sense, is the natural heat of the earth which is present in the earth's core, mantle and crust. From the surface, the natural increase of temperature with depth in the earth is on average between 3°C to 4°C per 100 meter. This is called the temperature gradient and it varies based on factors such as the porosity of the rock, the degree of liquid saturation of the rock and sediments, their thermal conductivity, their heat storage capacity and the vicinity of magma chambers or heated underground reservoirs of liquid.

A high temperature gradient means that in order to obtain the same energy output, boreholes can be drilled less deep than with lower temperature gradients. This has a direct effect on costs.

Temperature profile of earth crust

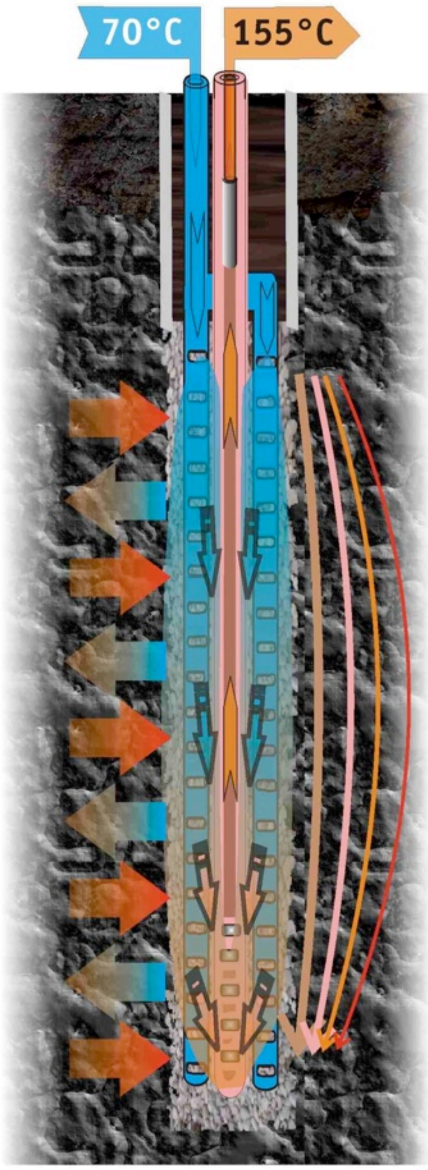


Hydrothermal energy flow

It is a proven fact that the Earth's crust is saturated with water. Not only do bore-holes in fractured rock or chalk fill with water up to between 5 -70 meters beneath the earth's surface, but this has also been confirmed in hard (crystal-line) rock. This last finding is critical as it allows exploitation of heat energy in all geographical locations, irrespective of the presence of subterranean hot water or steam reservoirs.

The presence of water facilitates not only vertical hydrothermal energy flows (convection), but also horizontal hydro-thermal energy flows (through convection, advection and diffusion). The full utilization of all these hydrothermal en-ergy flows enables commercially viable geothermal energy exploitation. Differences in pressure activate the energy flows.

Hydrothermal activation



Hydrothernal activation is induced by pressure differences, which give rise to mainly (horizontal) advection and dif-fusion

Geothermal systems

Geothermal heat extraction systems can be loosely categorized into open and closed-loop systems.

Open systems are defined as open-loop systems in which groundwater is used as a heat carrier and is brought directly to the heat pump. Between earth, ground water, and the heat pump exchanger there is no barrier. We can distinguish between single and multiple wells.

> Single well open-loop system
>
> A *single well* system is a bore-hole from which water is pumped up from the aquifer, passes through the heat pump's heat exchanger and is later discharged at the surface, for example into a lake or for irrigation purposes. No water is re-injected into the ground. There is a net loss of groundwater.
>
> *Standing column* wells are uncased bore-holes in direct contact with the surrounding aquifer, creating a standing column of water from the top of the groundwater table down to the bottom of the well. Heated water is drawn from the bottom part of the well and is returned at the top after passing through a heat exchanger. There is no net withdrawal of groundwater.
>
> Multiple wells open-loop system
>
> Double or *dual wells* consist of an injection well and a production well. Hot water is pumped out of the production well, passes through a heat exchanger, and the cooled water is re-injected into a second well some distance from the production well.
>
> *Hot-Dry-Rock* (HDR) is a variant of the multiple well system, whereby a reservoir of hot rock deep under the earth is used to heat water which has been injected into one or multiple injection wells. The heated water is returned to the surface by one or multiple production wells. Initially the injection water is pressurized in order to fracture the rock sufficiently to enable water to flow to the production wells. HDR has yet to be proven economically and commercially viable.

