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Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE

Schlussbericht 30. November 2008

ARBEITEN FÜR DAS IEA GEOTHERMAL IMPLEMENTING AGREEMENT (GIA) 2008

Jahresbericht 2008

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Zusammenfassung

Mit der Präsenz im Geothermal Implementing Agreement (GIA) der IEA kann die Schweiz regelmässigen Kontakt mit führenden Geothermie-Ländern pflegen, was den Weg zu ansonsten unzugänglichen Informationen öffnet. Zugleich lassen sich Schweizer F&E-Resultate international positionieren und durch die Kanäle der IEA verbreiten. Die Arbeiten für das IEA GIA im Rahmen ds Projektes Nr. 41'661 wurden 2008 durch Prof. L. Rybach ausgeführt. Er ist Vice Chairman des Executive Committee; somit ist die Mitwirkung der Schweiz an allen Entscheidungen garantiert. Ab Spetember 2008 ist Dr. Gunter Siddiqi (BFE) Swiss Executive Committee member, L. Rybach ist Alternate. Die Arbeiten laufen programmgemäss, die Resultate sind auf der IEA GIA Homepage ersichtlich und werden zudem durch sieben Anhänge dokumentiert.

Abstract

The participation of Switzerland in the IEA Geothermal Implementing Agreement (GIA) enables regular contacts and exchange with leading geothermal countries and opens pathways to otherwise inaccessible information. Swiss geothermal R&D results can be positioned internationally and disseminated through official IEA channels. The Swiss activities for the IEA GIA were performed in 2008 within the framework of project no. 41’661 by Prof. L. Rybach. He is Vice Chairman of the Executive Committee, which guarantees the direct involvement of Switzerland in all decision making. Since September 2008 is Dr. Gunter Siddiqi (BFE) the Swiss Executive Committee Member, L. Rybach is Alternate. The activities proceed as planned, the results are to be seen on the IEA GIA website and are further documented in seven Appendices.

1. Ausgangslage

Die Schweiz ist Teilnehmer des IEA GIA seit Anbeginn (März 1997). Die Teilnahme wird durch das BFE finanziert. Grundlage der Arbeiten in 2008 ist Vertrag Nr. 153'183, Projekt Nr. 41'661.

2. Ziel der Arbeit

Durch die Teilnahme der Schweiz am GIA wird im F&E Bereich ein regelmässiger Erfahrungsaustausch mit Ländern, die in der Geothermie führend sind, auf hohem Niveau ermöglicht. Hier sind insbesondere Informationen bezüglich Neuentwicklungen (z.B. EGS, *Enhanced Geothermal Systems*) zu erwähnen. Anderseits kann das spezifische know-how und die Errungenschaften der Schweiz im internationalen Rahmen eingebracht werden und somit Anerkennung erfahren und Verbreitung finden. Es sind weiterhin interessante und wertvolle Informationen und Kontakte zu erwarten, u.a. zu den neuen EGS-Projekten in Australien und USA.

3. Lösungsweg

Die Präsenz der Schweiz wird einerseits an den ExCo Meetings, an ausgewählten Annex Meetings, sowie an besonderen IEA Veranstaltungen (Workshops, Seminare) wahrgenommen, anderseits durch umfangreichen Schriftverkehr zwischen den Officers (Präsident, zwei Vizepräsidenten, GIA Sekretär) sichergestellt. Die Schweiz ist an diversen Annexe beteiligt, seit 2007 auch in Annexes I und VIII.

Besonders zu erwähnen ist hier die führende Rolle der Schweiz im GIA ExCo: Der Berichterstatter amtete 1997 – 2001 als Chairman, seit 2002 ist er Vice Chairman (mit besonderer Verantwortung in *Policy* und *New Participants*) und damit auch GIA Officer. Dadurch ist die Schweiz an allen Entescheidungsprozessen direkt beteiligt.

Darüber hinaus wird das IEA GIA an Veranstaltungen der IEA öfters durch ExCo Vice Chairman L. Rybach vertreten, so auch in der Berichtsperiode am ENGINE Final Conference in Vilnius/LT am 15. Februar 2008 unter „Ongoing cooperative EGS activities within the IEA GIA framework" (**ANHANG I**).

4. Ergebnisse

4.1 Arbeiten in Annex-Sitzungen

Vorgängig der 19. IEA GIA ExCo Sitzung fanden in Paris/F am 16. April Annex-Sitzungen statt, An der Annex I Sitzung referierte der Berichterstatter über Kommentare zu Arbeitspapieren bezüglich EGS-induzierte Seismizität, insbesondere zu „Revised DRAFT 18 Jan. 2008 Protocol for Induced Seismicity Associated with Enhanced Geothermal Systems - Prepared and reviewed by co-workers under the IEA-Geothermal Implementing Agreement Annex 1, Task D (Induced Seismicity)“.

An der Annex VIII Sitzung wurden Ergebnisse der Studie des GREGE über die Eigenschaften geothermischer Fluide aus der Schweiz und Umgebung präsentiert (**ANHANG II**); in der Folge hat der Berichterstatter die Erweiterung dieser Studie mit Einbringung in Google.earth angeregt (inzwischen vom BFE in Auftrag gegeben).

4.2 Arbeiten im ExCo

4.1.1 ExCo Sitzungen

Die 19. Sitzung des IEA GIA ExCo fand am 17. und 18. April am IEA Hauptsitz in Paris statt. Die notwendigen Vorbereitungsarbeiten (u.a. Mitwirkung an den Arbeiten für die zu behandelnden Geschäfte) begannen schon im Januar 2008. Anlässlich der Sitzung wurde ein Swiss Geothermal Update Report präsentiert (**ANHANG III**).

Dem Berichterstatter obliegt als ExCo Officer die Koordination der Arbeiten für neue GIA Participating Countries und Sponsors. Anlässlich der 18. ExCo-Sitzung wurde der Stand der Bestrebungen präsentiert, für die GIA weitere Teilnehmer zu gewinnen. Nachdem die Geothermal Group des APPA - Spanish Renewable Energy Association die Bereitschaft signalisierte dem IEA GIA als Sponsor beizutreten, hat L. Rybach das offizielle Einladungsschreiben am 24. Juni unterzeichnet. Inzwischen ist die APPA Geothermal Group ein IEA GIA Sponsor.

Für den IEA GIA Annual Report 2007 wurde der Beitrag der Schweiz abgeliefert (**ANHANG IV**).

Die 20. Sitzung des IEA GIA ExCo fand am 9. und 10. Oktober im Hotal Paradise in Busan/Südkorea statt. Dabei hat der Berichterstatter einen weiteren Swiss Geothermal Update Report beigesteuert, welches die aktuellen Entwicklungen beinhaltet (**ANHANG V**).

Die umfangreichen Sitzungsprotokolle werden, sobald genehmigt, auf die GIA Webseite **www.iea-gia.org** gestellt.

4.1.2 Weitere Arbeiten für die IEA GIA

- Der umfangreiche und aufschlussreiche GIA Annual Report 2007 wurde nach diversen Vorläuferversionen, an denen der Berichterstatter massgebend beteiligt war, ist in Fertigstellung durch das GIA Sekretariat in Neuseeland (wird aufgeschaltet auf http://www.iea-gia.org/publications.asp).
- Eine weitere Tätigkeit von des Berichterstatters für das GIA ExCo war die Organisation von Kommentaren zum Bericht *Fridleifsson, I.B., R. Bertani, E. Huenges, J. W. Lund, A. Ragnarsson, and L. Rybach (2008). The possible role and contribution of geothermal energy to the mitigation of climate change. In: O. Hohmeyer and T. Trittin (Eds.) IPCC Scoping Meeting on Renewable Energy Sources, Proceedings, Luebeck, Germany, 20-25 January 2008, 59-80.*

  Die zahlreich eingegangenen Kommentare sind auf der GIA Webseite unter „IPCC Geothermal Document“ auf http://www.iea-gia.org/publications.asp aufgeschaltet.
- Ausgehend von dieser Aktivität wird nun von GIA Sekretär M. Mongillo und L. Rybach in Madrid am 5./6. Mai 2009 ein Workshop „Geothermal Energy - Its Global Development Potential & Contribution to the Mitigation of Climate Change” organisiert. Dabei sind eingeladene Experten-Referate und *round table discussions* vorgesehen (**ANHANG VI**).
- Anlässlich des International Conference and Exhibition RENEWABLE ENERGY 2008 (RE2008) in Busan/Südkorea wurde ein IEA GIA Ausstellungsstand eingerichtet; der Unterzeichnete hat einerseits Ausstellungsmaterialien geliefert, anderseits war er an der Betreuung des Standes beteiligt.
- Schliesslich wurde beim RE2008 am 15. Oktober das paper *C. J. Bromley, M. Mongillo, L. Rybach, Y. Song (2008): Geothermal Energy - IEA-GIA's Efforts Towards Accelerating Development of this Global, Under-utilized Renewable Resource* präsentiert **(ANHANG VII**).

4.1.3 Laufende Administration

Der Berichterstatter wirkt als GIA ExCo Vice Chairman und Officer an allen Vernehmlassungen und Entscheidungen mit. Die weiteren Officers sind Dr. Chris Bromley (ExCo Chairman), Dr. Allan Jelacic/USA (ExCo Vice Chairman), Dr. Mike Mongillo/New Zealand (GIA Secretary). Die Arbeiten werden weitgehend per e-mail abgewickelt. Im Durchschnitt erfolgt täglich mindestens ein e-mail- Wechsel(!). Diese Arbeiten nehmen entsprechend viel Zeit in Anspruch.

Besonders zu erwähnen sind die zahlreichen, oft umfangreichen Stellungnahmen zu IEA Publikationsentwürfen. Der Unterzeichnete ist Mitglied des IGA Review Committee; so wurden u.a. Inputs geliefert zu „Materials analysis“ bei geothermischen Erschliessungsarbeiten oder Kommentare zu IEA Energy Technology Perspectives 2008.

Der Unterzeichnete kommentierte die Revision des Geothermal Implementing Agreement Document in zwei Phasen. Im weiteren wurde der Entwurf zum Artikel *Bromley, C., Mongillo, M. (2008): Geothermal Energy from Fractured Reservoirs – Dealing with Induced Sesimicity. IEA Open Energy Technology Bulletin no. 48* kommentiert.

5 Diskussion

Konkrete, sichtbare Erzeugnisse sind wie erwähnt auf der IEA GIA Homepage sowie aus den **ANHÄNGEN I - VII** ersichtlich. Weitere Details sind ebenfalls unter **http://www.iea-gia.org/** zu finden. Der Antrag auf Erhöhung der Mittel (inkl. BFE Beitrag) für 2008 wurde genehmigt.

6 Schlussfolgerungen, Ausblick

Es kann vorbehaltlos festgehalten werden, dass die Beteiligung der Schweiz am IEA GIA weiterhin erfolgreich verläuft und die erwarteten Benefits erbringt. Die Schweizer Beteiligung erfolgt in drei Annexen (Annex I *Environmental Impacts of Geothermal Development*, Annex III *Enhanced Geothermal Systems* und VIII (*Direct Use of Geothermal Energy*). Im ExCo wirkt in 2009 Dr. G. Siddiqi als ExCo Member, L. Rybach als Alternate und Vice Chairman.

