1 EUSUSTEL WP3 Report – Geothermal power production

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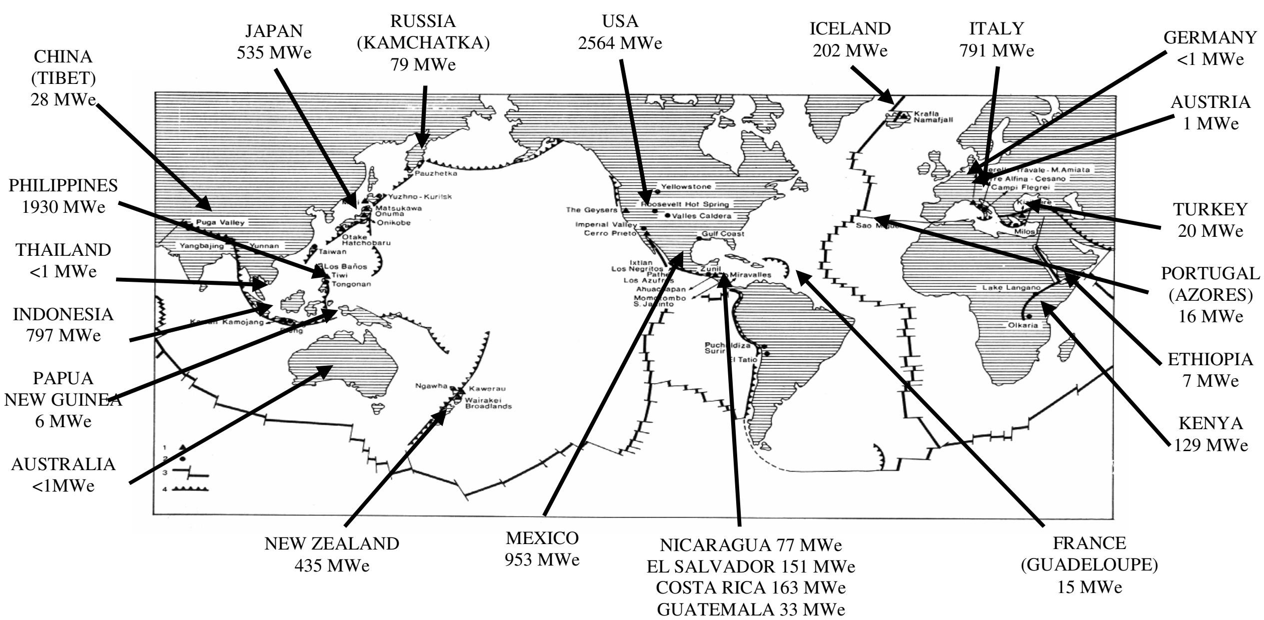
1.1 Introduction

Mankind has used geothermal energy for several thousands of years, originally only in thermal applications such as therapeutic baths, space and water heating and agriculture. In the beginning of the twentieth century the first transformation of geothermal heat energy into electrical energy was made in Italy by prince Piero Ginori Conti. The first commercial geothermal power generation began in Larderello, Tuscany, Italy in 1913 [2]. Today geothermal energy is the third largest renewable power source in the world, after biomass and hydro [2]. The worldwide annual geothermal power production in the year 2005 was 57 TWh from 24 countries while the EU-25 production of geothermal power was 5.5 TWh [10]. The total geothermal power capacity installed in the world is shown in figure 1.1.

Figure 1.1: Worldwide geothermal power capacity installed in early 2005 [10].



Geothermal energy originates from the earth's molten interior and the decay of radioactive materials. Heat is brought near to the surface by deep circulation of groundwater and by intrusion into the earth's crust of magma. On average, the temperature of the earth increases by about 3 °C for every 100 meters of depth [1]. Each and every year, more than 100 000 TWh of heat energy is conducted from the earth's interior to its surface [1]. That is more than the total worldwide annual use of energy. 2004, the worldwide electricity consumption was 17 500 TWh[1] and the worldwide total energy use was 46 500 TWh[2] [2]. The total storage of geothermal energy is even greater, estimated at 5 billion TWh [1]. Of course not all heat energy can be transformed into

[1] BP Review 2005, http://www.bp.com/downloads.do?categoryId=9003093&contentId=7005944 (2005-10-04)
[2] EIA Energy Outlook 2005, http://www.eia.doe.gov/oiaf/ieo/highlights.html (2005-10-04)

electricity, mainly because it is mostly much dispersed, but enough to make geothermal energy an interesting and possibly significant contributor to the world's energy demand.