In *closed-loop systems*, a heat transfer fluid is continuously circulated through the earth in a closed pipe system without ever directly contacting the soil or water in which the loop is buried or immersed.

Hydrothermal power plants

The geothermal power plants require high temperature steam or water in order to generate electricity. Temperatures can vary between relatively low 100 °C to more than 300 °C. Wells several kilometers deep can provide these temperatures.

There are currently three main types of hydrothermal plant technologies in use. Dry-steam plants directly use geothermal steam to drive the turbines. Flashed-steam plants pull deep, high-pressure hot water into lower-pressure tanks, where it flashes to steam and drives the turbines. Binary-cycle plants pass moderately hot geothermal water by a secondary fluid with a lower boiling point than water. The secondary fluid flashes to steam, and drives the turbines. Hybrid plants use a mix of these technologies.

Geothermal Electricity Generation

Current technology

At present most geothermal power is generated from open-loop systems such as dry-steam plants placed over large natural reservoirs of steam (The Geysers in California, USA or Larderello, Italy) or flashed-steam plants which draw on super-heated water reservoirs (Wairakei, New Zealand). This technology is restricted to relatively few specific geological and geographical settings. Dissolved chemicals and minerals in the water provoke corrosion, scaling and some extent of surface pollution unless the water is treated and re-injected.

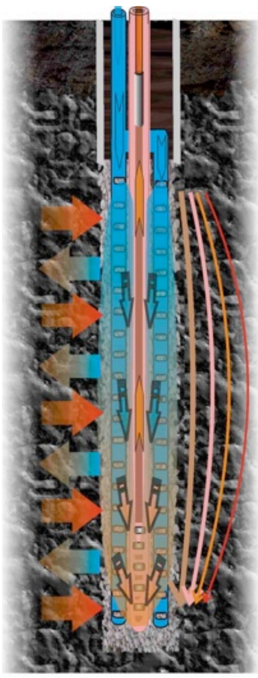
Where there are no natural subterranean reservoirs of hot water, but only an abundance of hot rock (Cooper Basin, in South Australia), various projects using Hot-Dry-Rock method have been initiated or completed. Main disadvantages of the HDR method are the necessity for two separate bore holes, the artificial widening (fracturing) of crevices in the deep-seated rock and the requirement of a sufficiently hot rock zone. The high pressure water injections necessary to fracture the deep-seated rock have been proven to cause earthquakes. Also there is a substantial exploration risk, in that the injected water is ultimately not available in sufficient quantity for the production wells. The underground water flow dilutes minerals and chemicals from the rock which could corrode or eventually clog parts of the system. HDR is only an option in specific locations. HDR is not yet economically viable or even near-commercial.

Traditional single well systems such as standing column wells and closed-loop systems are in use for geothermal heat generation, but they have not been able to generate sufficient heat for economically viable electrical power generation.

Advanced heat extraction technology

Knowledge of geothermal heat extraction based on advanced technologies has not been widely published, but some installations have already been functioning effectively since over 25 years. More than 450 boreholes using this technology have been installed in Switzerland, Germany and Austria. The following short discussion of these geothermal heat extraction systems is necessary as a background to the application of the technology to electricity generation.

The three principle advantages over conventional geothermal energy technologies are: 1) the technology can be applied anywhere in the world irrespective of the local geological ground structure. 2) Energy output is a multiple higher than with closed-loop systems. 3) Risk minimization due to the elimination of the usual exploration risk. Effective energy output can be precisely calculated before project begin based solely on the required geothermal energy output and a geological profile of the ground.