Gestützt auf das *IEA GIA End of Term Report* sowie auf den *IEA GIA Strategic Plan 2007-2012*, welche unter Mitwirkung des Berichterstatters verfasst wurden, ist das GIA bis 2012 verlängert. Die Weiterführung der Schweizer Beteiligung, insbesondere durch aktive Beiträge an die Annexe I, III und VIII, ist dabei verstärkt anzustreben.

Symbolverzeichnis

IEA	International Energy Agency
GIA	Geothermal Implementing Agreement
ExCo	Executive Committee
ENGINE	EU Projekt „ENhanced Geothermal Innovative Network for Europe“
BFE	Bundesamt für Energie

Referenzen

Bromley, C., Mongillo, M. (2008): Geothermal Energy from Fractured Reservoirs – Dealing with Induced Seisimicity. IEA Open Energy Technology Bulletin no. 48

Fridleifsson, I.B., R. Bertani, E. Huenges, J. W. Lund, A. Ragnarsson, and L. Rybach (2008): The possible role and contribution of geothermal energy to the mitigation of climate change. In: O. Hohmeyer and T. Trittin (Eds.) IPCC Scoping Meeting on Renewable Energy Sources, Proceedings, Luebeck, Germany, 20-25 January 2008, 59-80.

Bromley, C.J., Mongillo, M., Rybach, L., Song, Y. (2008): Geothermal Energy - IEA-GIA's Efforts Towards Accelerating Development of this Global, Under-utilized Renewable Resource. Proc. RE 2008 (CD-ROM).

Zürich, 30. November 2008 **L. Rybach**

ANHÄNGE:

ANHANG I	Referat „Ongoing cooperative EGS activities within the IEA GIA framework", anlässlich des ENGINE Final Conference
ANHANG II	Referat "Report of Switzerland to IEA GIA Annex VIII meeting", 16 March 2008"
ANHANG III	Swiss Country Update for 19th IEA GIA ExCo meeting
ANHANG IV	Swiss input to IEA GIA Annual Report 2007
ANHANG V	Swiss Country Update for 20th IEA GIA ExCo meeting
ANHANG VI	Workshop announcement „Geothermal Energy - Its Global Development Potential & Contribution to the Mitigation of Climate Change"
ANHANG VII	Bromley, C.J., Mongillo, M., Rybach, L., Y. (2008): Geothermal Energy - IEA-GIA's Efforts Towards Accelerating Development of this Global, Under-utilized Renewable Resource. Proc. RE 2008 (CD-ROM).

ANHANG I

Referat „Ongoing cooperative EGS activities within the IEA GIA framework”, anlässlich des ENGINE Final Conference

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Ongoing cooperative EGS activities within the IEA GIA framework

Ladsi Rybach, GEOWATT AG Zurich (rybach@geowatt.ch)
Vice Chairman, IEA GIA Executive Committee

- The IEA GIA framework
- Ongoing activities related to EGS
- Results obtained so far
- Outlook

ENGINE Final Conference, Vilnius/LT, 12-15 February 2008

The International Energy Agency (IEA)

- Created in 1974 and based in Paris, France
- Independent international governmental agency linked to OECD
- Energy forum for 26 countries and Commission of the European Communities (EC)
- Strive to create conditions in which members' energy sectors promote sustainable economic development

IEA Implementing Agreements (IAs)

- International collaboration encouraged through Implementing Agreements (IAs)
- Provide management structure and legal means for guiding activities
- Participants are Contracting Parties (representing countries) and Sponsors (industry members), typically
  - Research institutions
  - Utilities
  - Industrial concerns
- Non-IEA member countries, or their designated organizations, may also participate

IEA Geothermal Implementing Agreement (GIA)

- Established in March 1997
- Provides flexible framework for international cooperation among national geothermal programmes for
  - Exploration
  - Development
  - Utilization
- Members currently include:
  - 11 Countries: Australia, France, Germany, Iceland, Italy, Japan, Mexico, New Zealand, Republic of Korea, Switzerland and the United States
  - The EC
  - 3 Industry Members: Geodynamics, Green Rock Energy and ORMAT Technologies
- Started 3rd 5-year Term of operation in April 2007

GIA 3rd Term Strategy 2007-2012

To meet the challenges, the GIA has set its 2007-2012 Mission:

To promote sustainable use of geothermal energy worldwide by improving existing and developing new technologies to render exploitable the vast and widespread global geothermal resources, by facilitating the transfer of know-how, by providing high quality information and by widely communicating geothermal's strategic, economic and environmental benefits.

Current GIA Research

Studies now being conducted in four research areas, specified in four Annexes

Annex I: Environmental Impacts of Geothermal Energy Development

- **Clearly identify possible environmental effects and devise and adopt methods to avoid or minimize their impact**
  - Investigate impacts development on natural features
  - Study problems associated with discharge and reinjection
  - Examine methods impact mitigation and produce environmental manual
  - **Investigate seismic risk from injection into enhanced geothermal system**
  - Investigate sustainable utilization strategies

Current GIA Research

Annex III: Enhanced Geothermal Systems (EGS)

- **Investigate new and improved technologies to stimulate geothermal resources to allow commercial heat extraction**

- Modify use of conventional and develop new geothermal technology to EGS
- Collect information needed for decision making, design and realization of commercial EGS plant
- Field studies of EGS reservoir performance

IEA GIA management

- **The GIA project activities are defined and organized in Annexes, the specific R&D activities as Tasks.**
- **The IEA GIA activities are governed by an Executive Committee (ExCo).**
- **The ExCo meets twice a year.**
- **At the ExCo meetings the GIA Participants regularly report about their activities, so e.g. the EC about the Soultz project.**
- **A dedicated Secretariat provides secretarial, administrative and other services.**
- **Formal ties between ENGINE and the IEA GIA have been established in 2006; Patrick Ledru is Member of the ExCo.**

EGS in IEA GIA Annexes and Tasks

With respect to EGS there are specific R&D activities, termed in the Annexes as Tasks:

Annex I - Environmental Impacts of Geothermal Energy Development – Annex Leader: C. Bromley
- **Task D: Seismic Risk of Fluid Injection into EGS (Task Leaders: R. Baria and D. Wyborn)**

Annex III - Enhanced Geothermal Systems (EGS) – Annex Leader: R. Baria
- **Task A: Economic modelling (completed in 2001)**
- **Task B: Application of Conventional Geothermal Technology to EGS (Task Leader: J. Renner)**
- **Task C: Data Acquisition and Processing (Task Leader: T. Mégel)**
- **Task D: Reservoir Evaluation (Task Leader: D. Wyborn)**
- **Task E: Field Studies of EGS Reservoir Performance (Task Leaders: P. Rose, A. Genter)**

Activities relevant for EGS and ENGINE are also conducted in Annex VII: Advanced Geothermal Drilling.

IEA GIA results

- **In general, results and products of IEA GIA are accessible through its website www.iea-gia.org - in particular under www.iea-gia.org/activities.asp/**
- **Collaborative EGS R&D activities undertaken by the IEA GIA address the issue of induced seismicity, particularly in relation to engineered or artificially fractured geothermal reservoirs.**
- **The focus for EGS is currently on the flourishing scene in Australia, where 6 companies are listed in the Australian Stock Exchange (ASX), 25 companies hold exploration rights over 170 licences, ranging in size from 120 to 12'000 km².**

Particular EGS results of IEA GIA (1)

EGS economic modelling (completed)

An economic model that allows the user to define the engineering and financial characteristics and the available geothermal resources of a proposed enhanced geothermal system project to determine the resulting economics and to optimize the plant configuration was completed in 2001 and is available for download on-line. Usefulness of the model has been demonstrated through extensive applications at Fenton Hill (USA), Soultz-sous-Forêts (France), and a site at Hunter Valley (Australia). The model operates on a PC in the Windows environment and is available at: http://web.mit.edu/hjherzog/www/ ; there go to go ONLINE DOCUMENTATION

Particular EGS results of IEA GIA (2)

Further, recent EGS results can be found on

http://www.iea-gia.org/publications.asp

EGS induced seismicity

The activities so far culminated in three international workshops, a "White paper" (IEA-GIA 2006), and a suggested Protocol (IEA-GIA, 2007).

A website was established to record detailed results of the research (http://esd.lbl.gov/EGS/).

EGS induced seismicity - downloads

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"White paper": Induced Seismicity Associated with Enhanced Geothermal Systems
(Produced in association with Annex I research)
To access, click: Induced Seismicity and EGS (doc, 1.2 MB)

Draft - "Protocol for Induced Seismicity Associated with Enhanced Geothermal Systems"
(Produced as part of the Annex I activities)
To access, click: Draft Protocol (doc, 53 kB)

Draft Report - Cooper Basin HDR Hazard Evaluation: Predictive Modelling of Local Stress Changes due to HFR Geothermal Energy Operations in South Australia
To access, click: Draft Report- Cooper Basin Hazard Evaluation (pdf, 3.65 MB)

„White paper"

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Induced Seismicity Associated with Enhanced Geothermal Systems

E. Majer, R. Baria, M. Stark, B. Smith, S. Oates, J. Bommer, and H. Asanuma

I. Introduction

Purpose and Objective

As the global demand for energy increases, it is evident that geothermal energy cannot play a significant part in meeting this demand unless the commercial resource base can be expanded by an order of magnitude or more. The geothermal resource is extremely large, and eventually this potentially-economic resource must be accessed. The United States Geological Survey (USGS) estimates that in the 48 contiguous states alone, there are 300,000 quads of energy in the 200°C heat sources down to 6 km. Obviously, because the U.S. uses only 100 quads per year, the potential of geothermal energy is enormous. To access this energy, both sufficient fluid and permeability must be present in the heated rock. Each may exist together, or separately, or not at all. Thus, the need exists to enhance permeability and/or fluid content, to enhance geothermal systems. As with any development of new technology, some aspects of the new technology have been accepted by the general public, but some have not yet been accepted and await further clarification before such acceptance is possible. One of the issues associated with Enhanced Geothermal Systems (EGS) is the role of microseismicity during the creation of the underground reservoir and the subsequent extraction of the geothermal energy.

„Traffic light" system

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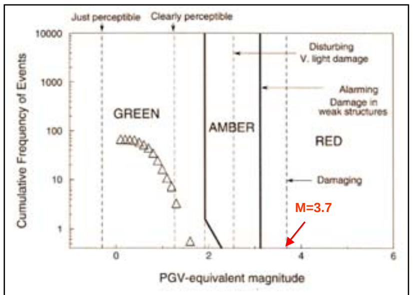

Figure 8."Traffic light" boundaries superimposed on recurrence defined in terms of magnitudes adjusted to produce the same epicentral PGV if their focal depth were exactly 2 km. The triangles represent the cumulative recurrence data from the three episodes of pumping (totalling 54 days of pumping) normalized to a period of 30 days, from Bommer et al. 2006.

„Protocol"

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(DRAFT FOR DISCUSSION)
PROTOCOL FOR INDUCED SEISMICITY ASSOCIATED WITH ENHANCED GEOTHERMAL SYSTEMS

INTRODUCTION

As the global demand for energy increases, the contribution from geothermal energy can be extremely large if resources developed with Enhanced Geothermal Systems (EGS) technology are incorporated in the total energy picture. The geothermal resource is extremely large, and eventually this potentially-economic resource must be accessed. The United States Geological Survey (USGS) estimates that in the 48 contiguous states alone, there are 300,000 quads of energy in the 200°C heat sources down to 6 km. Obviously, because the U.S. uses only 100 quads per year, the potential of geothermal energy is enormous. Because implementation of EGS affects subsurface conditions, especially fractures, there may exist the potential to cause induced seismicity. Induced seismicity has occurred in the development and production of oil and gas resources, large water impoundments, and mining applications. In each of these instances, properly monitored and analyzed induced seismicity has provided valuable information in developing the particular resource, but has not prevented the technology from proceeding. To help gain acceptance from the general public for geothermal generally and EGS specifically, it would be beneficial to clarify the role of microseismicity (MEQ, "micro-earthquakes," etc.) during the development stages of the underground reservoir and the subsequent extraction of the geothermal energy.