Geothermal energy is considered to be a renewable energy source, and so it is in this report too. But strictly speaking it is not. Locally, the extraction rate of heat often exceeds the reservoir replenishment rate. Though, with good reservoir management the geothermal energy source can be productive at least during the lifetime of the geothermal installations. [2] Axelsson et. al. [9] put it this way:

> *"Sustainable development involves meeting the needs of the present without compromising the ability of future generations to meet their own needs. At the core of this issue is the utilization of the various natural resources, including the worlds' energy resources. Geothermal resources have the potential of contributing significantly to sustainable energy use in many parts of the world. The terms renewable and sustainable are often mixed up. The former concerns the nature of a resource while the latter applies to how a resource is utilized. In many cases several decades of experience have shown that by maintaining production below a certain limit a geothermal system reaches a kind of balance that may be maintained for a long time. A definition is reviewed, which argues that sustainable geothermal utilization involves utilization at a rate, which may be maintained for a very long time (100-300 years)."*

1.2 General issues on geothermal power technologies

There are several different types of geothermal energy wells. They differ in terms of, for example, permeability of the rock and occurrence, temperature and salinity of water. These features lead to different technologies to extract the energy and produce electricity. These are described in chapter 1.3. Of the different occurrences of geothermal energy mentioned below, only natural hydrothermal systems are part of the power generation system today. All the other occurrences are to be regarded as resources for the future.

Natural hydrothermal systems

Natural hydrothermal systems are, up to now, the only geothermal resources that have been exploited commercially for electric power generation, because they are the cheapest and simplest to exploit. They spontaneously produce hot water, typically appearing on the earth's surface such as geysers and hot springs. Five features are essential for making a hydrothermal geothermal resource operational for power production [6]:

- a large heat source
- a permeable reservoir
- a supply of water
- an overlying layer of impervious rock
- a reliable recharging mechanism

Natural hydrothermal systems occur preferably in or near the boundaries of crustal plates. The seismic activity adjacent to these boundaries creates not only a source of heat relatively near the earth's surface, but also a rock, enough permeable allow an adequate supply of indigenous fluid. If the pressure on the fluid on the reservoir is too low to prevent boiling, a vapour phase is formed in the upper parts of the reservoir. Since most of the dissolved minerals are concentrated in the liquid phase, the vapour can be used directly in a turbine to produce electricity, with little risk of scaling[3] or turbine blade damage. [5]

Hot dry rock (HDR)

Rocks with poor permeability and/or lack of water still can be prospective sources of geothermal energy exploitation. The rock can be fractured in an artificial way, by injecting highly pressurized water into a drilled well, a so-called injection well. The water opens existing fractures and creates new ones. When the fractured volume is suitably large and the permeability is sufficient, another hole, the production hole, is drilled. Ideally, a closed loop is created whereby cold water is pumped down the injection well, is heated by the hot, fractured rock and then returned to the surface through the production well. [2, 5]

Magma

Magma bodies contain a huge potential resource for electricity production. This is mainly due to the extreme temperatures of the magma, normally greater than 650°C. Magma bodies can be found at depths of around 7 kilometers. The problems associated with extraction of this vast energy resource are above all the requirements on the equipment used at this high temperature and pressure. Drilling to a depth of 7 km is feasible today, but the techniques and materials have still to be further developed to cope with the extreme conditions. [2, 5]

Geopressured systems

A geopressured system consists of geopressured deep reservoirs (4-6 km of depth) in large sedimentary basins containing hot pressurized water. It can therefore deliver energy in three forms; thermal energy (hot water at 150-180°C), hydraulic energy (pressurized water at 600 bar) and chemical energy (the geofluid is assumed to be saturated with methane gas, 0.69-0.89 m3 CH4/kg water). [2, 5]

1.2.1 Peculiarities

There are some general advantages and disadvantages with geothermal energy, compared to other energy sources and they are listed below.

Advantages

- Geothermal energy conversion has small and manageable environmental effects compared to other energy conversion technologies. It is a reliable and predictable energy source suited to provide base load power, and it is also easy to regulate and can therefore act as peak power, see figure 2.1.

[3] Scaling: Chalky deposit that can strongly disturb the flow of geothermal fluid and thereby increase the power conversion efficiency.

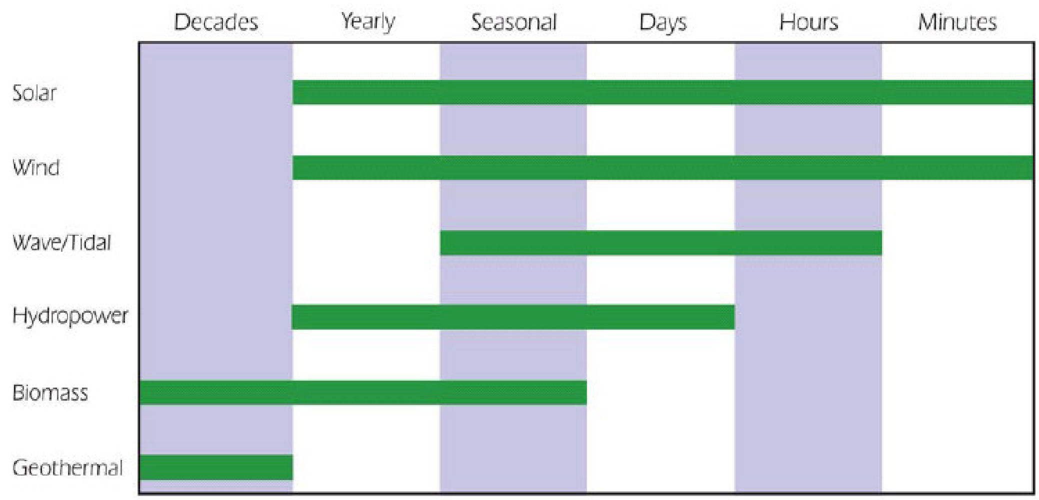


Figure 2.1. Timescales of natural cycles of renewable energies. [8]