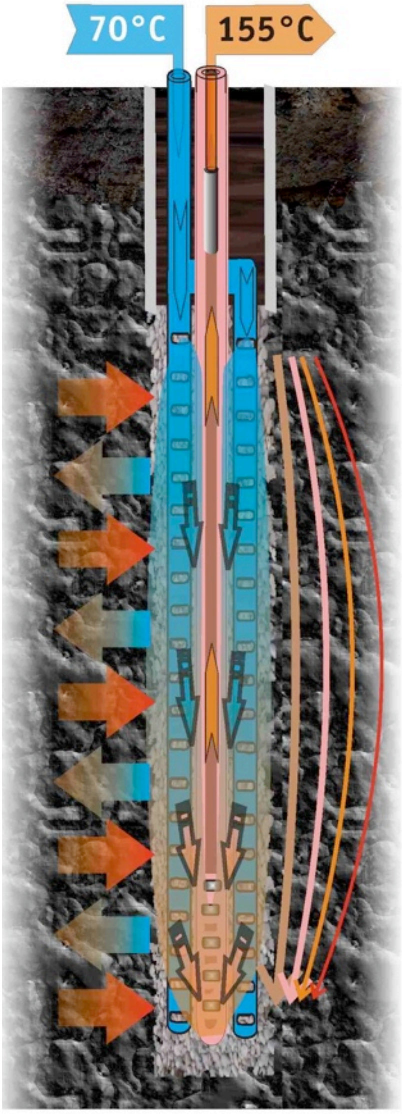


Advanced systems are a significant evolution of the standing column well. They unite the advantages of a single open well with those of closed-loop systems and the energy output of Hot-Dry-Rock systems, but with none of the disadvantages. These statements are based on empirical data.

This technology uses a single well. The well is only cased for its uppermost section, where the earth is not solid or water saturated. A set of pipes is installed in the water-filled well. In the center a thermal-insulated production pipe has been installed. This pipe is fitted with a pump placed a certain distance below the earth surface. Once extracted and cooled, the water is led back into the same well by another set of pipes which have perforations calculated to regulate the flow of the water. The well is filled with gravel for the purpose of stabilization and better water flow regulation. The dimensions of the pipes, the speed of water circulation, the amount and size of the perforations are calculated to maximize energy output.

Traditional closed loop systems and standing column wells can only extract the energy from the immediate surrounding well wall or rock. The amount of extracted energy is dependent on the thermal conductivity of the rock or sediment. Clay is a relatively poor conductor at an approximate 2 Watt per meter-degree Kelvin (W/m/K) whereas the conductivity of granite is close to 5 W/m/K .

Advanced geothermal energy extraction technologies take advantage of the horizontal hydrothermal energy flows in water saturated rock. These flows (mainly advection and diffusion and to some extent convection) are activated by pressure differences between the cooler descending water and the hot water present in the rock and represent approximately 80% of the total energy flow. As a result, the extracted energy is a multiple of that possible by traditional technologies.



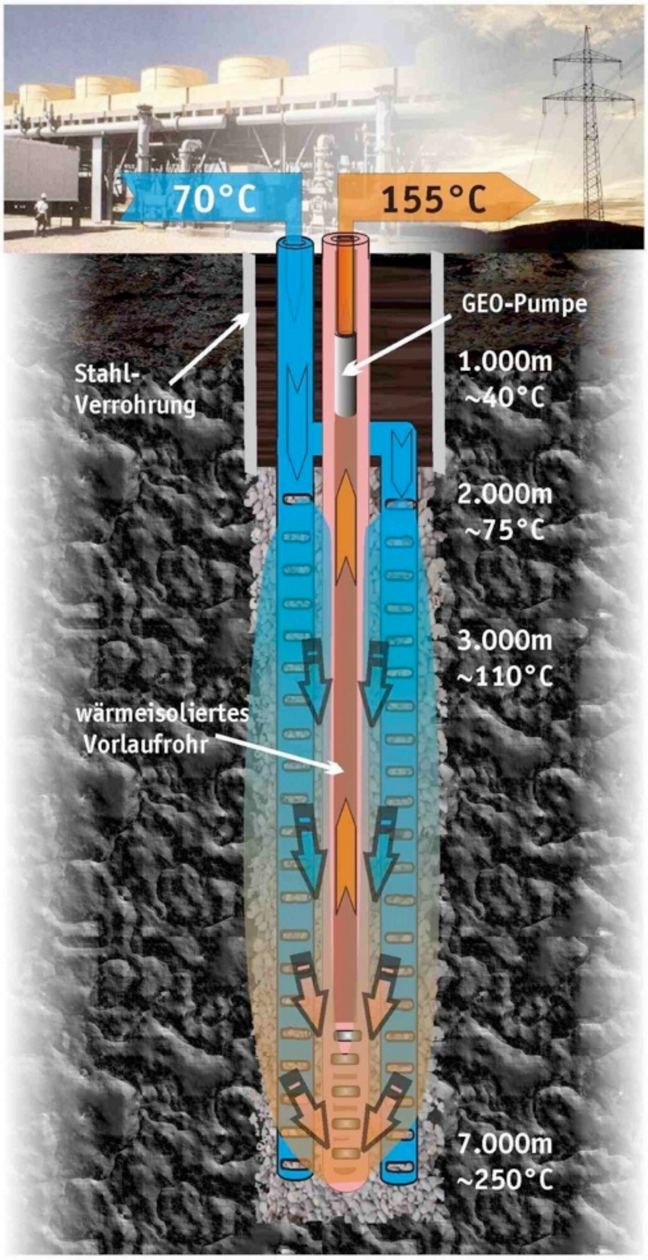
Horizontal permeability is more important than vertical permeability