„Protocol"

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cause extensive damage. For example, experience and scientific data indicate that the vibration at depth due to fluid injection is unlikely to cause any damage to most modern buildings. On the other hand, the sound emitted can be a nuisance, particularly at night or on a very calm day, when the ambient cultural noise is very low. On some occasions, observers have reported that the effect from a microseismic event sounds like a small explosion, a truck going by, or a thud from a small object hitting a hard floor.

POSSIBLE STEPS IN ADDRESSING EGS INDUCED SESIMICITY ISSUES

Induced seismicity is one of a number of issues that the developer needs to address in order to proceed with project development. This document outlines the suggested steps that a developer could follow in extending their education and outreach campaign and cooperating with regulatory authorities and local groups. The following steps (not necessarily in the order given) are proposed for handling of the induced seismicity issue as it relates to the whole project.

Step One: Review Laws and Regulations
The developer should conduct a thorough study and evaluation of applicable laws and governing regulations that may affect the project. These legal stipulations may apply at national, state/provincial, county/town, or local levels of government. Any legal precedents that include induced seismicity (or related activity, such as noise) should be identified and assessed relative to the proposed project. The developer should formulate a plan for meeting any legal requirements.

Cooper Basin/Australia - EGS Seismic Risk Study

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Cooper Basin HDR hazard evaluation: Predictive modeling of local stress changes due to HFR geothermal energy operations in South Australia

The University of Adelaide

October 2006

Report Book 2006/16

DRAFT

Cooper Basin Seismc Risk Study

open for comments

on www.iea-gia.org

Methodology of seismic risk analysis

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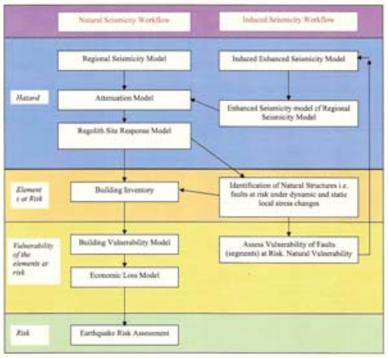

Figure 1: Flowchart describing earthquake risk assessment process used for natural seismicity and that proposed for induced seismicity (after Sinadinovski et al., 2009).

Table of EGS-related events

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DATE	TIME (UTC)	LAT	LON	DEPTH	MAG	COMMENTS
19611228	73435.6	-28.12	141.57	10	4.7	SW Queensland
19630330	124027	-27.2	140.9	10	3.8	No comments for this record
19630331	2545	-27.2	140.9	10	4	No comments for this record
19790610	3323.9	-28.027	140.336	15	2.9	No comments for this record
19850130	204129.6	-26.58	140.94	0	3.1	No comments for this record
19880622	63133	-26.708	140.28	7	3.5	BIRDSVILLE
19890808	65423.4	-27.63	141.52	10	3.3	No comments for this record
19970205	1514.6	-28.803	139.117	0	4.3	Mid North SA
19990306	235440.9	-28.506	139.072	5	4.1	Near Mungeranie Homestead SA
19990603	155343	-27.128	140.8	0	2.6	Near Haddon Corner SA
20010227	10206.4	-28.67	142.082	0	3.3	Grey Mare Range near Cameron Corner, QLD
20010309	161001.7	-28.604	141.995	8	3.2	Cameron Corner area Qld
20011212	4325.97	-28.63	139.121	10	3.1	Etadunna Area SA
20021011	70933.13	-28.007	140.698	9.9	2.8	Innamincka SA.
20031113	140327.7	-27.884	140.744	0	3	Innamincka SA.
20031202	140024.2	-27.846	140.711	1	3.3	Innamincka SA. Felt.
20031204	15545.32	-27.858	140.65	0	3.6	Innamincka SA.
20031205	174538	-27.776	140.632	6.7	3.7	Innamincka SA. Felt.
20031207	12142.14	-27.73	140.523	5	3.3	Innamincka SA.
20031207	80303.06	-27.741	140.548	10	2.7	Innamincka SA.

Identified fault segments, ready to shear

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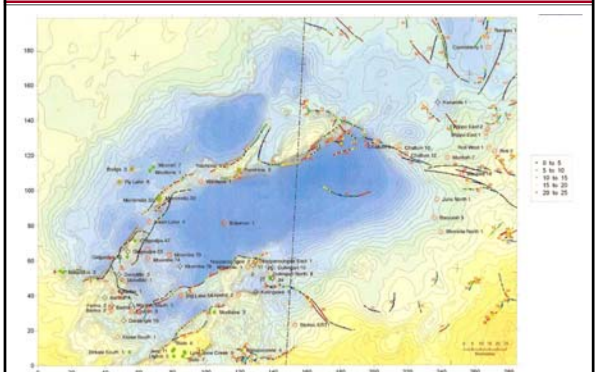

Figure 13 Slip tendency values for faults in the Cooper-Eromanga Basin basement faults. Stress regime expected strike-slip; Case 1.

Seismic risk distribution around well Habanero-1

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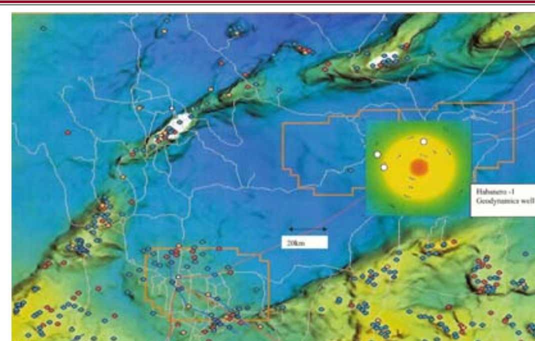

Figure 9 Map of basement in the Cooper Eromanga basin showing well locations. The inset bullet figure shows the attenuation radiation distance from Habanero 1 at the centre of the Geodynamics site.

OUTLOOK

EGS R & D work will continue in the various Annexes and Tasks of IEA GIA;

Hopefully the impressive EGS activities in Australia will trigger similar activities elsewhere;

International cooperation in EGS is already significant and should be even more intensified.

Prof. Dr. Dr.h.c. L. Rybach
GEOWATT AG Zurich
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CH-8093 Zurich, Switzerland
rybach@geowatt.ch

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ANHANG II

Referat “Report of Switzerland to IEA GIA Annex VIII meeting”, 16 March 2008”

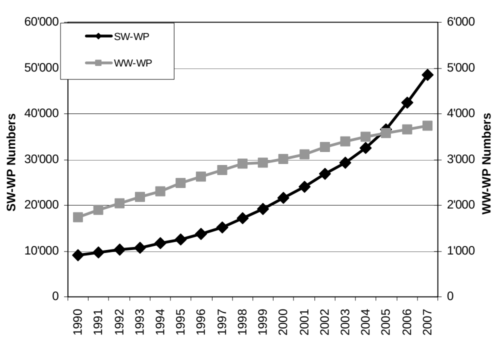
Report of Switzerland to IEA GIA Annex VIII
Paris, 16 April 2008

L. Rybach, GEOWATT AG Zurich

- Switzerland is Participant in ANNEX VIII, officially since June 2007
- Main geothermal activities of Switzerland are in direct use (highlights follow)
- Some recent activities in ANNEX VIII Tasks

Achievements of Switzerland in geothermal direct use

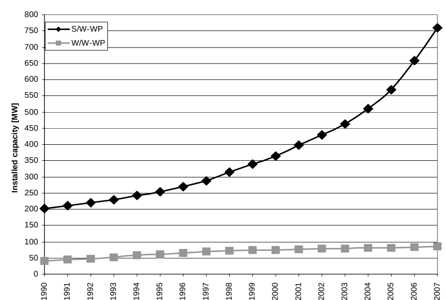
- Steady growth of geothermal heat pump installations
- High areal density (> 1 GHP system every km²)
- High energy supply density (GWh per km²) secures high international rank in direct use



Development of GHP sales in Switzerland 1990 – 2007

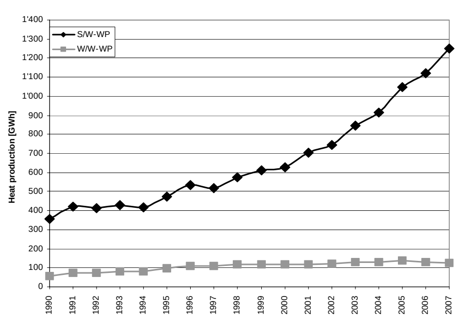
S/W-WP: BHE or horizontal collector systems
W/W-WP: Groundwater heat pumps

Development of geothermal heat pumps in Switzerland



S/W-WP: BHE or horizontal collector systems
W/W-WP: Groundwater heat pumps

Development of heat production by geothermal heat pump systems in Switzerland

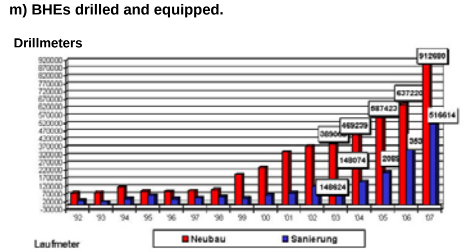


S/W-WP: BHE or horizontal collector systems
W/W-WP: Groundwater heat pumps

Number of wells (in Switzerland BHE boreholes)

There are statistical data for 2007. The total drillemters amount to 1'429'294 m (912'680 m for new installations, 516'614 m for Retrofitting. This would correspond to about 10'000 average depth (150 m) BHEs drilled and equipped.

Drillmeters



Development of BHE drilling in Switzerland 1992 - 2007

Red: for new buildings, blue: in renovation

Source: FWS – Förderverein Wärmepumpe Schweiz, www.fws.ch

Installed thermal power in Switzerland (2007)

Usage system	Installed capacity (MWth)
Heat pumps with borehole heat exchangers, horizontal collectors	749.5
Groundwater heat pumps	77.7
Geostructures (“energy piles”)	8.9
Deep borehole heat exchangers	0.2
Deep aquifers for district heating	2.4
Tunnel waters	5.2
Spas, wellness facilities	36.4
Total	**880.3**

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Development in heat production of Swiss geothermal installations (GWh/year)

Usage system	2004	2005	2006	2007	% in 2007
Heat pumps with borehole heat exchangers, horizontal collectors	897.5	1030.8	1102.0	1229.8	73.0 %
Groundwater heat pumps	112.5	118.4	113.0	112.2	6.7 %
Geostructures (“energy piles”)	14.5	16.3	17.8	18.4	1.1 %
Deep borehole heat exchangers	1.0	1.0	1.0	1.0	0.1 %
Deep aquifers for district heating	18.4	18.7	17.6	15.4	0.9 %
Tunnel waters	4.0	4.0	4.0	2.7	0.2 %
Spas, wellness facilities	312.7	304.6	304.6	304.6	18.0 %
Total	**1360.6**	**1493.8**	**1560.0**	**1684.1**	**100.0**

Table 1. The world-wide top 15 in geothermal direct use, and ranking in terms of areal density of production capacity. Ranking calculated from data in Fridleifsson et al. (2008).