- This is becoming more and more important as renewable intermittent energies, such as wind, solar, wave and tidal power, are taking place in the energy system.
- Geothermal heat can be used to supplement biomass or fossil fuel in electricity generation and thus act as a fuel saver.
- Geothermal activities use less land area than almost any other energy source, only 404 m2 of land occupied per GWh/year over 30 years. That can be compared with coal plants that use nine times as much land area [1]. See table 2.1.

Table 2.1. Land occupation for different power production technologies. [1]

Technology	**Land occupied (m^2 per GWh/year over 30 years)**
Coal (incl. coal mining)	3 642
Solar thermal	3 561
Photovoltaics	3 237
Wind (land with turbines and roads)	1 335
Geothermal	404

- A geothermal power station is built up by modules, making it easy to increase the capacity installed. It is economically competitive even in rather small station sizes.
- There is a potential of improving geothermal power plants since the technology in some ways still is immature. Hammons [3] argues for a cost reduction of geothermal electricity of up to 25% in comparison with today's costs. This would give geothermal energy conversion a better cost-competitiveness than today.
- Like other renewables, geothermal power production requires no utilization of fuel (oil, coal, natural gas) and is therefore insensitive for fluctuations in fuel price. Geothermal power is thus more attractive with increasing fuel prices; the higher the fuel price, the more competitive geothermal energy conversion is.
- There are possibilities to extract useful minerals from the geothermal water.

Disadvantages

- It is hard to predict the potential of a given site. This is due to expensive examination of the properties of the rock, such as permeability and hardness and properties of the water, for example corrosiveness. To predict the abundance of water is also hard, and the result is often quite unreliable. The great variation in prerequisites even over short distances in each of the three spatial dimensions and for all of the issues mentioned above makes it even more difficult to make a good estimate of the potential.
- Most interesting geothermal sites occur in geologically instable areas, with volcanoes and earthquakes, which induces a safety risk.
- The capital costs are high due to a large initial investment cost. This is a disadvantage that geothermal energy shares with other renewable energy sources.

1.2.2 Environmental aspects

Geothermal power production is environmental very benign. The energy from the earth is often considered as renewable (for a further discussion of the renewability see 1.1 Introduction). The operation of the plant can be almost free from emissions and waste. Nevertheless there are several environmental aspects that have to be considered.

- Steam from geothermal fields has a content of non-condensable gases that can cause **gaseous emissions**. In back pressure turbines, the simplest form of steam turbines, the steam is exhausted directly to the atmosphere from the steam turbine, without any condensation. In closed-loop systems the condensed steam is reinjected into the well without any contact with the atmosphere. These systems are therefore almost free from emissions and waste. Table 2.1 shows the range of gaseous emissions. In a particular geothermal field the content of gases tend to decrease with time as a result of production [2, 11].

Table 2.2. Gaseous emissions from geothermal power production. [2, 11]

Emissions	kg/MWh$_e$		Comment	Ref
	Min	**Max**		
CO_2	4 (0)	740	122 kg/MWh$_e$ in average[4] [11]. 0 for closed-loop systems [2].	[11]
H_2S	0.5	6.8	Half of emissions from coal-fired plants	[2]
NH_3	$5.7x10^{-2}$	1.94	Rapidly dispersed in the atmosphere	[2]
Hg	$4.5x10^{-5}$	$9.0x10^{-4}$	Comparable with emissions from coal combustion	[2]
NaCl		$1.2x10^{5}$	This is with a 30% salt concentration by weight	[2]
NO_x	-	-		[2]
PM_{10}	-	-		[2]
^{222}Rn	3 700	78 000	The unit is becquerel/kWh	[2]

[4] Based on a study of the MW weighted CO_2 emissions from 85% of the world wide running geothermal power plant capacity (August 2001)

As seen in table 2.2, the CO_2 emissions vary a lot, depending on the particular geological structures of the given geothermal reservoir. The CO_2 flux varies from almost nothing to values comparable with those from fossil fuel combustion. The CO_2 is produced at depth, mainly by thermo-metamorphism of marine carbonate rocks. It is important to keep in mind that the processes of CO_2 generation are independent of geothermal exploitation and that some of the CO_2 emissions would occur even naturally, without geothermal exploitation. [14]

- The discharge of wastewaters can potentially cause **liquid effluents**. Geothermal fluids can contain chemicals such as boron, fluoride and arsenic. To prevent these chemicals from getting out in the environment surrounding the geothermal power plant, the water can be treated, re-injected into the reservoir from which it was taken, or both. [2, 4, 5]