Although these wells are similar to an open-loop system, it is virtually a closed-loop system, because the same water circulates continuously in the system. As such, this technology can also be installed in aquifers which are a source of drinking water. Longtime functioning wells have proven that heat depletion is not an issue as long as the geothermal energy withdrawn from the ground is in balance with natural geothermal energy replenishment. Temperature measurements have shown that low depth wells placed within 10 meters distance of each other do not affect each other's energy output.

Geothermal electricity generation with advanced extraction technology

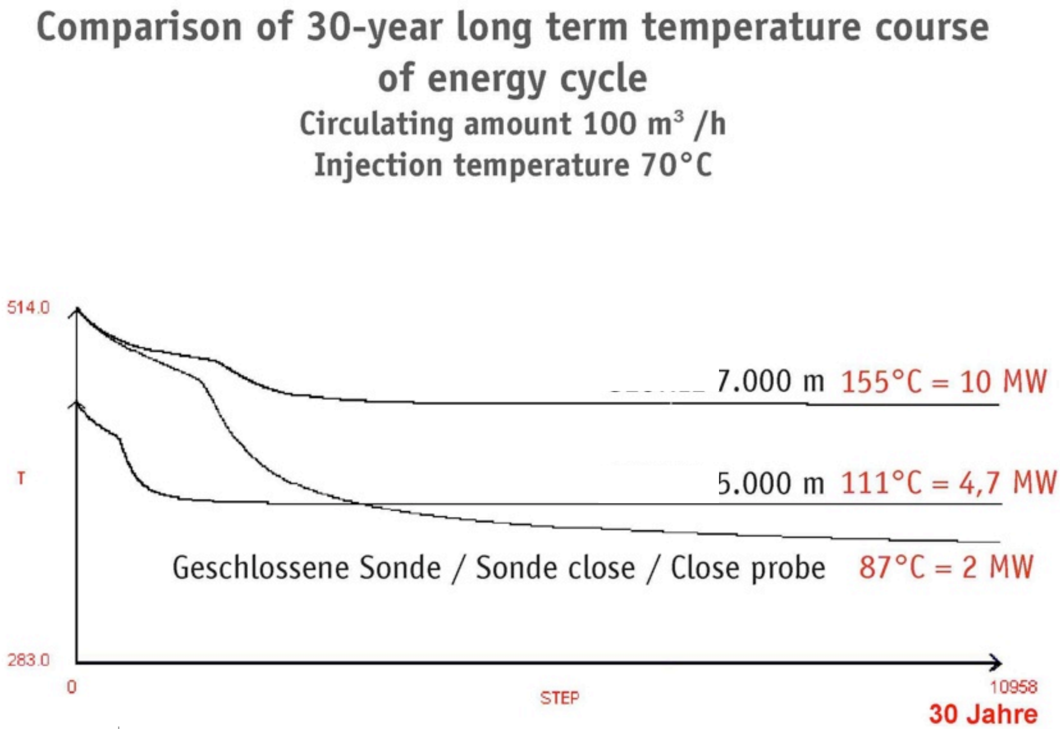
The principles underlying the geothermal heat generation by means of these wells also apply to electricity generation. We are able to provide you with longtime engineering and mining experience coupled with a vast empirical knowledge of thermal properties and hydrothermal energy flows at various depths and within a multitude of geological ground structure profiles. This knowledge has been derived from the data of 450 installations, over a time period of 25 years for some installations. The result is expert knowledge of how to construct the deep wells necessary for electricity generation in order to maximize geothermal energy extraction.