Country	GWh/yr	Country area 10^3 km^2	GWh/yr per 10^3 km^2	Rank
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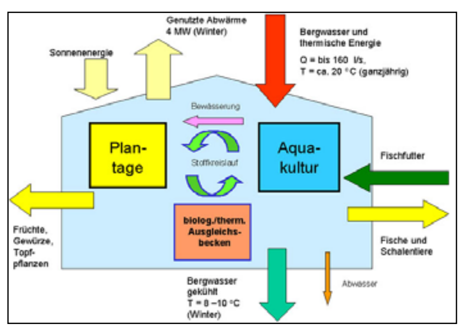
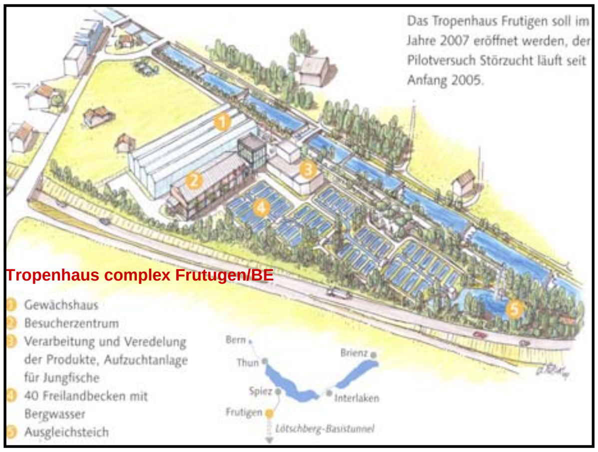
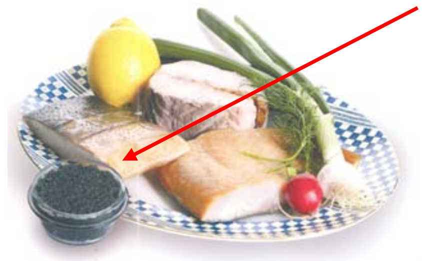
Sweden	10,000	450	22.2	6
USA	8,678	9809	0.88	13
Turkey	6,900	779	8.86	7
Iceland	6,806	103	66.1	1
Japan	2,862	378	7.57	8
Hungary	2,206	93	23.7	5
Italy	2,098	301	6.97	10
New Zealand	1,968	271	7.26	9
Brazil	1,840	8512	0.22	14
Georgia	1,752	70	25.0	4
Russia	1,707	17075	0.10	15
France	1,443	544	2.65	11
Denmark	1,222	43	28.4	3
Switzerland	1,175	41	28.7	2



Cascaded use of tunnel water LBT, Frutigen/BE
partly realised, partly in construction **www.tropenhaus-frutigen.ch**





Kaviar

Neben dem ausgezeichnet mundenden Störfleisch, für das zahlreiche Zubereitungsarten bekannt sind, gehört der Störkaviar zu den berühmtesten Delikatessen auf unserer Erde. Durch mildes Salzen und eine gute Verpackung wird der Kaviar haltbar gemacht. Unser Ziel ist, den Kaviar aus Frutigen zu einem Markenbegriff für eine nach den Grundsätzen der Bioproduktion hergestellte Schweizer Delikatesse von höchster Qualität werden zu lassen.

✓ Achevements of Switzerland in direct use

Contributions to ANNEX VIII Tasks

→ a) **Resource characterization**
b) Cost and performance
d) Equipment performance
e) Design configuration and engineering standards

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Task a) RESOURCE CHARACTERIZATION

Extensive data base of chemical characteristics:
well compiled catalogue of geothermal fluid properties.

Sonney, R., and Vuataz, F.D., 2007. BDFGeotherm: the Database of Geothermal Fluids in Switzerland. Proceedings WGC2007

Sonney, R., and Vuataz, F.D.: Chemical data of geothermal fluids from Switzerland: a new interactive database. Geothermics (in print)

➢ ***could be expanded by google.earth***

Fields	Description of fields
Table 1. Description	
Code	Simplified name of catchwork, primary key
Location, country, canton, elevation, X and Y coordinates	Geographical general information
Type, name, number, depth and year of realization of catchwork	Catchwork general information
Primary and secondary exploitation	General information about catchwork exploitation: none, buildings heating, drinking water, electricity, heating network, thermal using.
Table 2. Geology	
Code	Primary key
Type and age of surface formation and deep reservoir	General information about type of rocks and its geological age
Regional and local tectonic context	General information about geological context of infiltration of geothermal fluid and the presence of local geological structure as fractures, faults, folds.
Catchwork log	Picture of geological log of boreholes
Table 3. Hydraulics	
Code	Primary key
Discharge/Flow	Catchwork discharge/flow in L/s. Because of a great variability of this parameter, we selected one of the three following types: annual average value, measured value associated with analyses and value of production yield.
Surface temperature	Measured temperature at the wellhead and in the springs
Permeability	Permeability of geological reservoir in m/s
Exploitation procedure	None / Artesian / Free flow / Pumping / Reinjection / Borehole Heat Exchanger (BHE)
Static and dynamic water level	Elevation of water table in m.a.s.l. with and without pumping exploitation

Data base content (1)

Sonney & Vuataz

Fields	Description of fields
Table 4. Hydrochemistry	
Code	Primary key
Sampling name and date	General information about the sampling
Geochemical types	Simplified and detailed geochemical type of analysed water
Temperature, conductivity and pH	Value of analysed physical parameters
Ca, Mg, Na, K, Li, Sr, HCO_3, SO_4, Cl, F, SiO_2, TDS	Value of analysed chemical parameters in mg/L. TDS = Total Dissolved Solids
Ionic balance	Calculated ionic balance in %
Variability of TDS	Variability of TDS calculated from several chemical analyses
Comments	Comments about the chemical analyse described before
Table 5. Isotope	
Code	Primary key
Sampling name and date	General information about the sampling
Water stable isotopes	Value of ^{18}O and ^{2}H in ‰
Radioactive isotopes	Value of ^{3}H in TU and ^{14}C in pmc
Residence time	Estimation of groundwater residence time given in years or with symbols ">" and "<"
Infiltration elevation	Mean elevation of the basin in m.a.s.l. calculated from data of water stable isotope
Comments	Comments about the isotopic analyse described before

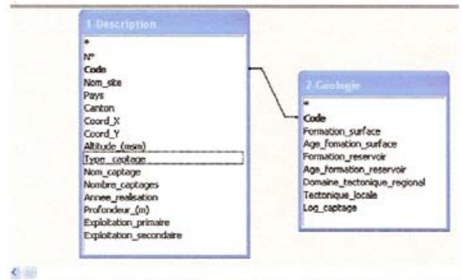
Data base content (2)

Sonney & Vuataz

Fields	Description of fields
Table 6. Geothermal parameters	
Code	Primary key
Surface temperature	Measured temperature at the wellhead and in the springs
Reservoir temperature	Min and max temperatures of the deep reservoir calculated from geothermometric methods, mixing models or modelling of chemical equilibrium.
Depth of reservoir	Top depth of geothermal reservoir in m.a.s.l.
Geothermal gradient	Average geothermal gradient in °C/km calculated from the height of boreholes or included from bibliography.
Potential geothermal energy	Potential geothermal energy in $kW_{thermal}$ calculated from catchwork hydraulic data
Table 7.1. Author	
Number of author	Number allotted for each authors, primary key
Author	List of author(s) and co-author(s) classified alphabetically
Table 7.2. Table-links	
Code	Primary key
Number of author	Number allotted for each authors, primary key
Number of bibliography	Number allotted for each references, primary key
Table 7.3. Bibliography	
Number of bibliography	Number allotted for each references, primary key
Bibliography	List of bibliography classified alphabetically

Data base content (3)

Sonney & Vuataz



Screen example (1) *Sonney & Vuataz*

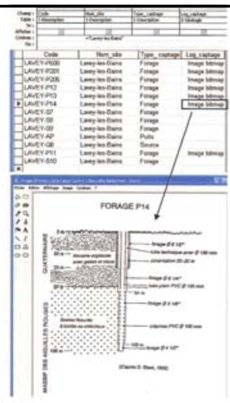
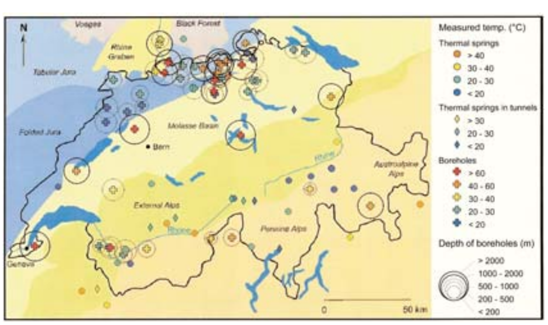


Figure 2: Realization and result of the query. Search of lithological logs in Lavey-les-Bains (Switzerland).

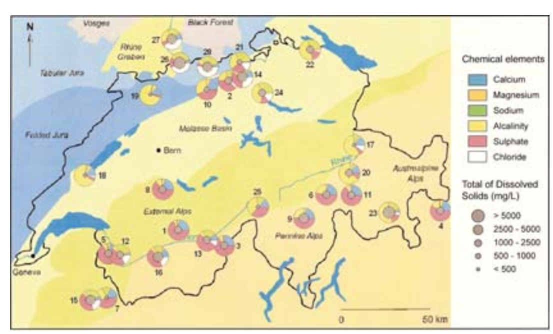
Screen example (2)

Sonney & Vuataz

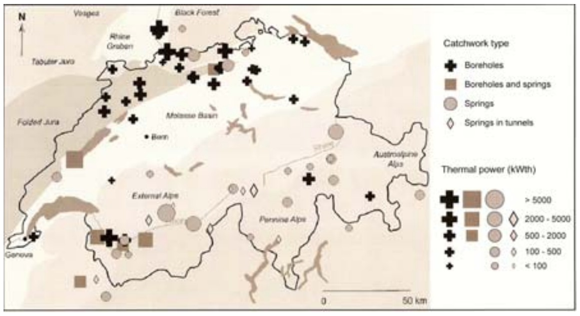
Location of data sources *Sonney & Vuataz*



Temperature and well depth *Sonney & Vuataz*

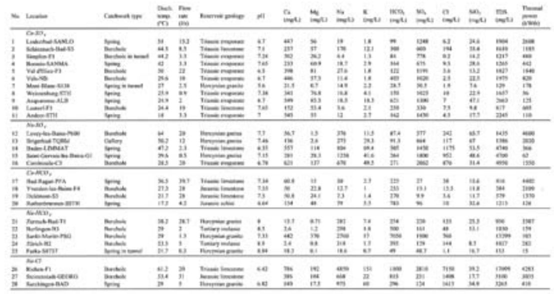


Chemical composition, TDS *Sonney & Vuataz*



Thermal power of produced or usable fluids *Sonney & Vuataz*

Chemical types of selected fluids *Sonney & Vuataz*



➢**Tabled sites could be visualized on *google earth***

✓ Achevements of Switzerland in direct use

Contributions to ANNEX VIII Tasks

✓ a) Resource characterization

→ **b) Cost and performance**

d) Equipment performance validation

e) Design configuration and engineering standards

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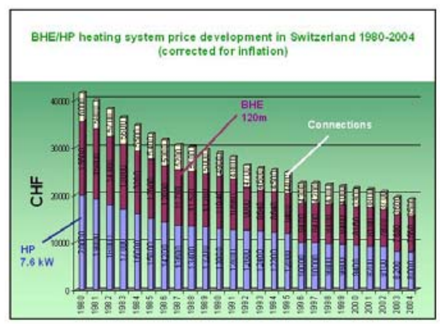
Task B: Cost & performance - Swiss learning curve



Installation costs of BHE-coupled geothermal heat pumps decrease significantly over time in Switzerland. 1 CHF ≈ 1 US $ (March 2008). From Rybach and Minder (2007).