- When geothermal energy is used to generate electricity, there is always **waste heat** that has to be rejected, with possible detrimental environmental effects. A slight increase (2-3 °C) of temperature in a body of water can damage its whole ecosystem. There are many ways to avoid these problems. The wastewater can be cooled in special storage ponds or cooling towers, it can be reinjected into the geothermal well to maintain the pressure or it can be used directly for house or greenhouse heating. Furthermore the size of geothermal plants seldom exceeds 50-100 MW_e, resulting in waste heat rates that usually have small local consequences. [4, 5]

- Geothermal energy conversion involves a certain **use of land** even though it is less than almost any other energy source. Typical requirements include structures to house the power-generating and heat-exchange equipment, land space for wellheads, and a pipe distribution system.

- The **use of water** has to be controlled to avoid water leakage and thus allow the geothermal power plant to last longer. This is done by using total reinjection, non-evaporative cooling, and general pressure management in closed-loop recirculating cycles.

- The **noise level** is a potential environmental problem that is overcome today. With silencers the noise level decreases to 75-90 dB which is an acceptable noise level. At free discharge, noise levels amount to 90-122 dB. [2]

- Geothermal activities that involve fluid extraction can cause **subsidence of the land surface** and **induce seismicity**. Yet the most active geothermal regions have a high level of natural seismic activity. Current data suggest that seismic risks in geothermal developments are low. The risk of subsidence of land surface can be minimized reinjecting replacement fluids. [5]

- During the construction of a geothermal production field some **solid waste** (particularly rock from drilling) is produced that has to be disposed of in an environmental friendly way. Because of the relatively small amounts of solid waste (some hundreds or thousands of cubic meters per bore hole – in comparison with for example a hydropower dam this is a small amount) this should not be a problem. The removed rock can even be used, for example for road construction. [4, 5]

Emissions to air and water differ greatly depending on which technique is used. Binary plants, in which the geothermal fluid is passed through a heat exchanger and reinjected without exposure to the atmosphere, will discharge neither gas nor fluid to the environment. The hot dry rock (HDR) technique does not involve the use of underground water. It is not clear whether an artificial addition of water into the rocks lead to similar effluents as when natural water is used.

1.2.3 Economical aspects

Geothermal power installations are – when the natural conditions are good – economically very competitive power plants, even compared to traditional energy sources such as coal, nuclear and hydro. The installation cost ranges from 640 000 to 2 400 000 Euro/MW and the resulting electricity cost from 16 to 80 Euro/MWh[5] [16]. The World Energy Council [1] lists three factors affecting the growth of the geothermal industry. These are:

1) **The prizes of competing fuels, especially oil and natural gas**. Like other renewable energy resources the most important factor for the competitiveness of geothermal power is the oil prize. As the oil prize is very volatile and is very likely to continue to rise (during 2005 alone the oil prize has risen roughly 50%[6]) due the undisputable coming scarcity of oil[7] one can assume that geothermal power, together with the other renewable energy resources, will be more competitive in time.

2) **Accounting for environmental costs**. Another factor that indicates that the competitiveness for geothermal energy will increase is the accounting for environmental costs (so called internalization of external costs) that increasingly affects fossil fuels, as a result of public pressure, domestic regulatory actions and international treaties. The areas where geothermal energy and other renewable energy technologies have significant advantages over fossil power generation technologies are many and widespread, for example CO_2 emissions, air pollution, hazardous waste generation, water use and pollution. These costs can be assumed to be counted for in a greater and greater extent, which increases the competitiveness of geothermal energy [1].

3) **The rate of future technological development**. Research and development will reduce the energy cost for all geothermal projects as well as the uncertainty,

[5] USD/EUR=1.25, www.valuta.se. 2004-01-01.
[6] http://www.worldoil.com/INFOCENTER/STATISTICS_DETAIL.asp?Statfile=_selectedworldoil
[7] See for example www.peakoil.com

especially of natural hydrothermal systems and its reservoir performance. The oil and gas industry gives a helping hand in improving the technology.

Even though geothermal power production industry in some ways is a mature industry, and that it is helped by the progress in the oil and gas industry, more specific geothermal research is needed, especially as there are several upcoming and promising occurrences and technologies, mentioned in chapter 2 and 3.3.

The most negative economical aspect with geothermal power is the high cost and uncertainty associated with exploring new geothermal sites. In other words the risk is high compared to other energy sources. Roughly, 50% of the cost of a geothermal power plant is related to the identification and characterization of reservoirs, and to the drilling of production and reinjection wells. 40% goes to power plants and pipelines while 10% goes to other activities [2]. The finished wells costs are in the range of 1.5-3 million Euro, with a cost of 800-1 200 Euro per drilled meter[8] [2].

