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The Swiss Federal Office of Energy's Path on the Road to Utilizing Switzerland's Geothermal Resources – From Research & Development to Pilot- and Demonstration Projects

Gunter Siddiqi[1], Rudolf Minder[1]

1. Background

In the context of this contribution, geothermal energy includes the production of both heat and power from stored thermal energy in the Earth's crust. Broadly speaking one may refer to shallow geothermal resources that are often utilized by ground source heat pumps, generally to depths of 150–200 m. Hot water aquifers with temperatures above 60°C and depths to approximately 2 km (assuming a geothermal gradient of 30°C per km) may be utilized by direct heating schemes. A highly successful scheme, in operation since 1994, is located in the community of Riehen (Canton of Basle-City). One may utilize hot water to produce both, power and heat from even greater depths (today some 5 km); provided thermal gradients are high enough, the presence of an aquifer or permeable structure, and a satisfactory production rate. The ultimate prize and unlocking the huge geothermal resource base will be attained if the probability of success of finding and developing geothermal heat resources does not critically depend on encountering water bearing formations or structures. Rather the resource will be developed due to a combination of high temperature at depth, and the safe, reliable and predictable technology of creating subsurface heat exchangers via hydraulic, chemical or thermal stimulation (this technology is commonly referred to as Engineered/Enhanced Geothermal Systems with a number other terms in existence such as Hot Dry Rock, Hot Wet Rock, Hot Fractured Rock, Hot Rock, Man-made Geothermal Systems, petrathermal systems and more).

Switzerland continues to move towards the wide-spread use of renewable energies and energy-efficient technologies to satisfy its domestic demand for energy. A national energy program (SwissEnergy[1]) and corresponding cantonal programs provide the framework for continued uptake of sustainable and environmentally less harmful energies and technologies. Historically, the programs have relied more heavily on incentives and voluntary measures than on compulsory measures.

An increased utilization of geothermal energy is one of the contributing elements that will allow Switzerland to move towards an even more environmentally friendly and sustainable energy mix. Switzerland's geothermal resources like those of many regions worldwide are vast but remain largely untapped. Two companion studies (Baujard et al. 2007, Signorelli & Kohl 2007) that were funded by the Swiss Geophysical Commission and the Swiss Federal Office of Energy suggest that the technical potential is vast let alone the theoretical potential (Fig. 2).

The utilization of shallow geothermal resources at depths of less than 200 m via ground source heat pumps is not expected

[1] Swiss Federal Office of Energy, Department of the Environment, Transport, Energy and Communications. Postal Address: Swiss Federal Office of Energy, CH-3003 Bern, Switzerland [gunter.siddiqi@bfe.admin.ch, rudolf.minder@bluewin.ch]

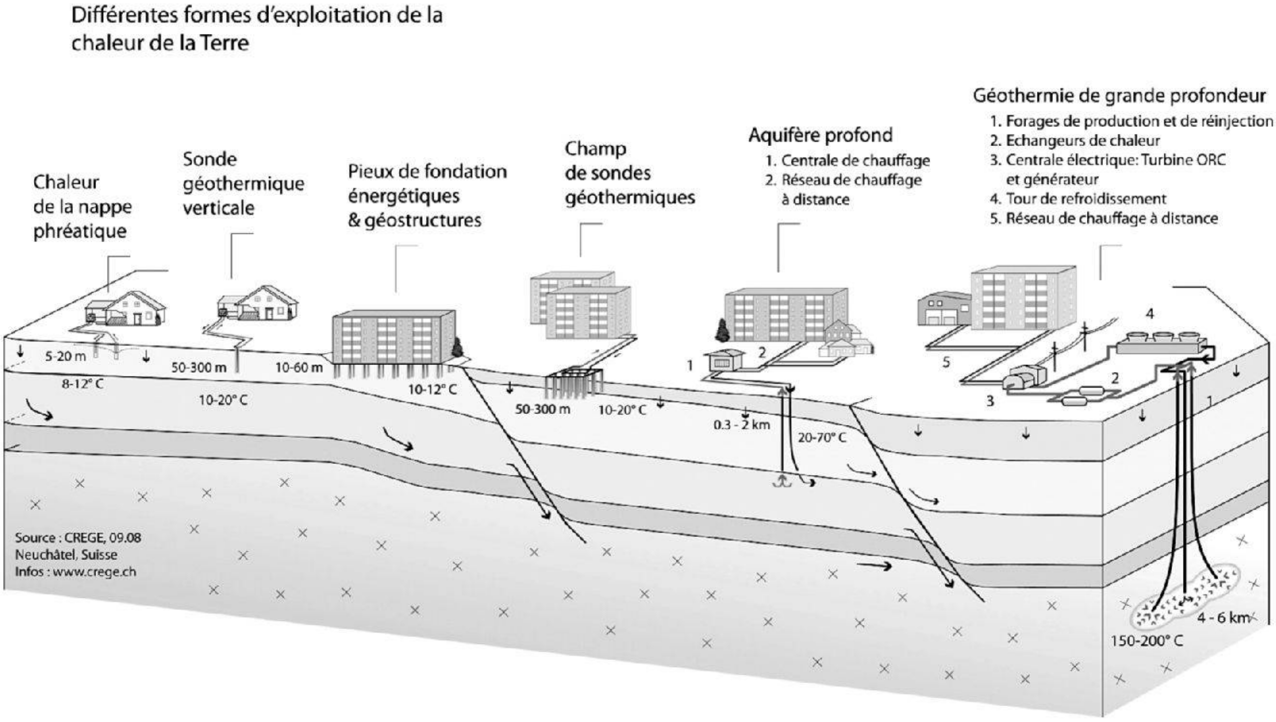

Fig. 1: The utilization of geothermal energy in Switzerland depends on depth, temperature at depth, technology readiness levels and customer demand (Source: CREGE).

