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SWISS GEOTHERMAL UPDATE 1995 - 2000

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ABSTRACT

The R & D efforts in the past years led to remarkable achievements in direct uses of geothermal energy in Switzerland: areal density of borehole heat exchanger systems for decentral space heating is highest worldwide; novel solutions like combined heat extraction/storage, energy piles, tunnel water use are supported by governmental aid. While a white spot on the world geothermal map in the mid 1970'es, today it occupies the prominent world rank three in direct use. The risk guarantee system for aquifer drilling >400m which terminated in 1998 led to some success (e.g. the first doublet system in Riehen/BS which is being extended into Germany) but also to a number of failures.

The heat supply from geothermal sources is via electric heat pumps (HP). In 1998 the heat production for direct applications (mainly space and domestic water heating) was 618 GWh, the geothermal input (before the HP) amounted to a total of 410 GWh. Over 90 % of this is supplied by shallow systems (horizontal coils, borehole heat exchangers (BHE), and groundwater wells. Annual growth rate is 12 %. The BHE's nowadays reach 200 m depth; drilling and installation cost is around 40 $/m. Nearly 20'000 BHE/HP systems operate to date, mainly for single family dwellings and smaller building complexes. With one BHE/HP system every two km^2 Switzerland is the world leader. Several systems operate with BHE groups, deep BHE's and in combined heating/cooling use. A substantial R & D project („Deep Heat Mining") aims at the realisation, before the year 2007, of a co-generation facility producing heat and electricity from fractured crystalline basement. Substantial basic research is conducted in parallel to investigate, within framework of the European Hot Dry Rock Program (Soultz/F), coupled thermal, hydraulic, rock mechanics, and chemical processes in fractured media. Further international activities (e.g. participation in the IEA Geothermal Implementing Agreement) are summarized.

The standard Country Update reporting tables show numbers for the year 1990; it is anticipated that the geothermal production will amount to about 680 GWh in the year 2000.

1. INTRODUCTION

Switzerland is a small country (41'000 km^2, 7 million population) with a remarkably low reliance on fossil fuels for electricity generation (see Table 1). There is no geothermal-based electricity (Table 2 is therefore missing), only direct use.

This is the fourth Swiss geothermal update, summarizing R & D efforts and results. The previous ones appeared in five-year successions (Griesser and Rybach 1985, Rybach and Hauber 1990, Rybach and Gorhan 1995), followed by an intermediate report (Rybach and Gorhan 1997).

Of the policy background the still ongoing parliamentary discussions about the introduction of a CO_2 tax and the action plan "Energy2000" (E2000) which is nearing to its end must be mentioned (details see below). A major change in governmental support policy took place in 1998 when the risk guarantee system for aquifer drilling > 400 m terminated.

A brief summary of geothermal direct use in Switzerland is given below. First, the role of geothermal energy utilisation is positioned within the global and the Swiss energy scene. Thereafter, near-surface thermal water occurrences are treated, followed by deep, stratiform aquifers. Then the unique experience with the numerous borehole heat exchangers is highlighted (including some specific applications) and some prospects of tunnel waters are outlined, followed by a summary of the new "Deep Heat Mining" (DHM) project. Finally the Swiss activities on the international geothermal scene are summarized.

2. GEOTHERMAL UTILISATION IN THE GLOBAL AND THE SWISS ENERGY SCENE

The achievements of Switzerland in the direct use of geothermal energy are remarkable: while a white spot on the world geothermal map in the mid 1970s, today it it occupies a prominent world rank in direct use. With an installed capacity of about 70 W_{th} per capita it ranks number three behind Iceland and New Zealand (see Chapter 4).

On the national scene the utilisation is embedded in the above-mentioned action plan E2000. This ten year program aims, for the year 2000, at a) stabilising CO_2 emissions at the 1990 level, b) additional production of 3'000 GWh heat from renewable sources (3 % of total heat demand), c) additional 300 GWh electricity production from renewable sources (0.5 % of total production), and d) efficiency improvement of hydropower; power uprate (10 %) of nuclear power plants as well as saving and rational use of energy. In 1995, at mid-way, the E2000 goals were generally fulfilled to 50 %. Today it is questionable whether the goals will be reached to 100 % by the year 2000.

Geothermal direct use developed rapidly over the last 5 years. Table A shows the significant role of geothermal production in comparison with other renewable sources; Table B presents the breakdown of different geothermal sources. The input data are from a statistical survey and represent the situation in 1997 (Rybach and Wilhelm 1999). It is anticipated that the geothermal production will amount to about 680 GWh in 2000.