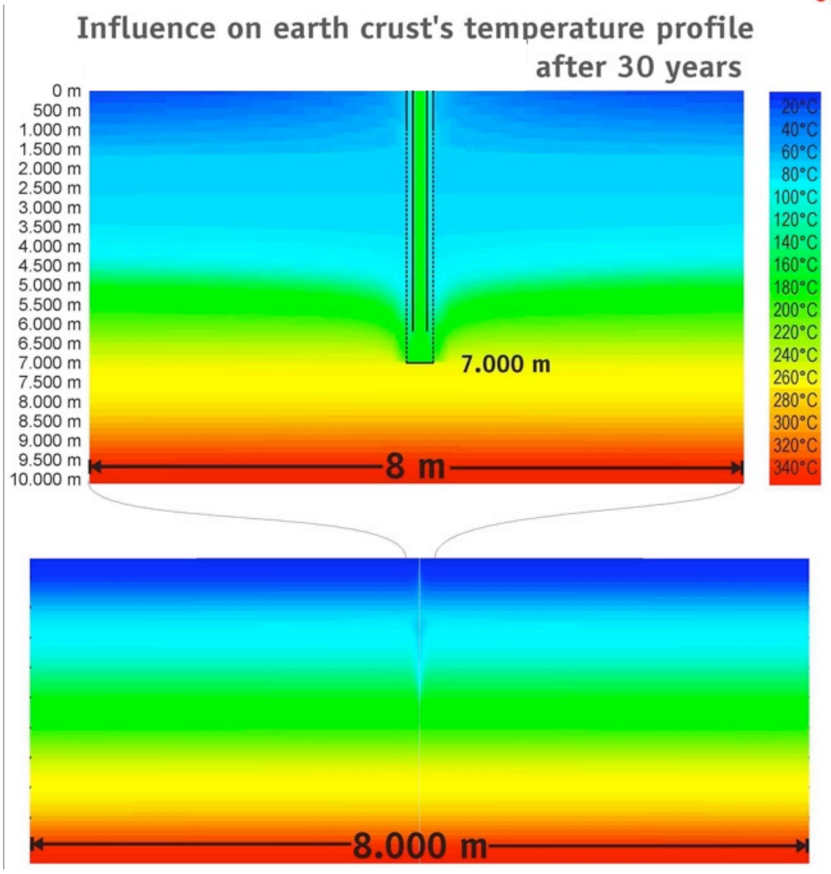
This experience forms the basis for the design of the deep wells necessary for efficient electricity generation. In following example, water heated to 155 °C is delivered to a geothermal power-station from 7000 meters depth. The heat is extracted from the water, which has now been cooled to about 70 °C and returned into the same well.



Water cooled to 70 °C flows through the gravel-filled well and is heated by direct contact with the earth. The resulting heated and pressurized water is transported to the surface via a heat insulated pipe.

Following simulated calculations show the constant baseload yield of energy generation from a typical 7000 meter deep well located in Europe and how this compares to closed-loop systems over a 30 year period. The energy output is 10 MW of geothermal heat. This would be sufficient to generate a baseload of between 1.5 MW to 2 MW electrical power together with approximately 6 MW thermal heat energy. A 7000 meter deep closed-loop system would not produce more than 2 MW total heat energy.





Summary

This introduction to advanced geothermal energy technologies shows how electricity generation by means of an advanced heat extraction system is superior to conventional technologies and to the Hot-Dry-Rock system:

- *Location*: the fact that water saturated rock is present in all geographical locations allows activation of hydrothermal energy flows by this technology. It is no longer essential to drill into hot water reservoirs or to recreate these artificially in hot dry rocks.
- *Energy output*: is a multiple higher than with closed-loop systems. This technology maximizes energy output and enables commercially viable geothermal energy exploitation. The coefficient of performance is 4.5 and higher (for every one unit of energy used to power the system, more than 4.5 units are extracted as geothermal heat).
- *Risk minimization* due to the elimination of the usual exploration risk. Finding hot water reservoirs is not necessary, neither is fracturing deep-seated rock. This technology works with a single well, as opposed to the dual wells necessary with HDR systems. Effective energy output can be precisely calculated before project begin based solely on the required geothermal energy output and a geological profile of the ground.
- *Cost*: high energy yields and the lower costs of single well technology compared to HDR make this technology commercially viable. Wells need to be drilled less deep than with closed-loop systems, thereby reducing drilling costs. Risk minimization contributes to the accuracy of investment calculations before project begin and reduces insurance premiums.
- *Longevity*: existing installations have been functioning since over 20 years without noticeable depletion of the geothermal heat output, because the energy extraction rate is in balance with natural energy replenishment. Deep wells can be installed within 100 meters distance of each other without measurable effect on energy output.

Technology transfer

For further information concerning advanced geothermal energy extraction technology please contact Günther Bassfeld at :

Bassfeld Technology Transfer

Ch. des Mollies 17

CH –1293 Bellevue,Switzerland

Tel. +41 (0) 22 774 2443

email: guenther@bassfeld.ch