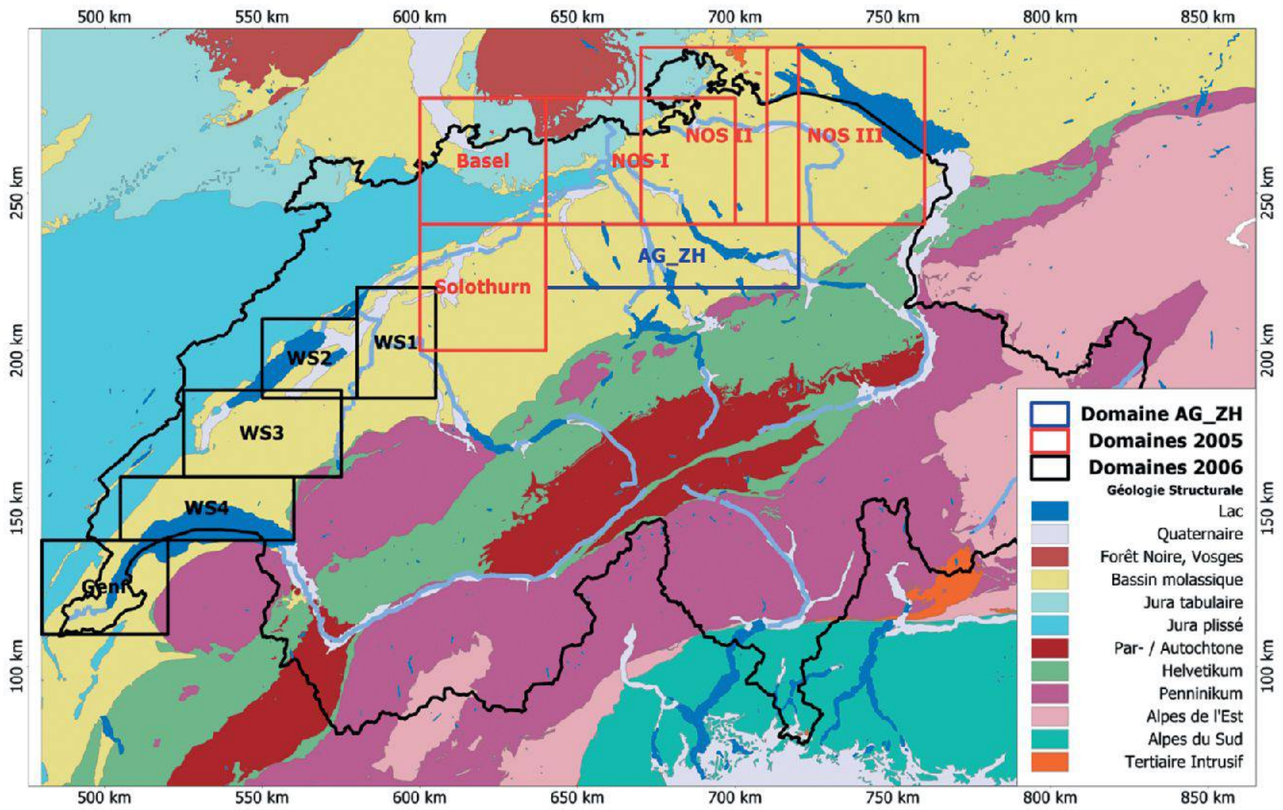

Fig. 2: Regions analyzed in the two companion volumes of the Swiss geothermal resources (Source: Baujard et al. 2007).

to be resource constrained at all. The ground source heat pump industry enjoys healthy and sustained growth rates in Switzerland reflecting a lively and competitive market place driven by customer demand without any major involvement of the research and development activities of the Swiss Federal Office of Energy.
Generally and somewhat simplified hydrothermal resources comprise resources located at depths greater than a few hundred meters with temperatures of less than 80–100°C as opposed to low temperature resources. The temperature range corresponds to today's cut-off for power generation using such heat resources. However, there is a long term trend towards progressively lower cut-off temperatures for power generation. The Swiss geothermal resources atlas describes low temperature resources that contain about ~ 10 Exajoule (or 2780 TerraWatthours [TWh], since 1 Exajoule ≅ 278 TWh) of heat that can be utilized technically. For comparison, the total primary energy consumption of Switzerland in 2008 was ~ 0.9 Exajoule or ~ 250 TWh[2]. Similarly, Switzerland consumes around 59 TWh of electricity per annum with an annual growth rate of ~ 1%.
Higher grade geothermal resources above 100°C but at depths less than 5 km contain about 26 Exajoule of heat. Assuming a further resource utilization factor that accounts for geometry, temperature, pay zone thickness, an area factor, conversion efficiencies and a capacity utilization factor of around 75 % one may envisage an ultimate installed capacity of 12–15 GW_{el} producing around 100 TWh of power per year for 30 years from geothermal resources to a depth of 5 km. With time and progress geothermal resources at even greater depths will become accessible. Depending on technology progress, location specific factors, aspects related to business development (supply and demand, supply chains, financial and manpower resources) one may expect that by 2035 between 1 and 10% of the technical potential to be developed. For example, scenarios developed within the framework of the Energy Perspectives of the Swiss Federal Office of Energy, or the «Energietrialog» suggest that by 2035 to 2050 between 1 and 5 TWh of the total 60–80 TWh of Switzerland's electricity power may realistically be generated utilizing geothermal resources.

To successfully bring Switzerland's geothermal energy resources to market, national geothermal stakeholders have to complete a number of journeys over the next few decades; one that covers technology research and development, piloting and demonstration; another one that enables the emergence of a geothermal industry that is active in Switzerland; a third journey has to be undertaken by the market in terms of a progressive development from a technology push towards a market pull and positive feedback loop between technology and market and finally a journey that regulators must undertake to ensure that regulations are appropriately adapted depending on the size and maturity of geothermal resource utilization (pers. communication C. Bremner, Head of International Development, UK Carbon Trust).
In the following sections we describe the role of the Swiss Federal Office of Energy on the technology journey with a specific focus on research, development and deployment of technologies and best practices to advance the utilization of deep, hydrothermal geothermal energy and Engineered/Enhanced Geothermal Systems.