3. THE SWISS GEOTHERMAL MIX

The Swiss mix has two main components: 1) shallow resources utilization (horizontal coils, borehole heat exchangers/BHE, foundation piles, groundwater wells; 2) use of deep resources (deep BHEs, aquifers by singlet or doublet systems, tunnel waters). Heat pumps (HP) are key components in practically all utilization schemes. The BHE/HP system is especially suitable for a country like Switzerland where construction space is limited and land expensive.

The above-mentioned statistical survey assembled available data on heat production from different geothermal sources. The values given in Table B refer to the year 1999; the total heat produced by geothermal installations amounted to 618 GWh (after the heat pumps) whereas the geothermal portion was 410 GWh. The corresponding figures in 1990 were 316 GWh and 211 GWh, respectively; this means an increase of 95% over nine years, or an average increment of > 11 % p.a. Fig. 1 shows the different proportions; the predominance of BHE systems is obvious. An additional 75 GWh is estimated to originate from thermal springs, used for balneology and space heating. The standard reporting Tables (no. 3 and subsequent) show numbers for the year 1999.

Essential for the drilling and development of deep resources has been the risk guarantee of the Federal Government: the total sum of $10x10^6$ US$ was available from 1987 to 1998 to cover the risk of drilling and testing of wells deeper than 400 m. Exploration and development of the deep resources definitely benefited from the guarantee. The success is not overwhelming: out of a total of 12 drillings performed under the risk guarantee five complete successes, one partial success and seven failures (=dry holes) are to be reported (Brunner et al. 1999; see also Fig. 2). It seems rather unlikely that deep drilling will be resumed without a Governmental risk guarantee in the near future.

3.1 Thermal springs

Most of the long-known thermal spring facilities produce their water from wells. The spa environs were prime targets of exploration and drilling, encouraged by the risk guarantee. Table 6 shows the wells drilled in the period 1995-1999; their success is mixed (Fig. 2, see also Table 6).

While the primary purpose of direct utilisation at the Swiss spa facilities remains balneology, space heating in the bathing facilities and of nearby buildings like hospitals is also established at several places. The total installed capacity at 17 different localities is estimated to be around 25 MW_t (based on discharge rates and temperatures), the annual utilisation, including balneology, to about 75 GWh. Environmental concern calls for the protection of thermal water occurences from human activities (Vuataz 1997). In Table C the contribution by spa uses is not included.

3.2 Deep aquifers

Drilling to tap porous or fractured aquifers at depth was also encouraged by the Governmental risk guarantee. One real success can be reported: the first Swiss doublet system in Riehen is operational since 1994 (geothermal capacity 4.7 MW_{th}, total heating power 15.2 MW_{th}); the district heating network is extended to the neighboring community Lörrach in Germany, thus providing the first example of a trans-boundary geothermal utilisation. Heat production from deep aquifers (both singlet and doublet operations) amounted to 36.3 GWh in 1999.

3.2 Deep Borehole Heat Exchangers

Deep BHE’s can be installed in abandoned drillholes, provided that consumers are nearby. Due to the considerably high hydrostatic and ground pressures this will require special construction, including materials like thermally isolated tubes and adequate heat extraction strategies. A deep BHE system can provide several hundreds of kW_{th} heating capacity. The first such installation in Switzerland was the 2.3 km deep BHE at Weggis/LU (a „dry“ geothermal borehole). Another deep BHE is in operation in Weissbad/AI where a 1.6 km drillhole failed to find formation water in Molasse rocks. At some of the “failure” sites of the risk guarantee drillings the establishment of a deep borehole heat exchanger is planned (Thonex/GE, St. Moritz/GR). Heat production from deep BHEs was 0.7 GWh in 1999.

3.3 Tunnel waters

Warm water frequently encountered during tunnelling („drainage waters“) can be directed from a tunnel portal directly to potential heat consumers instead of being wasted. However, the distance between portal and consumer should not exceed 1 to 2 km, because the length of a feeder pipe represents a major cost factor in such a project. According to the temperature of the tunnel water, a central or decentralized heat pump system might be applied for space heating.

Being a typical Alpine country, Switzerland has a great number of road and railway tunnels. The heat capacity of the 16 geothermally and economically most interesting tunnels in Switzerland amounts to more than 16 MW_{th}, enough to provide several thousands of inhabitants with heat energy. At four sites, tunnel water is already being used for space heating and domestic warm-water production, i.e. the Furka, Ricken, Gotthard road, and Mappo-Morettina tunnels. Another project using water from the Hauenstein tunnel with a capacity of 1.5 MW_{th} is under construction. Heat production in 1999 was 3.8 GWh. Of future interest are the Gotthard and Lötschberg base tunnels of the recently started AlpTransit project. Theoretical calculations and actual temperature measurements in deep exploratory excavations indicate a considerable heat potential.