✓ Achevements of Switzerland in direct use

Contributions to ANNEX VIII Tasks

✓ a) Resource characterization

✓ b) Cost and performance

→ **d) Equipment performance validation**

e) Design configuration and engineering standards

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Task D: Equipment performance validation

Quality labels for GHPs:

D – A – CH label for heat pumps

Swiss label for BHE drillers

✓ Achevements of Switzerland in direct use

Contributions to ANNEX VIII Tasks

- ✓ a) Resource characterization
- ✓ b) Cost and performance
- ✓ d) Equipment performance validation
- → **e) Design configuration and engineering standards**

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Task E: Engineering standards

SIA standard (norm)

for GHPs with BHE

62 pages

2008 (in consultation)

Report of Switzerland to IEA GIA Annex VIII
Paris, 16 April 2008

L. Rybach, GEOWATT AG Zurich

- **In summary: there is quite some action in Switzerland in issues covered by IEA GIA Annex VIII „Direct use“**

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ANHANG III

Swiss Country Update for 19th IEA GIA ExCo meeting

Swiss Geothermal Update Report to 19th GIA ExCo

L. Rybach[1,2]

1) Institute of Geophysics, ETH Zurich, Switzerland;
2) GEOWATT AG, Zurich, Switzerland (rybach@geowatt.ch)

- This is the 1st Swiss update in 2008; the full 2007 report will be part of the IEA GIA Annual Report 2007. Again the actual highlights are given this time.
- The report covers the
  - Highlights & achievements
  - Institutional framework
  - The current geothermal scene
  - Market development
  - Publications/meetings, education, websites
  - International activities

Highlights and achievements

The main achievement is the steady growth of geothermal direct use, mainly based on the ongoing dissemination of geothermal heat pump system. They are now increasingly installed –also in larger complexes– for space heating, cooling, and domestic hot water production.

The total installed capacity for direct use secures Switzerland a prominent international rank.

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Table 1. The world-wide top 15 in geothermal direct use, and ranking in terms of areal density of production capacity. Ranking calculated from data in Fridleifsson et al. (2008).

Country	GWh/yr	Country area 10^3 km^2	GWh/yr per 10^3 km^2	Rank
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France	1,443	544	2.65	11
Denmark	1,222	43	28.4	3
Switzerland	1,175	41	28.7	2

National policy / Strategy

The overall framework is defined in SWISSENERGY.

Basis: new energy and CO_2 laws
Targets until 2010:
- reduction of fossil energy carriers by 10 % (relative to 1990)
- reduction of CO_2 emissions by 10 % (relative to 1990)
  - limitation of electricity consumption increase to 5 %
  - increase of renewable contributions by 1 % to electricity and 5 % to heat demand

Instruments
- modernization of buildings
- increasing use of renewable energies
- energy efficiency in transportation, devices…

National policy / Legislation

The Energy Law
stipulates the rational use of energy and the increasing use of renewables

The CO_2 law
should enforce the CO2 reduction target set by SWISSENERGY
Instruments: voluntary measures, measures by decree, flexible mechanisms (Kyoto)
Decreeted measures:
- CO2 tax on fossil fuel (0.03 CHF per liter oil, 0.025 CHF per m3 gas in 2008)
- "Klimarappen" (clima cent) on gasoline/diesel (0.01 CHF per liter)

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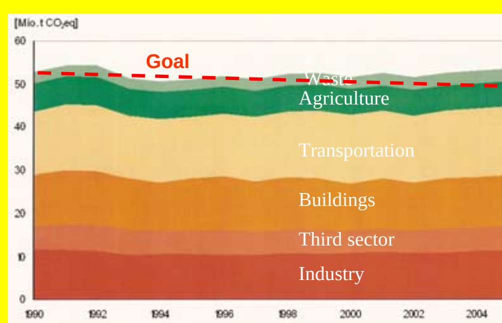
Sources of CO_2 emissions in Switzerland



Kyoto resolution

National policy / Investments

Private investments

The overwhelming majority goes to installation costs of GHP systems (approx. 150 MCHF in 2007)

So far 60 MCHF have been invested to the Deep Heat Mining Project in Basel

Government expenditure in geothermal R & D

The Swiss Federal Office of Energy provided funding in 2008 for

- Research and Development: 0.85 MCHF
- R & D: 0.15 MCHF
- Supporting the Swiss Geothermal Association SVG: 0.5 MCHF

National policy: pending issues

- **feed-in tariffs**
- **governmental risk guarantee**
- **special fund for deep geothermal resources**

decided upon but not yet implemented.

Current status

a. Electricity production

So far no kWh electricity is produced from geothermal sources in Switzerland.

Deep Heat Mining Project Basel

The project has been suspended by the local authorities in the wake of induced seismic events in late 2006 and early 2007 (maximum magnitude 3.4).

To date over 2500 (smaller) damage claims have been submitted and over 3 MCHF compensations paid.

In February 2008 a seismic risk study has been commissioned; its result is expected for end of 2008.

On 1 March 2008 the State Attorney of Canton Basel City has opened the prosecution process against the project responsible. The trial is expected to take place later this year.

Whether the project will be definitely stopped or continued -and if so, under what conditions- will depend on the results of the risk study.

Basel-1 wellsite November 2006

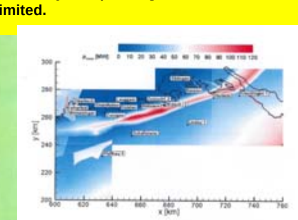
Stimulation gear, December 2006

Rather empty wellsite, Dec. 2007

Photos: GEOPOWER AG

Potential study

The Swiss geothermal resource assessment project came to a temporary end (Signorelli & Kohl 2007). It comprises mainly the northern part of Switzerland, with sufficient data density. For power generation several suitable regions have been delimited.



Heat extraction potential, Top crystalline basement

b. Direct use

Installed thermal power in Switzerland (2007)

Usage system	Installed capacity (MWth)
Heat pumps with borehole heat exchangers, horizontal collectors	749.5
Groundwater heat pumps	77.7
Geostructures ("energy piles")	8.9
Deep borehole heat exchangers	0.2
Deep aquifers for district heating	2.4
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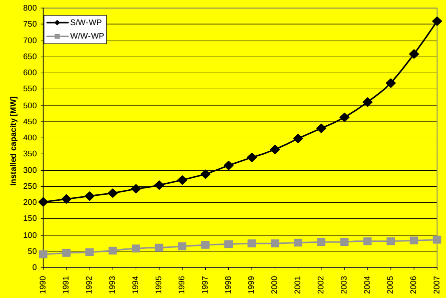
Spas, wellness facilities	36.4
Total	**880.3**

Development of ground-coupled heat pumps in Switzerland



S/W-WP: BHE or horizontal collector systems
W/W-WP: Groundwater heat pumps

Development in heat production of Swiss geothermal installations (GWh/year)

Usage system	2004	2005	2006	2007	% in 2007
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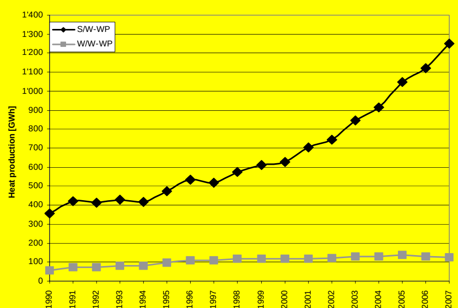
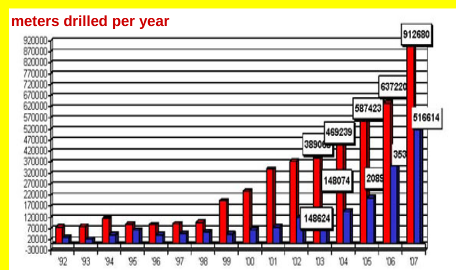
Development of heat production by geothermal heat pump systems in Switzerland



S/W-WP: BHE or horizontal collector systems
W/W-WP: Groundwater heat pumps

Number of wells (in Switzerland: BHE boreholes)

There are now statistical data available for 2007. With the total drilling meters were nearly 1’500 km.
This would correspond to about 10’000 average depth (150 m) BHEs drilled and equipped.



Red bars: new installations, blue bars: renovation

c. Energy savings by direct use in 2007

i. ***Fossil fuel savings/replacement***
The total heat production of 1684 GWh (6 PJ) corresponds to the saving of 140’000 toe/year

i. ***Reduced/avoided CO_2 emissions***
This allow to avoid the emission of 445’000 tonnes of CO_2/year

Market development, constraints

The GHP market develops well

Constraints for power generation development are:

- **Governmental side: the Swiss Parliament voted for 60 MUS$ support for deep geothermal R&D but the Administration did not release the funds**
- **Private investors: wait to see the fate of the DHM project Basel**

Geothermal R & D in 2007

National

Here the numerous research projects, financed by the Swiss Federal Office of Energy SFOE must be mentioned first. Dr. Rudolf Minder (IEA GIA ExCo Alternate) is SFOE Research Program Leader. A selection of projects, by resource type:

- **Shallow: Enhanced Thermal Response Test, Operational experience Terminal E Zurich airport, Geocooling in MINERGIE buildings**
- **Deep: Geothermal fluid chemistry data base, Swiss contributions to EU project Soultz,General Swiss Geothermal Program PROGEOTHERM (elaborated by a team led by CREGE)**

Further research projects, like the Long-term Program FEGES for Swiss geothermal power development, financed by the Swiss Geothermal Association SVG (the Swiss Geothermal Competence Center).

International Cooperative Activities

Switzerland is GIA Participant (Annexes I and VIII)

Switzerland is also active within R&D programs of the European Union. Cooperation is ongoing in the following EU geothermal projects:
•EGS Scientific Pilot Plant Soultz/F
•ENGINE
•I-GET
•GROUNDHIT

Besides, participation in EU project GROUND-REACH

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Geothermal education (formation and post-graduate)

Mandated by SFOE to SVG, withtin the EnergySwiss framework

Educational events in 2007 (German, French and Italian parts of Switzerland)

Formation
- 10 courses
- 188 participants

Continuing education
- 15 courses
- 5 excursions
- 644 Participants

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Geothermal websites in Switzerland

SVG/GEOTHERMIE.CH	**www.geothermal-energy.ch**
BFE (SFOE)	**www.bfe.admin.ch**
CREGE	**www.crege.ch**
FWS/Heat Pump Promotion Association	**www.fws.ch**
Geopower Basel AG	**www.geopower-basel.ch**
Geothermal Explorers Ltd.	**www.geothermal.ch**
Geowatt AG	**www.geowatt.ch**

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In summary:

- **Switzerland continues to be a leading country world-wide in geothermal heat pumps.**
- **The geothermal scene is active, with several encourageing developments (feed-in tariffs, governmental risk guarantee, special fund for deep geothermal resources, national programs PROGEOTHERM & FEGES);**
- **Switzerland is active in national and international R&D, the latter especially in GIA and in EU projects (ENGINE, I-GET; GROUNDHIT);**
- **The Swiss Geothermal Association is the Swiss Geothermal Competence Center; unified appearance as geothermie.ch**

Acknowledgement

The participation of Switzerland in the IEA GIA is financed by the Swiss Federal Office of Energy (SFOE), Berne. The support is gratefully acknowledged.