2. Federally sponsored research

Federally sponsored research aims to create and deliver knowledge to ensure sound, efficient and long-term fundamentals for administrative processes and decisions that are aimed at securing a safe, reliable and affordable energy supply for Switzerland. In addition the research is directed towards specif-

ic problems that are highly interdisciplinary and serve the development of evidence based public policies[3]. Energy related research is one of 11 policy sectors that benefit directly from federally sponsored research.
Focus areas include research on energy efficiency, renewable energy, nuclear energy and socio-economic factors that link energy, economics and society. To deliver the expected input into the federal administration, the Swiss Federal Office of Energy has annual budgets ranging from CHF 20–25 million during the last 5 years. Over the last 20 years, availability of research funds for energy has continuously decreased. In total, publically sponsored energy research amounted to ~ CHF 174 million (average of 2006/2007) compared to CHF ~ 250 million about 10 years ago (Source: Projektliste der Energieforschung des Bundes 2006/2007[4]).
Most of the energy related federal research funds are spent on intramural research and development within the Federal Institutes of Technologies (around 55%). The Swiss Federal Office of Energy is the second largest funding agency (~ 15%) ahead of the European Commission (~ 10%). Other agencies contributing each a few percent include the Swiss Secretariat for Education and Research, the Confederation's innovation promotion agency and Cantonal governments.
The Swiss Federal Office of Energy has also the remit to coordinate federally sponsored energy research by developing and implementing of the Energy Research Master Plan of the Commission Fédérale pour la recherche énergétique (CORE), an advisory committee to the Department of the Environment, Energy, Transport and Communications. The uses of public funds go towards research, development and deployment related to energy efficiency (~ CHF 67 million), followed by nuclear energy research (~ CHF 52 million) and renewable energy related research (~ CHF 39 million). In addition near CHF 16 million go towards research into the interplay of energy, economy and society[5] (all figures are average values for the years 2006 and 2007).
There are strongly competing demands on federal budgets, a strong drive and obligation to reduce budgets in line with the sovereign's decision not to increase governmental debt levels which result in severe cuts and little prospect for growth. Despite the public being strongly concerned about energy-related topics such as security of supply, sustainable development and reliability, energy related research is a low to medium-low R&D intensity sector where less than 2% of net annual sales are dedicated to R&D in Europe (Guevara et al. 2009).

3. Direct use of geothermal resources

The Swiss Geothermal Association[6] publishes annual statistics on the use of geothermal energy in Switzerland (Signorelli et al. 2009). In 2008 some 2.1 TWh of heat have been produced from geothermal systems (Tab. 1) of which 1.6 TWh are directly attributable to geothermal energy.
The compound annual growth rate since the year 2000 has been a highly satisfactory 9%, attesting to the maturity of the technology, the uptake in the market place and the popularity among consumers. Noteworthy is the continued very high uptake of borehole heat exchanger coupled systems. Together with groundwater heat pumps they have a total share of some 86% of heat production and continue to enjoy high growth rates both in terms of installed capacity and heat produced. Thermal spas continue to contribute around 0.3 TWh of produced heat in Switzerland (Fig. 3).

Energy Savings

The total heat production of 2128 GWh (7.7 PJ) in 2008 corresponds to saving of some 183'000 metric tonnes of oil equivalent per year. Assuming an emissions factor of 3.18

Geothermal System	Installed Capacity (MW_{th}) –2008	Compound annual growth rate 2000–2008	Annual total heat production (GWh) –2008	Compound annual growth rate 2000–2008
Heat pumps with borehole heat exchangers, horizontal collectors	861.2	11%	1573.7	12%
Groundwater heat pumps	143.0	5%	221.8	6%
Energy piles («geostructures»)	10.4	14%	21.5	14%
Deep borehole heat exchangers	0.2	0%	0.8	2%
Deep aquifers for district heating	5.0	0%	15.5	-2%
Tunnel waters	2.4	1%	4.3	3%
Spas, wellness facilities	34.9	-1%	290.4	-1%
Total	1057.0	10%	2128.1	9%

Tab. 1: Installed capacity for direct use and associated total heat production for 2008[7].

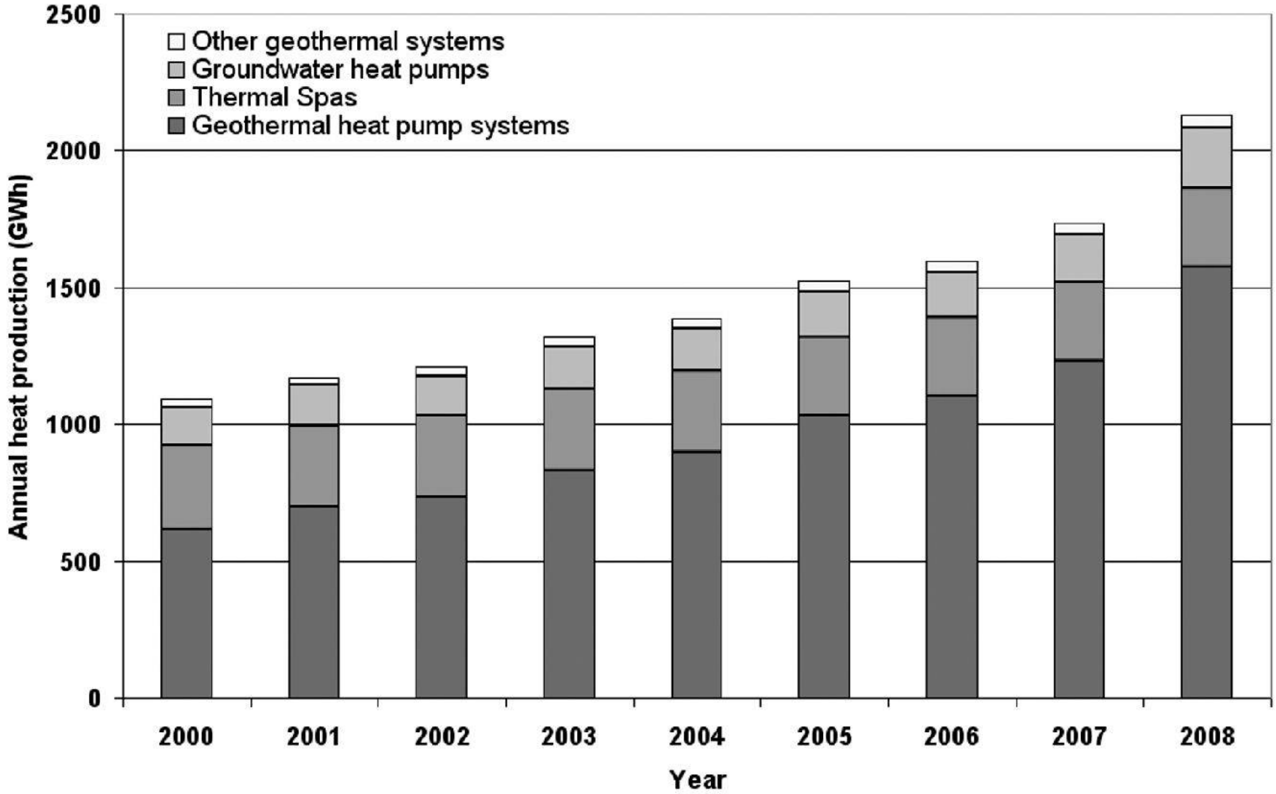

Fig. 3: Development of heat production of Swiss geothermal installations 2000–2008 (Source: Swiss Geothermal Association[8]).