3.4 Shallow resources

Shallow geothermal resources are ubiquitous, the technology to

tap them is readily available. Four main kinds are in use in Switzerland, all of them via ground-coupled heat pumps (HP): 1) horizontal heat exchanger coils, 2) borehole heat exchangers (BHE), 3) groundwater wells, 4) foundation piles. It is evident from Table B that the BHE/HP systems are clearly predominant, in fact they led to a great and general success in geothermal direct use in Switzerland, see below.

4. THE B H E SHOWCASE

The general popularity of heat pumps in Switzerland lead also to a real boom of heat pump (HP) coupled BHE systems. Today, every third newly built single family house is equipped with a HP system. Although air-source HP's are significantly lower in installation cost (there are no drilling costs as for a BHE system) nearly 40 % of the HP's installed today have a geothermal (BHE) source. The generally lower seasonal performance coefficient of air-source HP's (due to the low source temperature in winter) is the main reason of this high percentage. Seasonal performance coefficients > 3.0 for Swiss BHE/HP systems are common. The share of heat delivered by BHE/HP systems in the Swiss geothermal mix is overwhelming (see Fig. 2).

The most common BHE heating system with one or more boreholes typically 50 - 200 m deep is a closed circuit, HP-coupled system (Rybach and Eugster 1997). The BHE consists usually of double U-tube plastic pipes in grouted boreholes (Rybach 1998) and can operate in most geologic media, by conduction (no formation fluids required).

The boom resulted in the installation of nearly 20,000 BHE systems to date, with a total of about 4,000 km of BHE length. Technical and economic factors lead to the boom. Their synergy is responsible for the rapid market penetration (for details see Rybach and Eugster 1998). At present, 1 m of a BHE costs about 40 US$ (drilling and installation included). The number of installations increases in the last five years annually by > 15 %, as well as the heat production (see Fig. 3).

The widespread BHE installations secure Switzerland a leading position internationally: areal BHE density in Switzerland is highest worldwide (1 BHE installation every 2 km^2). Of all countries China has, with 2.1 GW_t, the largest figure in installed geothermal capacity for direct use, followed by the USA with 1.8 GW_t. China and the USA are huge countries. So some normalisation is needed to account for the country size. Normalisation was performed on the basis of the installed capacity and the country population: the installed geothermal capacity for direct use (W_t) per capita was calculated and the ranks listed (Table C). Rank three right behind leading countries like Iceland and New Zealand is indeed remarkable.

5. R & D HIGHLIGHTS

The Swiss Government is supporting geothermal R & D through two program lines: a) research, and b) promotion, especially of pilot and demonstration facilities. Whereas emphasis might change from year to year, focus is on subjects like tunnel waters, Deep Heat Mining (see below), and BHE related work. Some details are given below.

5.1 Experimental and theoretical BHE work

The BHE success story bases on extensive R & D efforts. The performance of several operating facilities is being monitored over years with special measuring equipment installed at the facilities. This provides a unique data base to assess long-term performance. E.g. at the site Elgg near Zurich ground temperatures at different depths and distances surrounding a BHE are recorded, along with atmospheric temperatures and operational parameters (hydraulic system flowrates, circuit temperatures, HP power consumption and run times), in 30 minute intervals over more than 10 years. In parallel, extensive theoretical investigations are carried out, mostly by numerical modelling (see e.g Rybach and Eugster 1998). The experimental work (monitoring of operational facilities) and the theoretical studies (modelling results) prove that the BHE systems, if properly designed, operate reliably also on the long term without negative environmental effects. In fact, a new thermal stability is reached in the ground around the BHE after a few years of operation, thus providing sustainable heat extraction (Rybach et al. 1999).

5.2 Novel frontiers in shallow resources

The utilisation of shallow geothermal resources in general and heat extraction by BHE's in particular is a prominent task with broad perspectives. This rapidly growing field of R & D in Switzerland can only briefly be summarised here, merely by mentioning the main topics and applications:

- New drilling methods: Reducing drilling and operation time can be a major cost saving factor. A specific R&D project identified a Swedish drilling tool, i.e. a very high pressure, hydraulic hammer, as the most suitable method to drill for borehole heat exchangers. In an actual field test in Weissbad/AI, an inclined drill hole of > 600 m was accomplished in less than three days.