1.3 Description of geothermal power technologies

Different power generating technologies are required for different occurrences of geothermal energy. In fact, no two geothermal sites are exactly alike. Therefore, energy conversion systems must be chosen and adapted to suit the particular site. Which technology that is required depends on the temperature and state of aggregation of the water that is used to extract the heat from the rock (if the water is steam, hot water, a mixture of these two or maybe non-existing naturally).

Roughly, the technologies can be divided into two types: the conventional steam turbine plant and the binary cycle plant. Table 3.1 shows a schematic comparison between the different types of power plants. The conventional steam turbine plants use steam or hot pressurized water to drive the turbine. The temperature of the steam/water has to be at least around 160°C. Binary cycle plants use a working fluid with lower boiling point than water to drive the turbine. Therefore water with a temperature of only 85°C can be used to generate electricity. Of course there is also a combination of these two concepts.

Table 3.1. Comparison between different technologies [2, 6]

Type of plant	**Temperature needed [°C]**	**Unit size – Installed capacity [MW_e]**	**Average power rating of unit [MW_e]**
Single-flash steam	200-260	3-90	28.1
Double-flash steam	240-320	5-110	30.1
Dry steam	180-300+	15-120	39.1
Binary cycle plants	85-200	1-10	1.8

[8] Prizes of 1998 (800-1200$/m), exchange rate USD/EUR=1.11 1998-01-01 (www.valuta.se) and inflation rate 1.5%/year.

1.3.1 Conventional steam plants

Conventional steam plants can be divided into sub-groups, depending on how they handle the steam. The first sub-group consists of dry steam power plants. The other sub-group consists of flash steam power plants.

Dry steam plants were the first type of geothermal power plant, both to be installed and to achieve commercial status. They are in general simpler and less expensive than the flash steam plant as they just have to handle steam and no geothermal brine[9]. Dry steam plants thus produce electricity from vapour-dominated reservoirs. Steam is extracted from the wells, cleaned to remove entrained solids and piped directly to a steam turbine where electricity is generated. See figure 3.1.

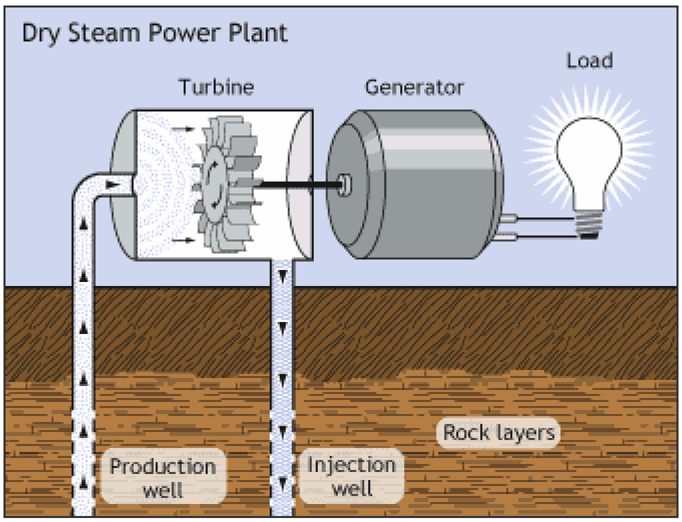


Figure 3.1. Basic principles of the dry steam power plant. From U.S. Department of Energy[10]

The most common steam plant today is the single-flash steam plant. It is the mainstay of the geothermal power industry and is often the first power plant installed at a newly-developed liquid-dominated geothermal field. The technique produces electricity from hot and high pressure liquid-dominated reservoirs by flashing the entering liquid into steam by reducing the pressure. The steam is then piped directly to a steam turbine. See figure 3.2.

A further development of this technique is the double-flash steam plant. As the name indicates, the difference in relation to the single-flash steam plant is that the remaining hot fluid from the first flashing stage is flashed again to make steam with a lower pressure than the primary steam. The steam is then fed into a second turbine or a dual-inlet turbine. The technique is similar to that of single-flash steam plants, but produces 15-25% more power for the same geothermal fluid conditions. The drawback is that the plant is more complex and hence more costly.

[9] Water saturated with salt
[10] http://www.eere.energy.gov/geothermal/powerplants.html

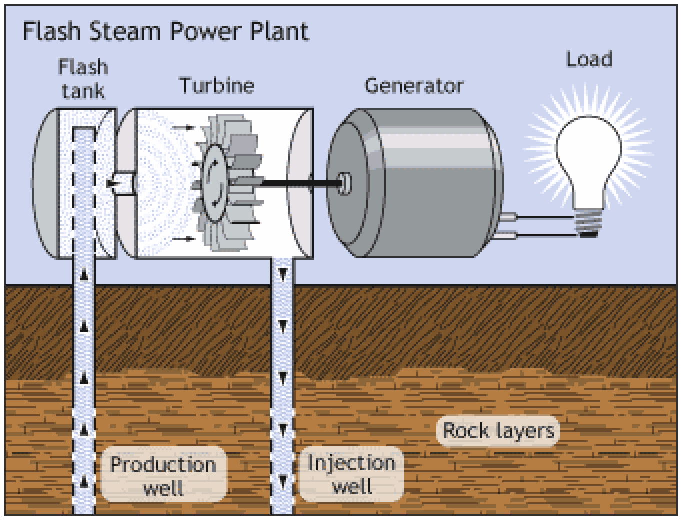


Figure 3.2. Basic principles of the flash steam power plant. From U.S. Department of Energy[11]