tonnes of CO_2 per tonne of heating oil, an estimated 581'000 tonnes of CO_2 per year have not been emitted. This figure is likely to be an upper bound to the actual figure. Of the 581'000 tonnes, an estimated 17% are a reduction owing to the use of geothermal energy in renovated building stock and some 83% have been avoided owing to newly constructed buildings that otherwise are likely to have been heated using heating oil. Switzerland's own electricity production (~60% hydro, ~40% nuclear) is almost free of CO_2 emissions. But, there is very active pan-European power trading which on occasion results in the import of fossil-fuel derived electricity. This contribution would actually lower the amount of reduced and avoided CO_2 emissions.

4. Market Development and Stimulation

2008 saw a continuation of the boom in the utilization of geothermal heat pumps. During the years 2000–2008, borehole heat exchanger systems have been deployed mostly in newly constructed real estate. However, as most of Switzerland's building stock is old and in need of renovation, the rate of deployment in renovated building stock has correspondingly accelerated over the last few years. A closely correlated marker is the meters drilled for borehole heat exchanger – coupled geothermal heat pumps (Fig. 4). Whereas the 2000-2008 compounded annual growth rate of meters drilled for such systems in newly constructed real estate amounted to 21%, the rate of growth for such systems in renovated building stock was 38%[10].

To allow for more wide-spread deployment of geothermal heat pump systems particularly in densely built-up environments, the Swiss Federal Office of Energy has sponsored the construction of a mini-rig for drilling shallow geothermal wells to depth of around 100–120 m depth (Fig. 5). The rig is expected to meet the growing demand of customers with limited and difficult-to-access space for geothermal heat pump systems. The small dimensions (a width of 1.00 m) and the light weight allow for fast deployment.

To ensure the wide-spread uptake of geothermal energy utilization, the Swiss Geothermal Association[6] provides educational activities at universities, colleges and technical colleges and further education seminar on a regular and as-needed basis. A few hundred technical and engineering professionals have taken part in those activities. In addition the Swiss Geothermal Association was instrumental in the revamped industry standard for borehole heat exchanger cou-

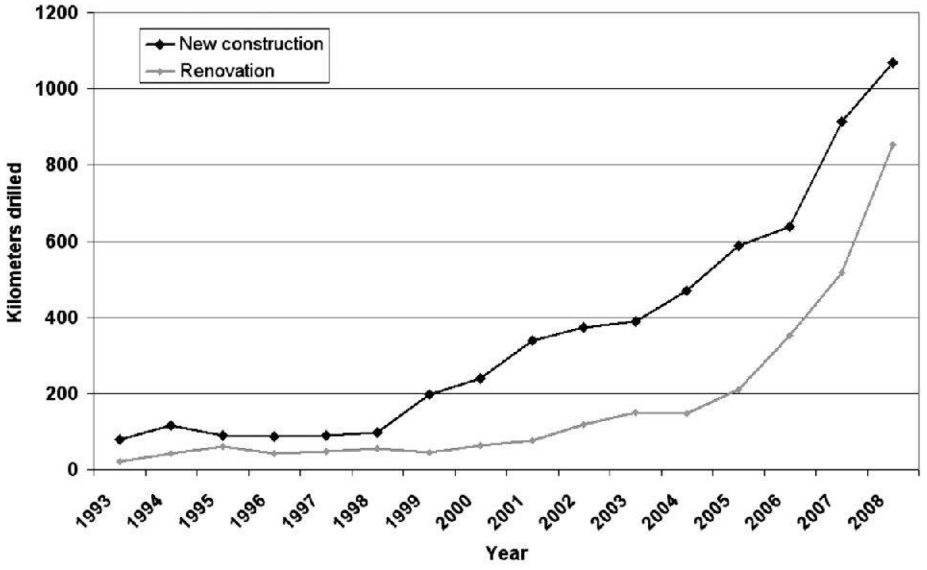

Fig. 4: Kilometers drilled – an indicator for market development for geothermal heat pump systems. In recent years geothermal heat pumps systems are increasingly deployed in the renovation of Swiss building stock[9] (last accessed on 25 April 2010).

pled systems (SIA 384/6) and contributed to the development and implementation of quality standards and certificates for the Swiss geothermal industry.

4. Hydrothermal Resources

Broadly and generally speaking Switzerland has a number of what might be informally termed «plays» (accumulations of geothermal heat with a particular combination of reservoir, heat source and sinks); one play related to the features of the Oberrheingraben as it extends into Northwestern Switzerland, the large and varied play associated with the Molasse Basin and lastly Alpine Valley-type plays like the Rhone Valley of the Cantons of Valais and Vaud. Oberrheingraben plays in Northwest-Switzerland utilize the presence of heat anomaly resulting from a failed rift structure. The Molasse Basin is a sedimentary basin several kilometers deep and containing some principal regional aquifers at depth which may present accumulations of hot brine in its pore space fed by major structures. Alpine valleys like the Rhone valley are relatively poorly understood from a tectonic-hydrologic view point. Sources of ubiquitous hot

Fig. 5: Light and compact mini-rig to drill shallow (100–120 m deep) wells for deployment of geothermal heat pumps systems (source: Terra AG and J. Wettstein).

springs and details of their sources are not well constrained, yet represent prime targets for exploration for geothermal resources that may be utilized for supplying heat to satisfy customer demand on surface and power generation.
A number of federally sponsored research, development and deployment activities are underway, both technology and project oriented. One continuing theme of sponsored projects includes feasibility studies for the utilization of geothermal resources in various tectonic setting. Currently underway are feasibility studies for the city of Winterthur. Similar to studies related to the cities of Zurich or St. Gall, local energy utility companies perform studies aimed at matching possible geothermal resources with demand on surface.