- Multiple BHE's: There is a tendency to increase the size of geothermal installations by using a multitude of BHE's. Extensive studies are being carried out to determine optimum depths and borehole spacings in order to guarantee an economic life span. As an example, the BHE field with 40 150 m deep BHE's at the Scuol/GR spa can be mentioned.

- Combined heat extraction/storage, heating/cooling: Multiple BHE's can also be used to access a ground storage volume for seasonal storage of waste heat from large buildings or with solar energy (solar collectors, flat building roofs, surfaces of streets or parking areas). Several such installations work satisfactorily (Meister jewellery factory Wollerau/SZ with 32 135m deep BHE's, the road bridge snow/ice melting system SERSO at Därligen/BE with 91 65 m deep BHE's, no heat pump).

- Energy (foundation) piles: Foundation piles can be equipped with heat exchangers. Two installations in Kreuzlingen/TG (Fotocolor: total pile length 1'023m) and Finkernweg (4'200m) can serve here as examples. But care must be taken: the general stability of the supported building must not be endangered due to friction loss and / or expansion / shrinkage caused by thermal stress within the piles. This problem is at present being addressed by a respective research project of the Swiss Federal Institute of Technology at Lausanne (EPFL), both in theory (by means of computer simulations) and by actual field tests (Laloui et al. 1999).

- There are also novel solutions on the economic sector: „energy contracting" is also available for BHE installations. This means that the installations are financed and operated by a contractor and heat is then sold to the consumer, based on long-term contracts. In this case, the designer, builder and operator comprise the same company, which helps to optimise design and performance.

5.3 Deep Heat Mining (DHM)

The Swiss Federal Office of Energy has initiated in 1996 a new project, called „Deep Heat Mining". This project aims at the realisation of a first pilot plant in Switzerland, between the years 2005 and 2010, to produce electricity and/or heat by the HDR technology. The current activities of a special team, assembling private companies as well as university institutes, extend over general site evaluation, feasibility studies, economic, public relations and financing considerations.

Stress field and temperature field data in crystalline basement indicate favourable conditions in the region of Basel. The first phase of a study has been completed with the aim to quantify minimum reservoir design parameters necessary for sustainable heat extraction combined with the production of electric power. Two potential sites for constructing a pilot plant in the immediate vicinity of the district heating system of the city have been identified for more detailed investigations. The drilling of a first 2500 m deep exploratory hole into crystalline basement started in 1999 and will later serve as a seismic monitoring well.

6. INTERNATIONAL ACTIVITIES

Swiss scientists are regularly active on the international geothermal scene. The synoptic interpretation of KTB observables (German Continental Deep Drilling Project) is to be mentioned here (Kohl and Rybach 1996, along with the POLYPROJECT MARMARA, an interdisciplinary approach to unveil the complex interplay of active tectonics, hydrogeology, geothermics and seismology in W Turkey (Pfister et. al 1997). Regardless of its non-member status, Switzerland participates in EU projects like the European Geothermal Atlas (Medici and Rybach 2000) and the European HDR Project in Soultz.

The primary goal of the Swiss contribution to the Soultz project is a quantitative understanding of the relevant physical processes which may govern the long-term production behavior of HDR reservoirs. In particular, the hydraulic, thermal and rock mechanic processes and their coupling are addressed. Field test data analysis indicates non-Darcian, non-laminar flow in the near and far field of the boreholes (for detailed description see Kohl et al., 1997). Data archiving of the Soultz project as well as of other HDR projects elsewhere is pursued as a parallel activity. These activities are supported by the Swiss Federal Office of Science and Education.

Closely linked to the Soultz and DHM activities is the participation of Switzerland in the Geothermal Implementing Agreement of IEA (Rybach 1998).

The Swiss Geothermal Association, affiliated to IGA, (presently over 300 members) is active also on the European Scene: key organizer of the European Geothermal Conference 99 (September 1999, Basel), founding member of EGEC and signatory of the Ferrara Declaration (May 1999).

Finally the involvement of the first author in international Postgraduate training (in Reykjavik/IC and Auckland/NZ, Açores/PT and Oregon/USA) can be mentioned.

7. CONCLUSIONS, OUTLOOK

Also during the period 1995-2000 geothermal R & D in Switzerland was in line with the general energy policy of the country (a.o. promotion of indigenous, environmentally benign energies). Whereas the Governmental risk guarantee program which terminated in 1998 yielded mixed results the utilisation of the ubiquitous shallow resources boomed into rapid market penetration of BHE/HP systems: Switzerland is now the world leader in this technology (one BHE/HP installation every two km^2). With an installed capacity of about 40 W_{th} per capita the country ranks number three worldwide in direct use behind Iceland and New Zealand.