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ANHANG IV

Swiss input to IEA GIA Annual Report 2007

SWITZERLAND

1. Introduction

a. Background

There is a significant move on energy scene in Switzerland towards renewable energies and to technologies that can mitigate climate change. The basis and the boundary conditions are defined by the official Swiss energy policy. New statistical data provide reliable numbers about development and use of geothermal resources in Switzerland.

b. Major highlights in 2007

The main achievement is the steady growth of geothermal direct use, mainly due to the advance of geothermal heat pump system. They are now increasingly installed also in larger complexes for space heating, cooling, and domestic hot water production.

The total installed capacity for direct use secures Switzerland a prominent international rank, see Table 1: Switzerland is number 2, right after Iceland.

Table 1: The world-wide top 15 in geothermal direct use, and ranking in terms of areal density of production capacity. Ranking calculated from data in Fridleifsson et al. (2008).

Country	GWh/yr	Country area 10^3 km^2	GWh/yr per 10^3 km^2	Rank
China	12,605	9571	1.32	12
Sweden	10,000	450	22.2	6
USA	8,678	9809	0.88	13
Turkey	6,900	779	8.86	7
Iceland	6,806	103	66.1	1
Japan	2,862	378	7.57	8
Hungary	2,206	93	23.7	5
Italy	2,098	301	6.97	10
New Zealand	1,968	271	7.26	9
Brazil	1,840	8512	0.22	14
Georgia	1,752	70	25.0	4
Russia	1,707	17075	0.10	15
France	1,443	544	2.65	11
Denmark	1,222	43	28.4	3
Switzerland	1,175	41	28.7	2

2. National Policy

a. Strategy

The governmental energy program *SwissEnergy*, which supports renewable energies, provides the general strategic framework for geothermal R&D. A new phase for the years 2006-2010 is now being implemented. The strategy is specified by new energy and CO_2 laws. In 2007 *SwissEnergy* initiated an investment volume of 1 billion Swiss franks, equivalent to 5'300 person years. *Note: nowadays 1 CHF is roughly 1 US$*

b. Legislation and Regulation

The Energy Law
stipulates the rational use of energy and the increasing use of renewables.

The CO_2 law
should enforce the CO_2 reduction target set by SWISSENERGY
Instruments: voluntary measures, measures by decree, flexible mechanisms (Kyoto)
Decreeted measures:
- CO_2 tax on fossil fuel (0.03 CHF per liter oil, 0.025 CHF per m3 gas since 1 January 2008)
- "Klimarappen" (clima cent) on gasoline/diesel (0.015 CHF per liter, since 1 October 2005)

c. Progress towards National Targets

The targets to reach until 2010 are:
- reduction of fossil energy carriers by 10 % (relative to 1990);
- reduction of CO_2 emissions by 10 % (relative to 1990);
- limitation of electricity consumption increase to 5 %;
- increase of renewable contributions by 1 % to electricity and 5 % to heat demand.

Instruments to reach the targets are:
-modernization of buildings;
-increasing use of renewable energies;
-energy efficiency in transportation, appliances and devices.

The progress is significant but still substantial efforts are needed to reach the targets until 2010.

d. Government Expenditure on Geothermal R& D

The Swiss Federal Office of Energy (SFOE) provided funding in 2007 for
- Research and Development: 0.70 MCHF;
- Pilot and Demponstration: 0.13 MCHF;
- Supporting the Swiss Geothermal Association SVG: 0.51 MCHF.

3. Current Status of Geothermal Energy Use in 2007

a. Electricity generation

So far no kWh electricity is being produced from geothermal sources in Switzerland. The Deep Heat Mining Project in Basel, aimed at co-generation by means of an EGS system, has been suspended by the local authorities in the wake of induced seismic events in late 2006 and early 2007 (maximum magnitude M_L = 3.4).

The Swiss geothermal resource assessment project produced its first publication (Signorelli & Kohl 2007). The corresponding resource atlas comprises mainly the northern part of Switzerland, with sufficient data density. The study determined heat in place in crystalline basement in a part of northern Switzerland (9'600 km^2; about 23 % of Swiss territory). The total is 1 million PJ, recoverable 11'000 PJ over 30 years. For power generation several suitable regions have been delimited.

b. Direct Use

Thanks to a potential study, commissioned by the SFOE and completed in 2008 (Signorelli et al. 2008) there are now reliable data for the installed capacity and the energy use in 2007. The study also depicts the development since 1990. Table 2 shows the distribution of direct use to different categories; the predominant contribution is from geothermal heat pumps (GHP). Among these the borehole heat exchanger (BHE)-coupled systems predominate.

Table 2: Installed thermal power for direct use in Switzerland (2007). From Signorelli et al. (2008).

Usage system	Installed capacity (MWth)
Heat pumps with borehole heat exchangers, horizontal collectors	749.5
Groundwater heat pumps	77.7
Geostructures ("energy piles")	8.9
Deep borehole heat exchangers	0.2
Deep aquifers for district heating	2.4
Tunnel waters	5.2
Spas, wellness facilities	36.4
Total	**880.3**

The GHP development trends are shown in Figures 1 – 3, covering the time span 1990 –2007. Again here the advance of BHE-coupled systems is clearly visible, while the groundwater heat pumps exhibit only slow increase.

The development in the different direct usage categories since 2004 is given in Table 3.

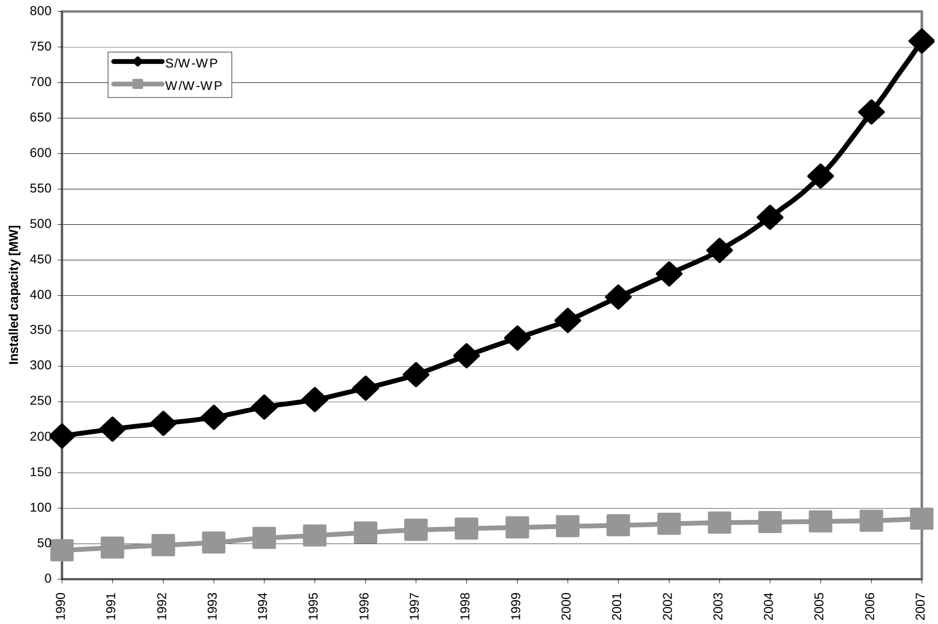

Figure 1: Development of ground-coupled heat pump capacity in Switzerland 1990 - 2007. S/W-WP: BHE or horizontal collector systems; W/W-WP: Groundwater heat pumps. From Signorelli et al. (2008).

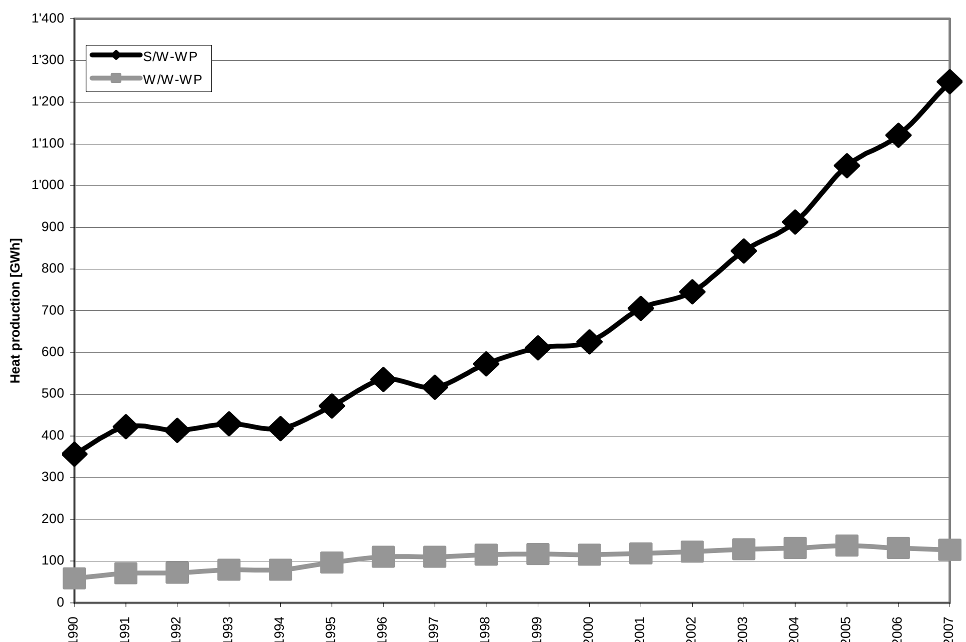

Figure 2: Development of heat production by geothermal heat pump systems in Switzerland 1990 – 2007. S/W-WP: BHE or horizontal collector systems; W/W-WP: Groundwater heat pumps. From Signorelli et al. (2008). The uneven increase is due to meteorologic factors (mild/normal winters).

Table 3: Development in heat production of Swiss geothermal installations 2004 - 2007 (GWh/year). From Signorelli et al. (2008).

Usage system	2004	2005	2006	2007	% in 2007
Heat pumps with borehole heat exchangers, horizontal collectors	897.5	1030.8	1102.0	1229.8	73.0 %
Groundwater heat pumps	112.5	118.4	113.0	112.2	6.7 %
Geostructures (“energy piles”)	14.5	16.3	17.8	18.4	1.1 %
Deep borehole heat exchangers	1.0	1.0	1.0	1.0	0.1 %
Deep aquifers for district heating	18.4	18.7	17.6	15.4	0.9 %
Tunnel waters	4.0	4.0	4.0	2.7	0.2 %
Spas, wellness facilities	312.7	304.6	304.6	304.6	18.0 %
Total	**1360.6**	**1493.8**	**1560.0**	**1684.1**	**100.0**

The number of boreholes drilled for BHE installations is highly remarkable. Alone in 2007 the total drilling length (meters) was nearly 1’500 kilometers, see Figure 3. This would correspond to about 10’000 average depth (150 m) drillholes, equipped with BHEs. The majority of the BHE systems are installed in new buildings but an important and increasing portion is for retrofitting existing buildings.