The large uncertainty of finding a geothermal resource and the value created by relatively cheap exploration programs is illustrated by the following hypothetical example; a geothermal energy project may have in the success case a net present value at a certain cost of capital of CHF 10 million, and a failure cost of CHF -5 million. The probability of success of finding and developing the resource is, however, only 15%. A simple and simplistic approach calculates the joint probability of a] finding a temperature anomaly at depth or temperature gradient of more than 30°C/km, b] encountering an aquifer or structure, which c] has sufficient permeability or transmissivity to meet the energy demand by customers on surface. In the absence of any indication one may estimate individual probabilities at 50% resulting in a joint probability of 12.5%. In other words, the estimated monetary value of the geothermal energy project is $0.875 \times (-5) + 0.125 \times (10) = -3.1$ million. The execution of an exploration program and, as a result, the likely increase in the (joint) probability of success and the estimated monetary value of a geothermal energy project is therefore an advisable value-added activity. Hence, the Swiss Federal Office of Energy sponsors a few projects that address exploration activities aimed at increasing the probability of success.
One such example is a reflection seismic campaign undertaken by a consortium (GP La Côte[11]). GP La Côte has identified 5 possible locations with demand for heat from geothermal resources thought to exist in the regional Dogger aquifer. The prospects are located in the communities of Nyon, Gland, Aubonne and Etoy. The objective of the seismic reflection survey is to confirm and position major structures and faults in particular (Pontarlier, Bonmont- Yvoire, St. Cergue-Luins) in the subsurface of the Lake Geneva region of the Canton of Vaud, and prioritize the exploration targets. A larger 3-dimensional seismic reflection campaign fully funded by the City of St. Gall (Canton of St. Gall) is currently underway to investigate the deep structure to the crystalline basement of the region around the St. Gall – the city has developed a vision for its energy demands by 2050 and intends to utilize indigenous resources from renewable energy to supply the demand.
Another example of identifying and delineating a geothermal resource is the utilization of temperature gradients in relatively shallow boreholes (here to about 500 m depth). Anomalously high temperature gradients together with the presence of warm or hot aquifers often delineate the outflow zone of a geothermal resource. At Brigerbad (Canton of Valais) a well has recently been drilled to a depth of 500 m. Currently underway is a measurement campaign to determine the temperature gradient and to characterize the subsurface hydrology and fluid geochemistry.

Where there are good indications of a geothermal resource, geothermal project developers have matured projects by moving beyond the feasibility and exploration stage to a concept selection stage. In certain locations projects are at a stage where energy supply concepts have been matched to customer demand and projects are in a detailed planning stage leading up to drilling of a first deep exploration and possibly development well. One such example is the project AGEPP which plans to sell heat to a number of customers (e. g. local communities of Lavey VD and St. Maurice VS) and produce power. The inter-cantonal project has very strong local roots and builds on a well-known heat anomaly and good indications that the source of the hot water – which today feeds a spa – may be as high as 100 to 120°C. The project owners, among others local utility companies such as Services Industriels de Lausanne and Romande Energie plan to develop a hybrid renewable energy project comprising a geothermal and biomass module to offset some of the subsurface risk.

In addition to project-specific support, the Swiss Federal Office of Energy funds research and development to ultimately drive down capital and operating expenditures. As in almost all subsurface activities of mining and resource industries, the cost of drilling is the key to determining whether geothermal energy can be utilized in an economically viable manner. Even elementary sensitivity studies on the impact of lower drilling cost and increased rig utilization (less down-time) on net present value of any energy project suggests that the two parameters have a strong influence on economic viability. While Switzerland is not a major player in the drilling industry its research institutes are active in developing a novel, revolutionary drilling technology. A research program is underway to test and measure engineering parameters for thermal spallation drilling. Unlike mechanical loads applied to comminute rock during the drilling process, thermal spallation drilling uses a flame to impose a thermal load within a short distance to the rock in a well bore. Strong thermal gradients, thermal expansion anisotropy and thermal expansion mismatch generate sufficiently high stresses to cause fragmentation of the rock (Fig. 6).
The relatively well-known technique in the mining industry has not yet been applied to the energy industry in any significant manner. The Swiss Federal Office of Energy and «swisselectric research» co-funded laboratory pilot project builds on the success of a research group at ETH Zürich who managed to solve an important milestone when flame stability issues in the presence of water at super-critical conditions (pressures larger than ~ 22 MPa and temperatures in excess of ~ 373°C) were resolved. Now a vessel is being built to determine engineering parameters for upscaling to a field pilot when thermal spallation drilling is applied to sedimentary, metamorphic and igneous rocks. The technology is in its infancy, many engineering problems need to be overcome, but public research funds may help bring the technology to critical milestones, which – if successful – may trigger interest from project developers, operators, and the energy industry.
Besides research and development projects that address high capital expenditures, the Swiss Federal Office of Energy supports activities that aim to keep operational expenses manageable. In terms of energy production, a geothermal well produces at best the energy of a marginal oil well (a few hundred barrels of oil per day). Maximum production uptime and minimal cost of intervention is therefore rather important. Operators often find that scaling and corrosion may cause impairment in the formation, in the inflow and outflow of a well and thus compromise well productivity. To develop a modelling capability verified against field observation, the Centre du Recherche en Geothermie (CREGE), a body of the Swiss Laboratory for Geothermics of the University of Neuchâtel, develops and adapts simulation techniques to ultimately model in a fit-for-purpose way scaling and precipitation in geothermal wells.

5. Enhanced/Engineered Geothermal Systems (EGS)

Undoubtedly the biggest and most challenging geothermal resources to be developed, Swiss geothermal actors have made significant contributions towards unlocking the Enhanced/Engineered Geothermal Systems. Researchers and small to medium sized enterprises (SMEs) have contributed over many years and decades to work undertaken at the highly successful European EGS project at Soultz-sous-Fôrets. There, since the 1980s scientists and engineers have very carefully and deliberately explored for and developed an EGS reservoir in the western edge of the Rhine Graben some 50 km north of Strasbourg in France. With initial major support from France, Germany and the European Commission the project is now owned by an industry consortium, the European Economic Interest Grouping[12] comprising a number of French and German utility and energy companies. Swiss researchers have been permitted to participate in this effort by the project's owners and funding agencies of the project. From 2010 onwards, the owners of the project will test a number of aspects related to sustained power production by extracting heat from the km^3-sized engineered subsurface heat exchanger, by testing a number of subsurface development configurations relating two production wells and two injection wells. Again, Swiss researchers and SMEs participate in this activity.