The achievements are backed by intensive research work, within the national as well as the international framework. In Switzerland, novel solutions are emerging which are carefully investigated (e.g. tunnel waters, energy piles). The contributions to various international activities but especially to geothermal EU and IEA projects are well received and appreciated. The progress in geothermal R & D can be mainly attributed to the persistent project promotion policy of the Swiss Federal Office of Energy.

In the years 2000-2005 especially the DHM project is expected to receive continuous support and attention.

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REFERENCES

Griesser, J.C., and Rybach, L. (1985). Overview of geothermal activities in Switzerland. *GRC Transactions,* Vol. 9, Part 1, pp. 185-190.

Kohl, Th., and Rybach, L. (1997). Thermal and hydraulic aspects of the KTB drill site. *Geophys. J. Int.,*Vol. 14, pp. 756-772.

Kohl, T., Evans, K.F., Hopkirk, R.J., Jung, R., and Rybach, L. (1997). Observation and simulation of non-Darcian flow transients in fractured rock. *Water Res. Res.,* Vol. 33, pp. 407-418.

Laloui, L., Moreni, M., Fromentin, A., Pahoud, D., and Steinmann, G. (1999). Heat exchanger pile: effect of the thermal solicitations on ist mechanical properties. *Bull. hydrogéol.,* Vol. 17, pp. 331-340.

Medici, F., and Rybach, L. (1999). Switzerland. In: *Atlas of Geothermal Resources in Europe*., Hurter, S. and Haenel, R. (eds)., pp. 81-82.

Pfister, M., Rybach, L., and Simsek, S. (1997). Geothermal rconnaisaance of the Marmara sea regin. In: *Active Tectonics of Northwestern Anatolia – The MARMARA Poly-Project*. Schindler, C. and Pfister, M. (eds.), pp. 503-535.

Rybach, L., and Hauber, L. (1990). Swiss Geothermal Energy Update 1985 – 1990 . *GRC Transactions* Vol. 14, Part II, pp. 239-246

Rybach, L., and Gorhan, H. (1995). Swiss geothermal energy update 1990-1995. In: *Proc. World Geothermal Congress 1995*, Vol. 3, pp. 2133-2139.

Rybach, L., and Gorhan, H. (1997). Geothermal research and development in Switzerland: Achievements and prospects. In: *Proc. NEDO International Geothermal Symposium Sendai,* pp. 342-350.

Rybach, L., and Eugster, W.J. (1997). Borehole heat exchangers to tap shallow geothermal resources: The Swiss success story. In: *Proc. 19th New Zealand Geothermal Workshop. Auckland,* S.F. Simmons, O.E. Morgan & M.G. Dunstall (eds.), pp. 63-69.

Rybach, L., and Eugster, W.J. (1998). Reliable long term performance of BHE systems and market penetration – The Swiss success story. In: *Proc. 2nd Stockton Geothermal Conference*, 15 p. 87-101.

Rybach, L. (1998). The IEA Geothermal Implementing Agreement – Status and Prospects. *GRC Transactions,* Vol. 22, pp. 55-60.

Rybach, L. (1998). Market penetration of BHE coupled heat pumps – The Swiss success story. *GRC Transactions* Vol. 22, p. 451-455.

Rybach, L., and Wilhelm, J. (1999). Swiss Geothermal Society (SGS) Presentation. *IGA News no. 35, January-March 1999*, pp. 9-10.

Rybach, L., Mégel, T., and Eugster, W. (1999): How renewable are geothermal resources? . *GRC Transactions* Vol. 23, pp. 563-567.

Vuataz, F.-D. (1997). Natural variations and human influences on thermal water resources in the Alpine environment. In: *Proc. 33e Conférence de la Société des Techniques Hydrothermales,* Hakone/Japon, 6 pp.

Table A. Heat production from different sources in 1999.