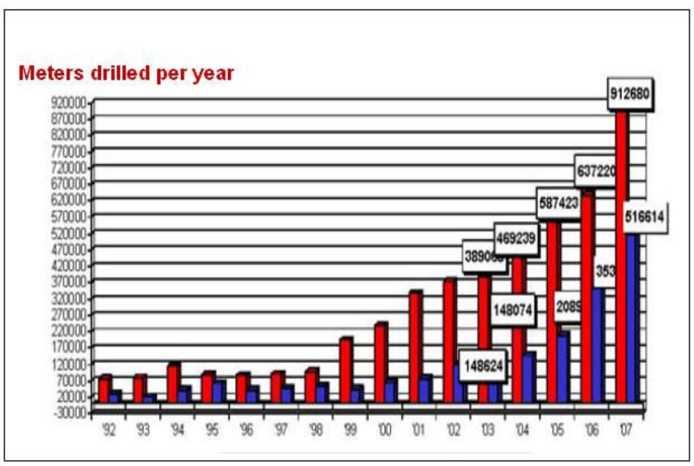

Figure 3: Development of total drilling for borehole heat exchanger-coupled geothermal heat pumps in Switzerland 1992 – 2007. Red bars: BHEs for new buildings, blue bars: for renovation. From Förderverein Wärmepumpen Schweiz (www.fws.ch) .

The GHP current development trends encompass more and more also large-scale installations (with >50 BHEs). Such installations are now designed, to provide space heating, cooling and domestic hot water, on the basis of large geothermal stores. In fall 2007 the opening of the completely renovated and largely extended top-class *Hotel Dolder the Grand* in Zurich has been announced. The original space has been more than doubled. Figure 4 gives more data. Also in 2007 the ambitious project *Science City* at the Zurich-Hönggerberg campus of the Swiss Federal Institute of Technology (ETHZ) has been started, with experimental boreholes to determine site conditions. All together four large geothermal stores are planned (total store volume: $8 \cdot 10^6$ m^3). Heating demand of the complex is 15 GWh/year, cooling demand 11 GWh/year. Over 750 BHEs, each 200 m deep, will be needed. Figure 5 shows a design sketch of the distribution network with the stores. The design of both objects is with Geowatt AG Zurich.

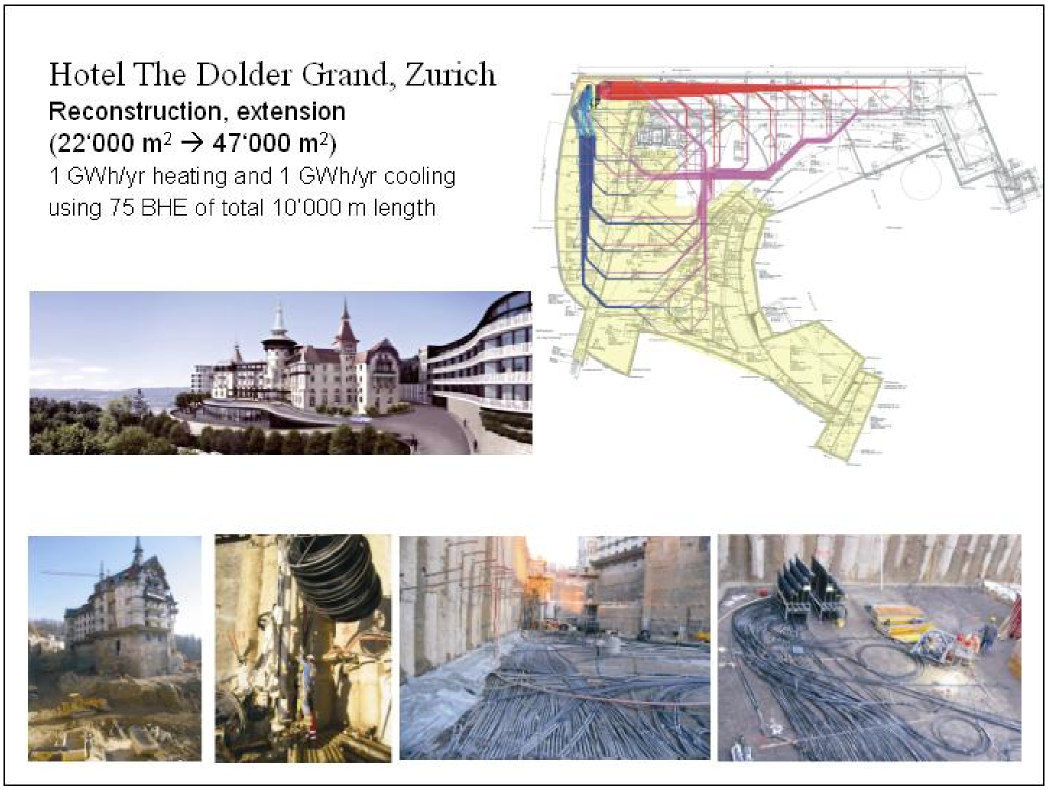

Figure 4: Geothermal store with the hydraulic connections (top right) for *Hotel Dolder the Grand*, Zurich. The middle picture shows the completed building complex, the bottom ones various construction changes.

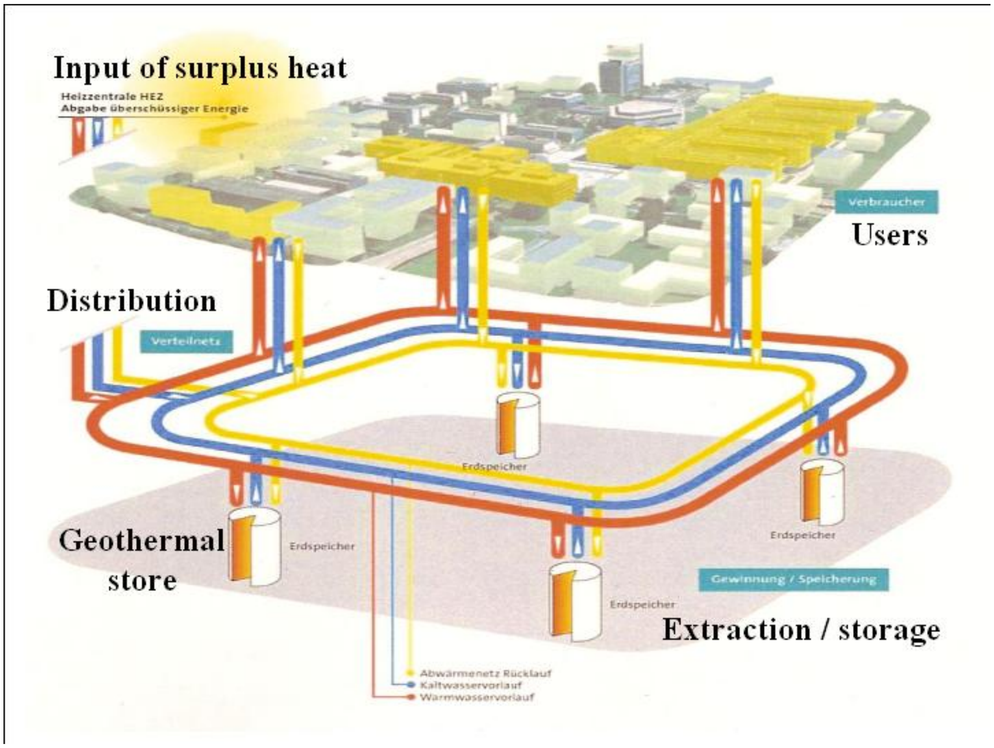

Figure 5: Four geothermal stores, built in succession, are in design for *Science City*, Zurich. Besides teaching and research facilities of ETHZ it will have living and recreation facilities. Red circuit: Warm water delivery, blue circuit: Cold water delivery, yellow circuit: Waste heat return.

c. Energy Savings

The use of emission-free geothermal resources in Switzerland enables to save considerable amounts of fossil fuels. The total heat production of 1684 GWh (6 PJ) in 2007 corresponds to the saving of 140’000 toe/year.

By this means the emission of additional 445’000 tonnes of CO_2/year can be prevented.

Here it must be mentioned that when it comes to heat pumps some caution about CO_2 emission issues is needed. Since heat pumps are usually driven by electric components the origin of the electricity and the corresponding CO_2 emissions must be considered. Although Switzerland’s indigenous electricity production (60 % hydro, 40 % nuclear) is practically free of CO_2 emissions, there is substantial import of electricity through the interconnected European grid for Swiss users. Unfortunately there are no statistical data about the exact source of such imports but sometimes the imported electricity can originate from Poland, where power generation originates nearly completely from coal-fired power plants.

4. Market Development and Stimulation

In 2007 the only booming development segment in geothermal utilization was that of geothermal heat pumps; Figure 3 testifies the constant increase of the corresponding activities.

The take-off of a real accelerated market penetration started apparently around the year 1998. This is about the time when the subsidy system of the Swiss Government for geothermal heat pump systems in earlier years (up to US$ 5000 when replacing an old fossil-fired system by a geothermal heat pump installation) terminated. But apparently there was enough information dissemination to the market. Nowadays there are still financial incentives like local electricity tariff rebates to help the advance of geothermal heat pumps.

5. Development Constraints

Although the permitting process for geothermal systems in direct use is relatively simple and comparable to other European countries there are also anomalies: there are still obstacles in the way of progress for geothermal heat pump systems. For example: in Canton Bern (the second largest Canton) it is forbidden to place borehole heat exchangers beneath buildings, whereas in the rest of Switzerland this is an increasing practice, mainly due to the high land prices.

6. Economics

The installation cost of geothermal systems did not significantly decrease in 2007. But with the current oil and gas price increase, most of such systems can be built and operated to yeald a return of investment in about 4-5 years. In general it is recognized that geothermal systems are indigenous and thus contribute to energy supply security.

Energy Contracting for geothermal heat pump systems is increasingly popular (the local electric utility builds, owns, and operates the system and the building owner receives monthly bills for heating, cooling and warm water). There is a ground price depending on the installation size and a variable price for heat, cold, and warm water delivery. Unfortunately the local utilities do not unveil price details.

There are no statistical data about employment in the Swiss geothermal sector. Some 150-200 people are working in this sector, most of them in drilling or engineering companies.

7. Research Activities in 2007

a. National activities

Numerous research projects have been financed by the Swiss Federal Office of Energy (SFOE) in 2007. Dr. Rudolf Minder (IEA GIA ExCo Alternate) is the SFOE Geothermal Research Program Leader. Here only a selection of projects can be mentioned, by resource type:

Shallow: Enhanced Thermal Response Test, Operational experience and optimization Zurich airport Terminal E, Geocooling in MINERGIE buildings

Deep: Geothermal fluid chemistry data base, Energy conversion processes for the use of geothermal heat,

The general Swiss Geothermal Action Plan PROGEOTHERM has been elaborated by a team led by the Neuchâtel Centre de Recherche en Géothermie CREGE. It comprises university level education (Master of Advanced Studies in Geothermal Energy), Research and Development, Pilot and Demonstration Facilities, Policy and Information.

Further research projects, like the Long-term Program FEGES for Swiss geothermal power development and a potential update study of tunnel water resources, have been financed by the Swiss Geothermal Association SVG (the Swiss Geothermal Competence Center).

b. International Cooperative Activities

Switzerland is a GIA Participant (Annexes I, III and VIII)

In 2007 Switzerland has also been active within R&D programs of European Union's FP6. Cooperation by numerous Swiss specialists has been provided to the following geothermal projects:
- •EGS Scientific Pilot Plant Soultz/F
- •ENGINE
- •I-GET
- •GROUNDHIT

Besides, Swiss researchers participated also in EU project GROUND-REACH.