Of national interest is naturally the life-cycle of the Basel EGS project from the feasibility stage to the abandonment stage. The project will be abandoned following the political decision of the Canton Basel-City to stop the project owing to expected large damages to assets in case of continued stimulation and a subsequent 30-year production period. This is the key result of a detailed risk analysis study that was financed by the Canton of Basel-City, the Swiss Federal Offices of Ener-

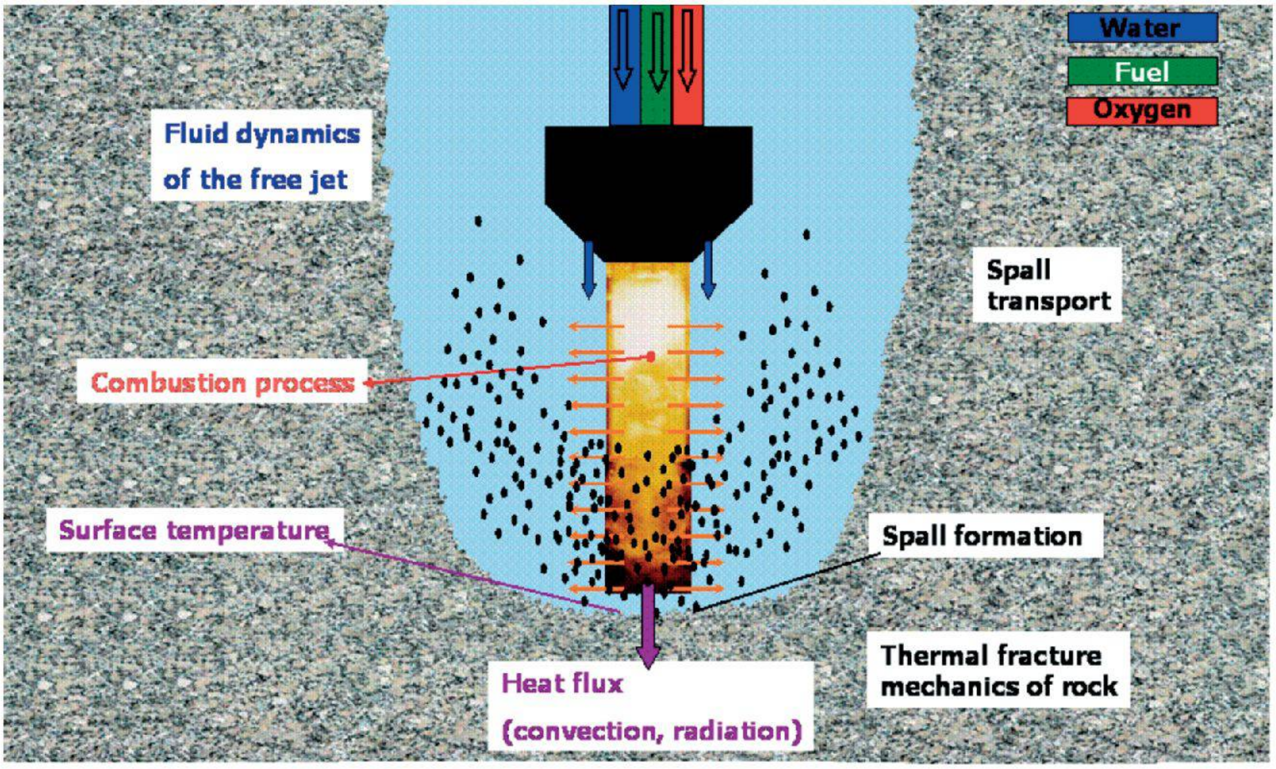

Fig. 6: Concept of thermal spallation and main research and development issues (Source: P. Rudolf von Rohr, ETH Zürich).

gy and the Environment and Geopower AG, the owner of the project[13]. While a deliberately highly conservative approach was taken to analyze the geologic setting, to set up of a three-dimensional static reservoir model, to dynamically model induced and triggered seismicity, and to incorporate the vulnerability of the region to finally compute likely damage cases, it soon became clear that significant and simplistic assumptions had to be made to arrive at a result in the study. For example, likely fault structures were planar 2-dimensional features whose fault rheology was simply described by a (high) coefficient of static friction. Similarly linear thermoelasticity was used to calculate stress changes on fault structures and in the rock matrix. There are many more aspects covering local geology and geophysics (including petrophysics), reservoir development, operation and management that are open for debate. Close study of the risk analysis opens many areas for scientific and engineering discussion and will undoubtedly trigger plenty of research and development.

The discussion about the future of the EGS project at Basel and the decision to stop the project were made without any measurement in the wellbore after the stimulation. No statements were possible on the physical condition of the wellbore (like pressures and temperatures) and on any indication regarding the permeability increase of the treated formation. Once approvals and permits had been obtained from the cantonal authorities, first measurements and low-rate, short-duration tests carried out in 2009 suggest that at a depth of 4600 m the formation has a temperature of 174°C with an expected but owing to an obstruction at 4700 m depth, unverifiable bottom-hole temperature of 185°C. A low-rate, short-duration production test suggests that the reservoir permeability has been increased by 2.5 to 3 orders of magnitude (Fig. 7).