Source	**Production (GWh)**
Biomass (e.g. wood)	**5’720**
Environment (air, water, ground) *(of which Geothermal:*	**1‘030** ***618)***
Solar	**260**
total	**7’010**

Table B. Contributions of different geothermal sources to heat production in 1999 (without thermal spring utilization; for this see Table 5)

System	**Production (GWh)**
Horizontal pipes	**32.0**
Borehole heat exchangers	***362***
Groundwater wells	**180**
Foundation piles	**2.8**
Deep borehole heat exch.	**0.70**
Deep boreholes (aquifers)	**36.3**
Tunnel waters	**3.80**
total	**617.6**

Table C: Geothermal direct use - world ranking

Rank	Country	Installed capacity (MWt)	Population (million)	Capacity per capita (Wt)
1.	**Iceland**	**1'443**	**0.27**	**5'344**
2.	**New Zealand**	**264**	**3.5**	**75.4**
3.	***Switzerland***	***525***	***7.0***	***70.0***
4.	**Sweden**	**330**	**8.7**	**37.9**
5.	**Macedonia**	**70**	**2.1**	**33.3**
6.	**Hungary**	**325**	**9.8**	**33.1**
7.	**Slovakia**	**100**	**5.3**	**18.9**
8.	**France**	**456**	**57.7**	**7.9**
9.	**USA**	**1'874**	**260**	**7.2**
10.	**Romania**	**137**	**33**	**6.2**

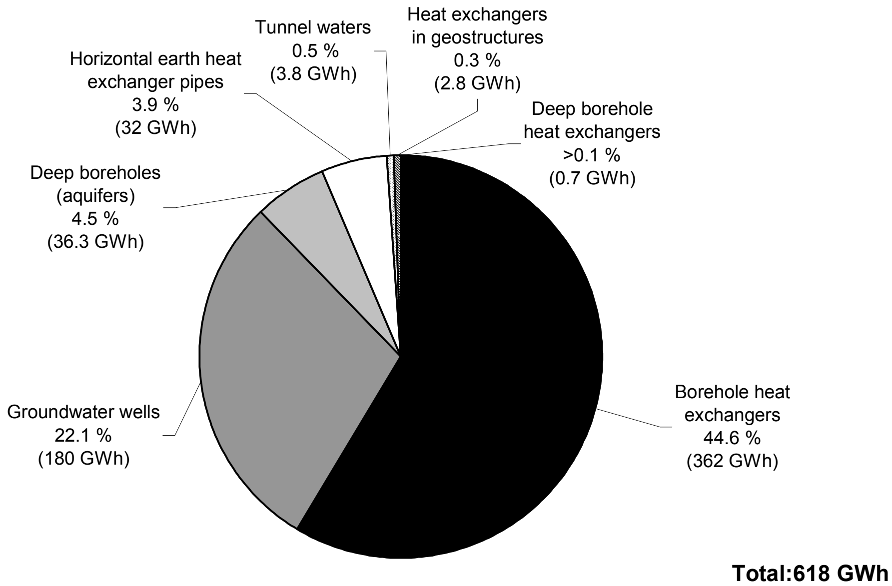

Figure 1. Contributions of the different geothermal sources to the total heat production for the year 1999.