Triple-flash steam plants also exist, with a three-stage flashing process. The triple-flash steam plant is not as common as the single- or double-flash steam plants. [1, 6]

1.3.2 Binary cycle plants

In the binary conversion process, the geothermal fluid is sent through a heat exchanger where it vapourizes a secondary working fluid with appropriate thermodynamic properties, typically a lower boiling-point than water. The working fluid is expanded in a turbine, condensed and reheated for another cycle, all in a closed loop. The spent geothermal fluids are usually disposed of by reinjection. See figure 3.3. This technique is the primary candidate for use with the hot dry rock (HDR) resource, due to the moderate temperature of the circulated fluids. Though binary cycle units are small in terms of rated power (in average 1.8 MW_e), a binary cycle power plant can consist of many units, making the power plant installed capacity between 30 and 200 MW_e. [1, 2, 6]

Binary cycle plants are useful:

- when the water in a liquid-dominated resource is not hot enough for efficient flash steam production
- for making use of the heat remaining in water separated from steam in flash steam plants
- for saline brine that cannot be flashed because of the resulting deposition of scale
- when the content of dissolved non-condensable gases in the geothermal fluid is high

[11] http://www.eere.energy.gov/geothermal/powerplants.html

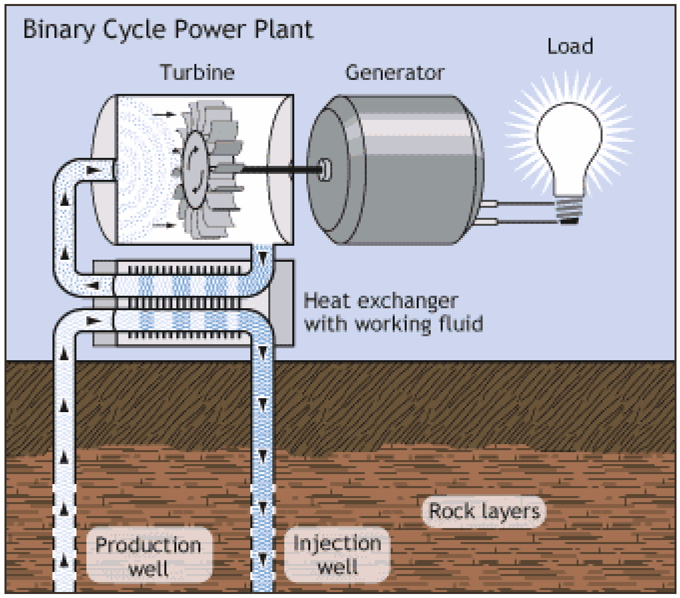


Figure 3.3. Basic principles of the binary cycle power plant. From U.S. Department of Energy[12]

The advantages with binary cycle systems, compared to conventional steam plant systems, are that:

- they enable utilization of moderate-temperature resources which exist at accessible depth almost everywhere in the world
- problems with corrosion and scaling are almost avoided
- environmental problems are minimized when using a closed-cycle system with reinjection of the geothermal fluid
- the conversion efficiencies are often higher than for flash steam plants wherefore smaller amounts of geothermal fluids are required per unit of electricity generated – This is due to the fact that binary power plants use all the water that is brought up from the geothermal well, whereas a typical flash power plant uses only the steam and discards up to two thirds of the fluid from the reservoir.

The disadvantages with binary cycle systems, in comparison with conventional steam plant systems, are that:

- they have to rely on external cooling (water or air) because of the lack of steam condensate.
- the working fluid can be harmful to the environment in case of leakage. It is therefore important to consider the environmental properties, for example poisonousness and potential as greenhouse gas.

[12] http://www.eere.energy.gov/geothermal/powerplants.html

There is a formula to estimate the net generated electric power (NEP) from a binary plant heat exchanger [4]:

$$NEP = (0.18T - 10)\frac{ATP}{278} \qquad (Equation\ 1)$$

where NEP = net electric power (kW)
T = inlet temperature of the primary fluid (˚C)
ATP = available thermal power (kW)

1.3.3 Future geothermal power technologies – Total flow turbines

This is an experimental process, based on using concurrently the steam, hot water, and pressure of geothermal resources (i.e. the total resource), thereby eliminating the energy losses associated with the conventional method of flashing and steam separation. No total flow device has yet achieved commercial status (6)

1.4 Present geothermal power market

As seen in figure 4.1, the amount of installed geothermal power capacity grows for every year, as well in EU-25 as worldwide. The distribution of various kinds of power plants is shown in table 4.1. Finally, table 4.2 concentrates on the geothermal power plants in EU-25 and its candidate countries.