The ETH domain has launched a 4-year, major research initiative («GEOTHERM») where among other topics the Basle data will be analyzed in great detail. The project consists of five interlinked modules. The modules intend to develop insights into the permeability creation process from wellbore and hydraulic observations, and to provide basic geological and stress information needed for the interpretation of the seismic studies and the numerical simulation studies. In addition, the relationship between stress heterogeneity and geological structures within the well will be described, and

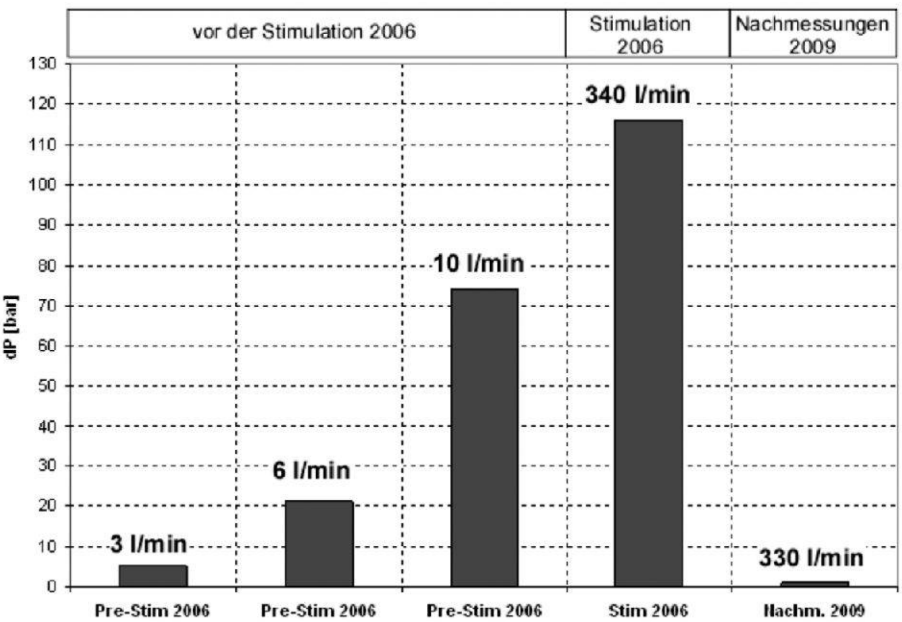

Fig. 7: Low-rate flow test at the Basel EGS well, Basel1 suggests a 2.5 to 3 order of magnitude increase in the permeability deduced from injectivity indices of the formation following the December 2006 stimulation (Source: Florentin Ladner, Geothermal Explorers Ltd).

the mechanisms of wellbore failure investigated. A hydro-thermo-mechanical modelling platform for the simulation of permeability creation processes conditioned by the wellbore and microseismic observations will be developed. The simulator will be fully-modular in structure, implement modern approaches to the representation of fractured reservoirs, and include a geomechanics module that allows the consequences of the 'fresh-fracture' of rock bridges within a brittle fracture zone to be simulated. The model will ultimately be extended to a full reservoir size and serve as a platform for simulating the impact of the fluid-rock interactions on the long-term behaviour of the reservoir during circulation. Finally a part of the GEOTHERM initiative is concerned with investigating the relationships between the deep and shallow geo-thermal resources in urban areas from the perspective of sustainable development.

6. Initiatives to promote the utilization of geothermal energy for power generation

According to Articles 15 a and 15 b of the Energy Act (Energiegesetz EnG, 730[14]) grid operators (represented by Swissgrid, the national grid company) are permitted to provide a risk guarantee for geothermal installations producing electrical power. A total of CHF 150 million will be made available for the risk guarantee scheme. The ultimate objective of the risk guarantee scheme is to facilitate the supply of power from renewable energy sources by harnessing geothermal energy resources of Switzerland by financial de-risking of a venture. Based on expected outcomes of a geothermal venture, the estimated monetary value of a project will be increased as abortive costs will be partially borne by the risk guarantee scheme. If project developers can not deliver agreed targets, a maximum of up to 50% of the total subsurface costs may be reimbursed. The costs include for example well pad construction, drilling and completion for production, injection and observation wells, borehole geology, logging and instrumentation, production, injection and circulation tests, reservoir stimulation, chemical testing etc. In addition the cost of financially engineering a project is expected to be lowered with an approved risk guarantee in place.

Articles 17 to 17 c of the associated Energy Ordinance (Energieverordnung EnV, 730.01[15]) specify the basic principles and processes. Further, Appendix 1.6 of the Energy Ordinance 730.01 specifies the minimum requirements for geothermal installations, the costs eligible for a risk guarantee and the applicable processes. The national grid company (Swissgrid) administers the funds (see[16] for details and[17] for the application form for the risk guarantee).

In addition to the risk guarantee the legislator has provided a preferential feed-in tariff for geothermal power projects. To finance the feed-in tariff, an annual charge of up to 0.6 Swiss cents per kWh has been levied

Nominal capacity (MW_{el})	Tariff (CHF/kWh)
≤ 5	0.30
≤ 10	0.27
≤ 20	0.21
> 20	0.17

Tab. 2: Feed-in Tariffs for electricity produced from geothermal resources. Tariffs decrease by 0.5% per year from 2018 on (Source: http://www.admin.ch/ch/d/sr/7/734.71.de.pdf).

since 01 January 2009 on high-voltage grid transmission costs, resulting in a capped fund availability of CHF 320–340 million per year. While in principle a maximum of 30% of the capped funds may be allocated to geothermal projects, the uptake of the feed-in tariffs by other renewable energy projects (each with own allotments) has been so rapid that by 01 February 2009 projects have been wait-listed. Projects will migrate towards the top of the waiting list when previously awarded projects are not realized within their allowed time-frame. To the best knowledge of the authors two geothermal power projects are waitlisted for the feed-in tariff provision.

7. Other relevant studies performed by the Swiss Federal Office of Energy

Increasingly stakeholders in any subsurface development (from shallow to the very deep) and legislative bodies become aware, that there exists the need for a systematic approach to the sustainable development (economically viable, environmentally sound and in the interest of the people) of Switzerland's subsurface[18].

In a related context, the Swiss Federal Office of Energy is funding a study to estimate whether Switzerland's deep subsurface of the «Mittel-» and «Unterland» has the potential to store significant amounts of CO_2. Foremost, the study aims to provide a scientific and evidence-based analysis for discussion whether this option to minimize CO_2 emissions into the atmosphere exists for Switzerland. Past assessments and discussions within legislative assemblies and the governmental administration were hampered by incorrect or non-existent analysis. The study, currently underway, focuses on the storage potential of deep-seated, regionally extensive, saline aquifers (top crystalline of the Molasse Basin, the Upper Muschelkalk and the Upper Malm) coupled with rock formations or units that may act as seals. A number of weighted criteria such as tectonics, hydrogeology, depth of storage and respective seals, knowledge etc. are used to rank locations (Fig. 8). Storage capacity factors will be used to derive semi-quantitative assessments for the theoretical storage potential.