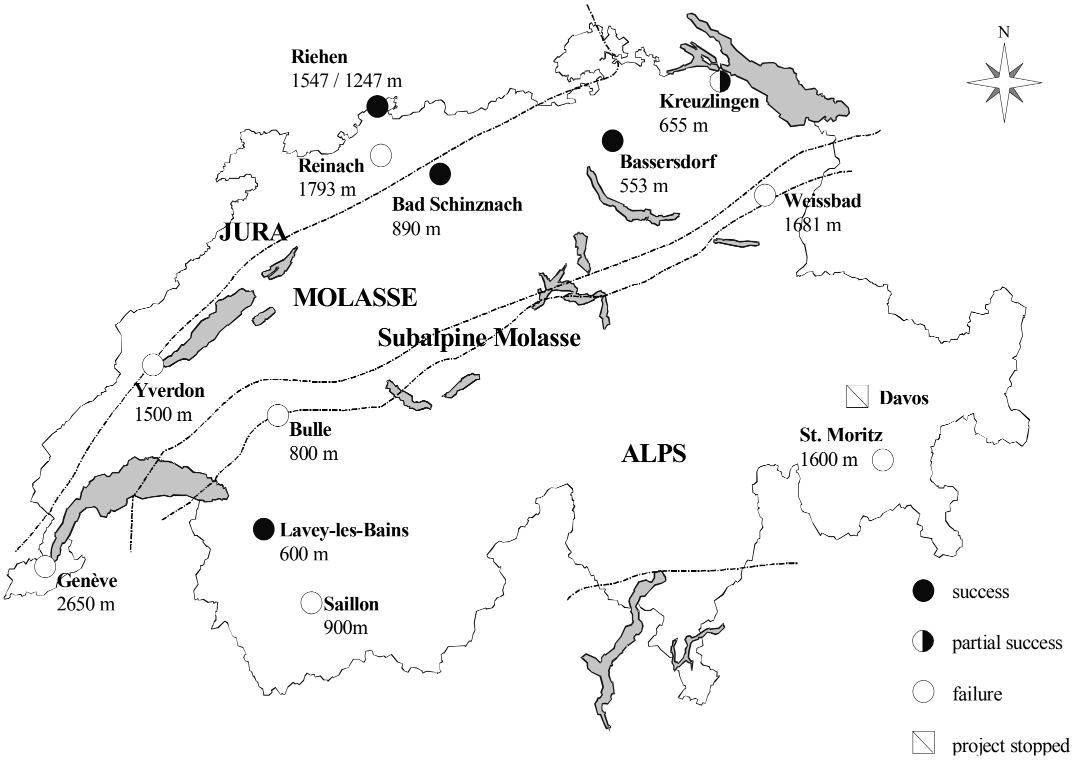

Figure 2. Location map of geothermal drillholes > 400 m executed within the Governmental risk coverage system 1987 –1998.

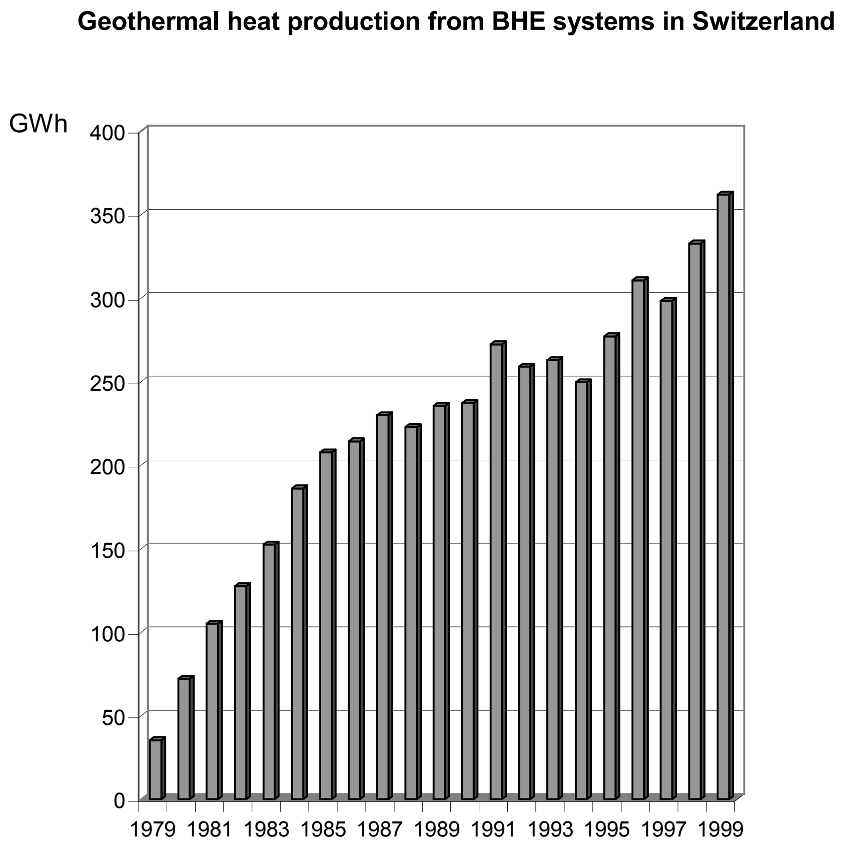

Figure 3. Geothermal heat production from borehole heat exchangers. The fluctuations around the development trend are caused by annual changes in heating demand (strong/mild winters).

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICTY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specifiy)		Total	
	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr
In operation in January 2000	-	-	1040	2650	13220	33340	3190	20710	-	-	17450	56700
Under construction in January 2000												
Funds committed, but not yet under construction in January 2000												
Total projected use by 2005			1060	2750	13250	33450	3190	20710			17500	56910

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 1999

[1] I = Industrial process heat
H = Space heating & district heating (other than heat pumps)
C = Air conditioning (cooling)
B = Bathing and swimming (including balneology)
A = Agricultural drying (grain, fruit, vegetables)
G = Greenhouse and soil heating
F = Fish and animal farming
O = Other (please specify by footnote)
S = Snow melting

[2] Enthalpy information is given only if there is steam or two-phase flow

[3] Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (°C) - outlet temp. (°C)] x 0.004184 (MW = 10^6 W)

or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

[4] Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)

or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

[5] Capacity factor = [Annual energy use (TJ/yr) x 0.03171]/Capacity (MWt)

Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% of capacity all year.