Figure 4.1. Worldwide and EU-25 geothermal power installation 1980-2004. [6, 7]

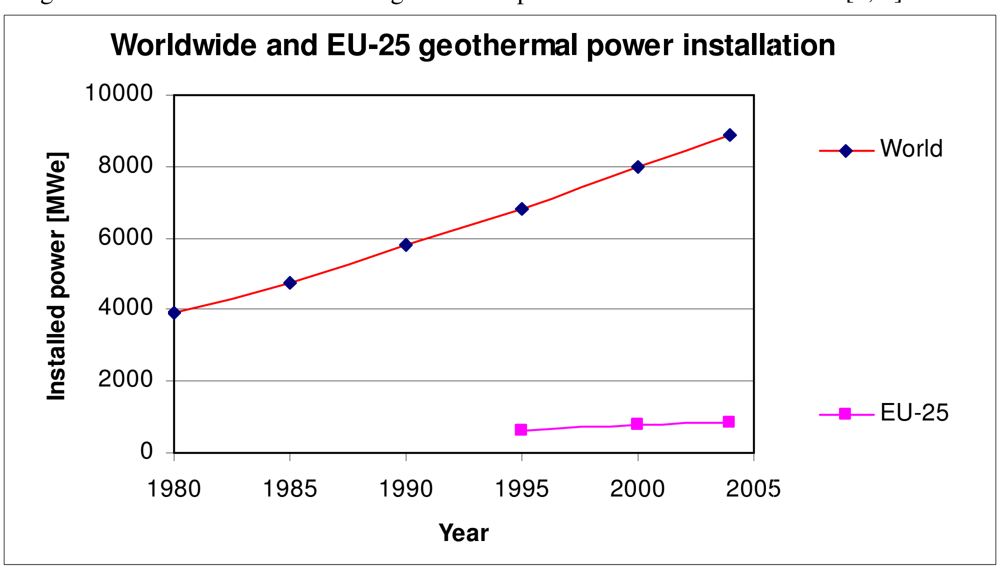


Table 4.1. Power plants distribution worldwide [6]

Category	Installed capacity [MW]	Share – Installed capacity [%]	Numbers of units	Share – Numbers of units [%]
Single-flash steam	3 541	39.9	135	28.9
Double-flash steam	2 197	24.8	70	15.0
Triple-flash steam	94	1.1	5	1.1
Dry steam	2460	27.7	63	13.5
Binary	274	3.1	155	33.2
Flash-Binary	301	3.4	38	8.1
Hybrid	6	0.1	1	0.2
Total	**8 873**	**100%**	**467**	**100%**

Table 4.2. Geothermal power plants in EU-25 and its candidate countries by number of units and installed MW for each type of plant. Note that the power plants in France and Portugal are situated in Guadeloupe and the Azores respectively. [6]

Type of plant	Italy		Austria		Germany		Turkey		(France)		(Portugal)	
	No	MW	**No**	MW	**No**	MW	**No**	MW	**No**	MW	**No**	MW
Single-flash	**1**	20					**1**	20.4			**1**	3
Double-flash									**2**	14.7		
Dry steam	**31**	770.5										
Binary cycle	**1**	0.7	**2**	1.25	**1**	0.2					**4**	13

1.5 Future development

A simple extrapolation of the plots shown in figure 4.1 can give an idea of the future development of geothermal energy conversion. This would give the results shown in table 5.1. According to the International Geothermal Association [14] the worldwide geothermal potential is 22 400 TWh/yr, of which 3 700 TWh/yr is in Europe. Half of this potential respectively is conventional technology and half is binary technology. The World Energy Assessment (WEA) estimates the potential future electricity cost to be 8 to 64 Euro/MWh[13] [16].

Table 5.1. Installed power [MW_e] by extrapolation of data from 1980 to 2004 (world) or 1995-2004 (EU-25). Data from [6, 7]

	Linear approximation	
Year	**World**	**EU-25**
2010	10 057	971
2020	12 147	1 179
2030	14 237	1 387

In the World Geothermal Congress 2005 in Antalya, Turkey, 24-29 April 2005, the members of the International Geothermal Association stated their plans for the year 2010. According to these statements, compiled in table 5.2, the growth rate of geothermal installations remains the same even the upcoming five years. On a longer view, for example to 2030, potential data is not very common. But as the last columns of table 5.2 indicate there is a huge potential, waiting to be taken into use.

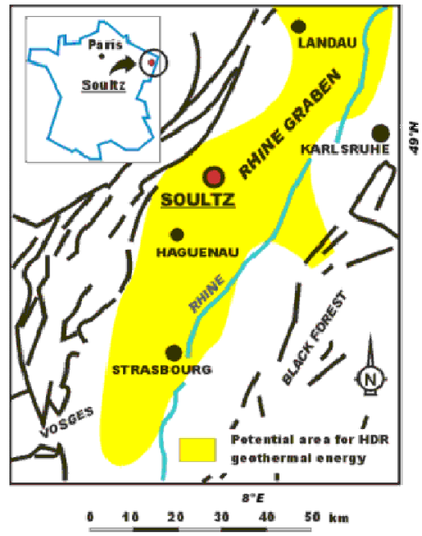
[13] USD/EUR=1.25, www.valuta.se. 2004-01-01.