8. International Cooperative Activities

Since Switzerland perceives geothermal energy (and EGS in particular) to be an increasingly important energy source in the coming decades, the Swiss Federal Office of Energy strives for international cooperation in developing geothermal resources and geothermal technology. On a policy level and on issues related to Switzerland's federally sponsored and coordinated geothermal activities, the Swiss Federal Office of Energy now aims for a tight cooperation and integration into the International Energy Agency's Geothermal Implementing Agreement. Similarly, Switzerland strives to pursue the development of its geothermal resources and on research and development within the European Union. Switzerland has continued to contribute to the EGS Project in Soultz-sous-Forêts (France) and to European research projects funded by the European Commission (e. g. ENGINE, I-GET). Recently the Federal Council approved the participation in the International Partnership for Geothermal Technology, a USA, Iceland and Australia based cooperative action to promote research and development in EGS-related technology. Some 16 topics have been ear-marked for specific project-related activities such as high temperature packers, zonal isolation, seismic risk assessment, high volume – high pressure hydraulic stimulation procedures, sharing of good practices etc.

9. Conclusion

This contribution intended to summarize the Swiss Federal Office of Energy's activities with a particular focus on its geothermal energy research, development and deployment (R, D&D) within the framework of directly sponsored governmental R, D&D. The vast potential of geothermal energy needs to be unlocked to supply Switzerland with clean, affordable and safe heat and power from indigenous renewable resources. Switzerland has a very active geothermal scene ranging from all-important project developers and owners, small and medium-sized enterprises to very active scientists and engineers at Swiss Universities of Applied Sciences, Universities and Federal Research Institutes. Future heat and power supply from geothermal resources will take decades to develop undoubtedly with plenty of set-backs and seemingly disappointing investments and results on the road to success. However, geothermal energy must be developed for Swiss society to become increasingly sustainable. The journey is not for the faint of heart.

Acknowledgment

The Swiss Federal Office of Energy acknowledges and deeply appreciates the Swiss and international geothermal community for their essential input and delivery of results that are highly relevant for the office. Many of the reports that members of the community have written can be found at the website of the Swiss Federal Office of Energy[19].

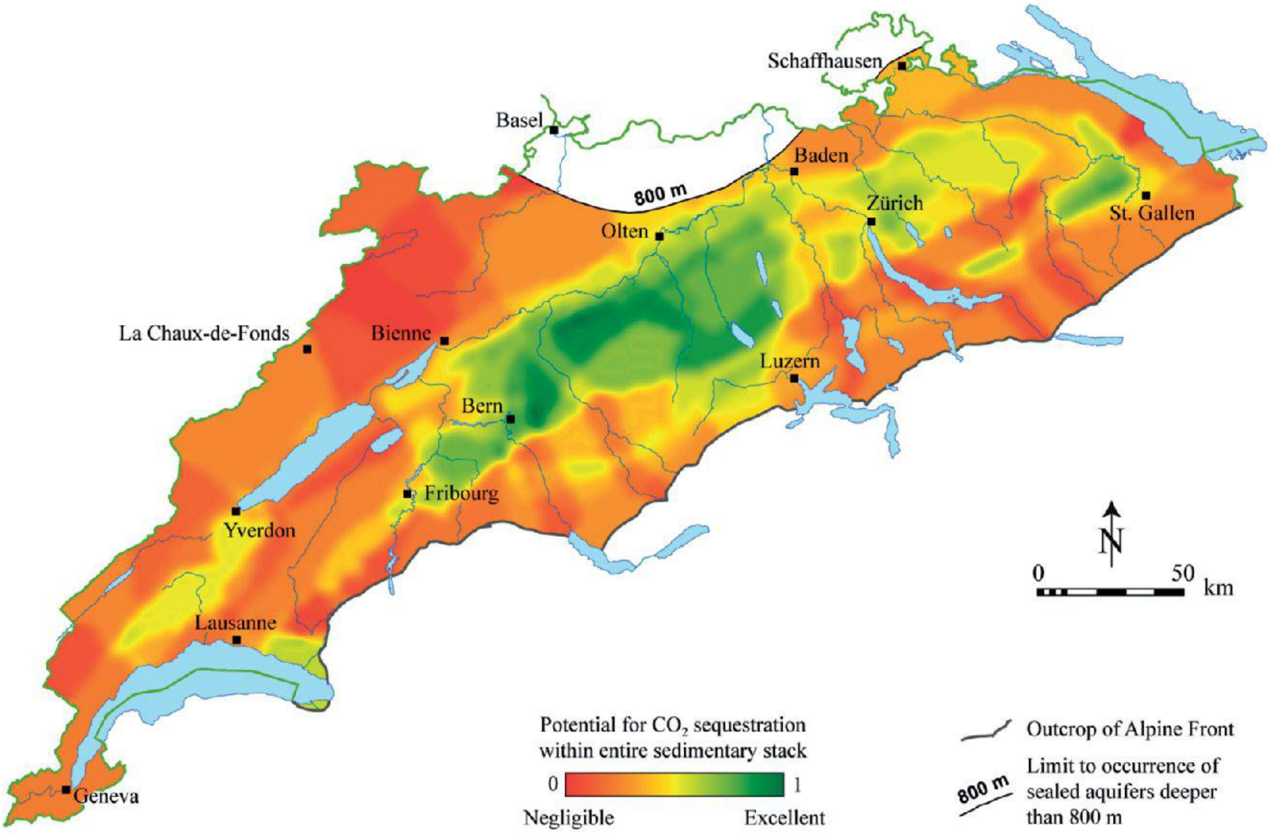

Fig. 8: Qualitative Assessment of the CO_2-Storage Potential of the Swiss Molasse Basin. Likely major aquifer and seal packages include the Malm with lower Freshwater Molasse (USM), the Muschelkalk with Gipskeuper and the Buntsandstein/Crystalline basement with the Anhydrite Group.

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Links

[1] http://www.bfe.admin.ch/energie/index.html?lang=en
[2] http://www.bfe.admin.ch/themen/00526/00541/00542/00631/index.html?lang=de&dossier_id=00763
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