Locality	Type[1]	Maximum Utilization					Capacity[3]	Annual Utilization		
		Flow Rate	Temperature (°C)		Enthalpy[2] (kJ/kg)			Ave. Flow	Energy[4]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5]
17 spa localities	B/H						~25		~270	~0.1
5 installations with free cooling	C						2,20		4,00	0,06
Därlingen/BE	S						0,06		0,32	0,17
TOTAL							~27.2		~274,32	

Note: please report all numbers to three significant figures

TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF YEAR 2000

This table should report thermal energy used (i.e. energy removed from the ground or water)

and not the heat rejected to the ground or water in the cooling mode.

1) Report the average ground temperature for ground-coupled units or average well water or lake water temperature for water-source heat pumps

2) Report type of installation as follows:
V = vertical ground coupled
H = horizontal ground coupled
W = water source (well or lake water)
O = others (please describe)

3) Report the COP = (output thermal energy/input energy of compressor) for your climate

4) Report the equivalent full load operating hours per year, or = capacity factor x 8760

5) Thermal energy (TJ/yr) = flow rate in loop (kg/s) x [(inlet temp. (°C) - outlet temp. (°C)] x 0.1319

or = rated output energy (kJ/hr) x [(COP - 1)/COP] x equivalent full load hours/yr

Locality	Ground or water temp. (°C)[1)]	Typical Heat Pump Rating or Capacity(kW)	Number of Units	Type[2)]	COP[3)]	Equivalent Full Load Hr/Year[4)]	Thermal Energy Used(TJ/yr = 10^{12}J/yr)[5)]
~17000 localities all over Switzerland	10	19	~17000	V/H	3	1600	1240
~4000 localities all over Switzerland	10	40	~4000	W groundwater	3	1600	614
7 localities all over Switzerland	23-69	2500	7	W deep aquifer	3	1600	114
6 localities all over Switzerland	15	500	6	W tunnel water	3	1600	11
TOTAL			~21000				1979

Note: please report all numbers to three significant figures

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT AS OF 31 DECEMBER 1999

1) Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (^oC) - outlet temp. (^oC)] x 0.004184

or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalphy (kJ/kg)] x 0.001

2) Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (^oC) - outlet temp. (^oC)] x 0.1319 (TJ = 10^{12} J)

or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

3) Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^6 W)

Note: the capacity factor must be less than or equal to 1.00 and is usually less,

since projects do not operate at 100% capacity all year

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Space Heating[4]	20,0	132,0	0.2
Air Conditioning (Cooling)	2,2	4,0	0,1
Greenhouse Heating	0,0		
Fish and Animal Farming	0,0		
Agricultural Drying[5]	0,0		
Industrial Process Heat[6]	0,0		
Snow Melting	0,1	0,3	0,2
Bathing and Swimming[7]	~25	~270	0,1
Other Uses (specify)			
Subtotal	~50	~400	
Geothermal Heat Pumps[8]	500,0	1980,0	0,3
TOTAL	~550	~2400	

4) Includes district heating (if individual space heating is significant, please report separately)

5) Includes drying or dehydration of grains, fruits and vegetables

6) Excludes agricultural drying and dehydration

7) Includes balneology

8) includes shallow and deep systems

Note: please report all numbers to three significant figures.

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 1995 TO DECEMBER 31, 1999

[1)] Include thermal gradient wells, but not ones less than 100 m deep

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1)]						
Yverdon-les- Bain	>50 °C		1			1.47
Saillon	30		1			0.90
Production	>150° C					
	150-100° C					
	<100° C					
Bad Schinznach	44.5		1			0.89
Lavey-les-Bain	69.0		1			0.59
Total			4	1		6.05

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES

(Restricted to personnel with a University degree)

(1) Government

(4) Paid Foreign Consultants

(2) Public Utilities

(5) Contributied Through Foreign Aid Programs

(3) Universities

(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
1995	2		4			5
1996	2		4			5
1997	2	1	4			5
1998	2	1	4			5
1999	2	1	4			5
Total	10	3	20	0	0	25

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (1999) US$

Period	Research & Development Incl. Surface Exploration & Drilling	Field Development Including Production Drilling& Surface Equipment	Utilization		Funding Type	
	Million US$	Million US$	Direct Million US$	Electrical Million US$	Private %	Public %
1985-1989	3.0	30.0	35.0	-	85	15
1990-1994	5.5	50.0	53.5	-	85	15
1995-1999	10.0	105.0	115.0	-	80	20