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

The project consists of four phases:

- Phase 1) Drilling of two wells to 3 600 m
- Phase 2) Drilling a well to 5 000 m
- Phase 3) Building of a pilot plant
- Phase 4) Building a geothermal production power plant

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.



F*igure 5.1. The Soultz-sous-Forêts program*

Table 5.2. Current use of geothermal energy and potential for electricity generation in EU-25 and its candidate countries country by country. Figures in *italics* are calculated from the projected installed power by assuming a 7000 h operational time per year. [12, 15]

Country	Installed power and generated electricity by 2003 [12]		Total projected (planned) production by 2010 [15]		Potential [15]	
					Technical	Commercial/ Realistic
	MW_e	GWh_e	MW_e	GWh_e	GW_e	GW_e
EU-25						
Austria	1.25	3	6	15	-	-
Belgium	0	0	0	0	-	-
Czech Republic	0	0	0	0	-	3.4
Cyprus	0	0	-	-	-	-
Denmark	0	0	0	0	-	-
Estonia	0	0	0	0	-	-
Finland	0	0	0	0	-	-
France (incl. Guadeloupe)	15	23	33	*231*	-	-
Germany	0.23	0.2	3	*21*	18-45[14]	-
Greece	0	0	20	*140*	-	-
Hungary	0	0	80	600	-	-
Ireland	0	0	0	0	-	-
Italy	790.5	5 036	882	6 000	-	-
Latvia	0	0	0[15]	0	-	-
Lithuania	0	0	0	0	-	-
Luxembourg	0	0	0[16]	0	-	-
Malta	0	0	-	-	-	-
Netherlands	0	0	0	0	-	-
Poland	0	0	0	0	-	-
Portugal (incl. the Azores)	16	90	35	275	-	-
Slovakia	0	0	6	40	-	-
Slovenia	0	0	0	0	-	-
Spain	0	0	0	0	-	-
Sweden	0	0	0	0	-	-
United Kingdom	0	0	0	0	-	-
TOTAL (rounded)	**823**	**5 150**	**1 060**	**7 300**		
Candidate countries						
Bulgaria	0	0	0	0	-	-
Croatia	0	0	4.4	34.3	-	0.38
Romania	0	0	0	0	-	-
Turkey	120 [7]	20.4 [6]	500	*3 500*	-	0.5 / 2[17]
TOTAL (rounded)	**120**	**20**	**504**	**3 530**		

[14] The total technical potential 1155 EJ [15] to 300 000 TWh [13] (partly heat conduction from the earth's interior but mostly storage) divided in 1000 years of use.
[15] http://www.geothermie.de/egec_geothernet/menu/frameset.htm
[16] http://www.geothermie.de/egec_geothernet/menu/frameset.htm
[17] Without/With subsidies

1.6 Conclusion

Geothermal power production is an environmentally benign way to produce electricity. As a typical base load provider, it is also very beneficial for the grid. Geothermal power production has got a history of almost exactly hundred years and today it is the third largest renewable power source in the world with a production of 57 TWh_e in the year 2005. In EU, almost all geothermal electricity is produced in Italy. This is due to the good natural conditions, with hot water situated near the surface of the earth. With these conditions, geothermal electricity is one of the cheapest ways to produce electricity. The investment cost is large (640 000 to 2 400 000 Euro/MW) but the running costs are low. The resulting electricity cost of geothermal power production today is approximately 16 to 80 Euro/MWh. The production in EU-25 in the year 2005 was 5.5 TWh and the total projected production by the year 2010 is 7.3 TWh.

To increase its share of the European electricity market and take a substantial part of the market, geothermal power industry has to adopt other means of transforming the heat energy into electricity. Three ways of doing this are hot dry rock (HDR), magma and geopressured systems. If these occurrences of energy can be fully exploited, the potential, in Europe as well as worldwide, is huge. It is hard to give just one figure of the potential of geothermal power production. The natural potential is several hundreds of thousands of TWh. The technical potential is much less, but still substantial, several hundreds of TWh. The commercial potential by the year 2030 is of the order of tens of TWh.

To fulfill this potential, geothermal power production need incentives. For instance, a correct internalization of external costs so that geothermal power production, and other renewables, can compete under the same conditions with fossil fuels. The fact that geothermal exploitation is a high risk business, means that the technology must be furthered and sources better understood. Funding research and development of future technologies, such as HDR, can boost the industry interest in geothermal energy.

But the most important factor for the competitiveness of geothermal power is the prizes of competing fuels, especially oil and gas. If the development of the last year continues and oil and gas prizes continue to rise, geothermal power is commercially viable to a much larger extent than otherwise and can grow substantially regardless of incentives and subsidies.

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