8. Geothermal Education

Basic and post-graduate teaching is organized by the SVG, mandated by the SFOE. The courses are distributed over whole Switzerland, i.e. courses have been held 2007 in the German, French and Italian parts of Switzerland. The following educational events have been organized:
Basic education: 10 courses, with 188 participants
Post-graduate events: 15 courses, 5 excursions (total 644 participants).

Publications

Re-edited and updated SVG Brochure "Nutzung der Erdwärme - Überblick, Technologie, Visionen"

GEOTHERMIE.CH – regular Bulletin publication of SVG (in German/French); two issues per year.

Article of L. Rybach about IEA GIA and Switzerland's participation in GEOTHERMIE.CH no. 43 (September 2007)

Geothermal websites in Switzerland

SVG/GEOTHERMIE.CH	www.geothermal-energy.ch
BFE (SFOE)	www.bfe.admin.ch
CREGE	www.crege.ch
FWS/Heat Pump Promotion Association	www.fws.ch
Geopower Basel AG	www.geopower-basel.ch
Geothermal Explorers Ltd.	www.geothermal.ch
Geowatt AG	www.geowatt.ch

In summary:

- Switzerland continues to be a leading country world-wide in geothermal heat pumps;
- The geothermal scene is active, with several encouraging developments;
- Switzerland is active in national and international R&D, the latter especially in GIA and in EU projects (ENGINE, I-GET; GROUNDHIT);
- The Swiss Geothermal Association SVG is the Swiss Geothermal Competence Center; unified appearance as GEOTHERMIE.CH

Acknowledgement

The participation of Switzerland in the IEA GIA is financed by the Swiss Federal Office of Energy SFOE, Berne. The support is gratefully acknowledged.

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ANHANG V

Swiss Country Update for 20th IEA GIA ExCo meeting

Swiss Geothermal Update Report to 20th GIA ExCo

L. Rybach[1,2]
1) Institute of Geophysics, ETH Zurich, Switzerland;
2) GEOWATT AG, Zurich, Switzerland (rybach@geowatt.ch)

- **This is the 2nd Swiss update in 2008; again the actual highlights are given this time.**
- **The report covers the**
  - **Highlights & achievements**
  - **Institutional framework**
  - **The current geothermal scene**
  - **Market development**
  - **Publications/meetings, education, websites**
  - **International activities**

1. Introduction

a. Background

There is a significant move on the energy scene in Switzerland towards renewable energies and to technologies that can mitigate climate change.

The basis and the boundary conditions are defined by the official Swiss energy policy. New statistical data provide reliable numbers about development and use of geothermal resources in Switzerland.

b. Major highlights

The main achievement is the steady growth of geothermal direct use, mainly due to the advance of geothermal heat pump system.

They are now increasingly installed also in larger complexes for space heating, cooling, and domestic hot water production.

This secures Switzerland a prominent worldwide rank: number two in terms of geothermal energy extraction per unit country area.

National policy: pending issues

- **feed-in tariffs**
- **governmental risk guarantee**
- **special fund for deep geothermal resources**

decided upon but not yet implemented.

(Swiss Country Report to 19th GIA ExCo)

CH - 8050 Zürich

2. National policy

Since the last ExCo meeting

- the feed-in tariffs for electricity from renewable energy sources and
- a risk guarantee scheme for geothermal facilities have been introduced;
- higher R&D funds for geothermal energy (CHF 40-60 mln over 4 years) have been approved by parliament, but no budget has been allocated

a. Feed-in tariffs

The cost-covering remuneration for feeding electricity from renewable energy sources into the grid is based on the new Federal Electricity Supply Act (entered into force on 1 January 2008).

The tariffs are specified in the Federal Electricity Supply Ordinance (entered into force on 1 April 2008).

The Ordinance defines the geothermal facilities (e.g. no combination with fossil generation), the tariffs, the duration, the application procedure, and requests transparency of operational data towards the SFOE.

Swiss feed-in tariffs for geothermal electricity

Nominal capacity (MWe)	Tariff (CHF*/kWh)
≤ 5	0.30
≤10	0.27
≤20	0.21
>20	0.17

***) 1 CHF ≈ 0.89 US$ (as of 17 September 2008)**

Tariffs decrease by 0.5% per year from 2018 on.

First experiences with the feed-in tariffs

A large number of applications have been submitted;

of the annual budget ceiling of CHF 330 mln, about
CHF 100 mln are potentially available for geothermal projects;

already a large number of applications have been granted.

Feed-in tariff applications status as of 31 July 2008

(M. Kaufmann, SFOE Energy Breakfast Zurich, 27 August 2008)

Source	Number of submitted applications		Accepted applications		Capacity of all applications		Capacity of approved facilities
		%		%	kW	%	kW
Solar PV	4'036	82	1'117	29	89'042	8	21'420
Wind	343	7	343	100	656'299	56	656'299
Hydro **(<10MW)**	347	7	347	100	238'264	20	238'264
Biomass	187	4	182	97	192'821	16	141'821
Geothermal	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total	4'913	100	2'049	42	1'176'426	100	1'057'804

b. Risk guarantee scheme

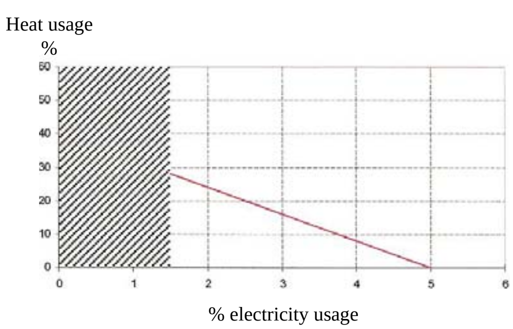
The Federal Electricity Supply Ordinance also describes the risk guarantee scheme.

The financing source is the National Grid Company (NGC).

For applicability the geothermal facilities must provide at least 1.5 % electricity utilization degree, as defined by a diagram.

The risk guarantee covers max. 50 % of the drilling and testing costs.

Usage degrees for geothermal facilities as defined by the Federal Electricity Supply Ordinance



Risk guarantee scheme (2)

The applications must contain numerous specifications like success/partial success/failure criteria.

The SFOE appoints a special committee for each application; the committee evaluates the application and gives a recommendation for the attention of the NGC.

In case of approval the SFOE designates an independent specialist to control the project implementation.

The details are fixed in a special guideline (soon in force).

c. CO_2 reduction policy

The CO_2 emission reduction strategy is specified by new CO_2 legislation.

Various instruments like voluntary measures, measures by decree, flexible mechanisms (Kyoto) are used to reach the goals.

Decreeted measures:

- CO_2 tax on fossil fuel for heating (0.03 CHF per liter oil, 0.025 CHF per m³ gas since 1 January 2008)
- "Klimarappen" (climat cent) on gasoline/diesel fuel (0.015 CHF per liter, since 1 October 2005; its increase to 0.0199 CHF/liter is now considered)

d. Progress towards national targets

The targets to reach until 2010, as defined by the Governmental energy program *SwissEnergy,* are:

- reduction of fossil energy carriers by 10 % (relative to 1990);
- reduction of CO_2 emissions by 10 % (relative to 1990); limitation of electricity consumption increase to 5 %;
- increase of renewable contributions by 1 % to electricity and 5 % to heat demand.

In 2007 there was some slowdown relative to 2006: energy saving of 3'600 TJ against 4'400 TJ in the previous year as well as a budget cut by 7 %.

e. Government Expenditure on Geothermal R& D

The Swiss Federal Office of Energy (SFOE) provides funding in 2008 for

- Research and Development: CHF* **0.85 mln**;
- Pilot and Demponstration: CHF **0.25 mln**;
- Supporting the Swiss Geothermal Association SVG: **CHF 0.51 mln.**

**) 1 CHF ~ 0.89 US$ (17 September 2008)*

3. Current status of geothermal energy use

a. Electricity generation

So far no kWh electricity is being produced from geothermal sources in Switzerland.

The Deep Heat Mining project in Basel is suspended by the local authorities; a seismic risk study has been commissioned but its funding not yet approved.

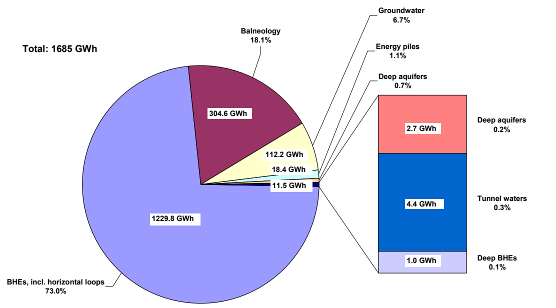
A number of potential hydrothermal projects are in the exploration phase (Cantons of Valais, Vaud, Zurich, St Gall).

b. Direct use

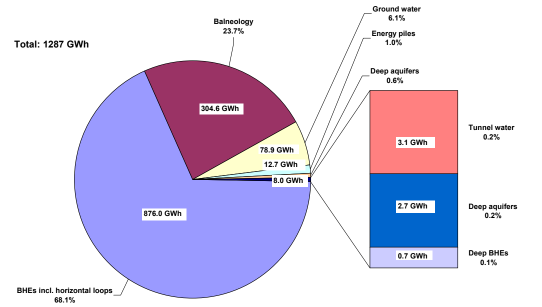
Thanks to a statistical study, commissioned by the SFOE and completed in 2008 (Signorelli et al. 2008), there are now reliable data about the installed capacity and the energy use in 2007.

The study also depicts the development since 1990.

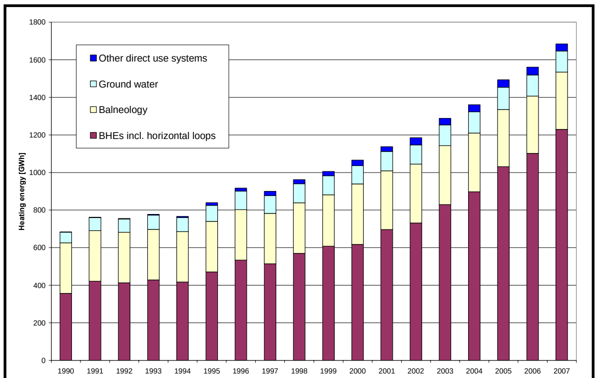
Statistical survey of geothermal direct use in Switzerland 1990 – 2007 prepared for or SFOE



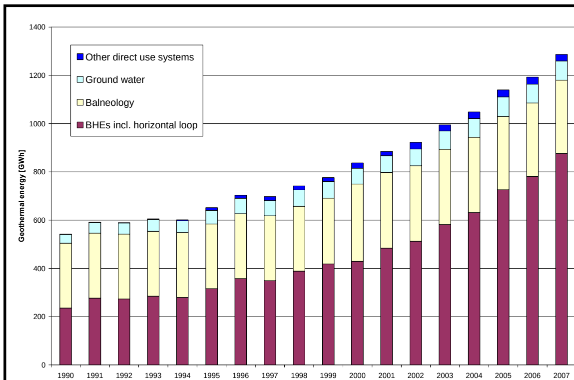
Total heating by geothermal installations in Switzerland 2007



Geothermal source part in total heating (before the heat pump)



Growth of energy use by geothermal installations in Switzerland



Growth of geothermal source part in total heating

The statistical diagrams show the distribution of direct use to different categories; the predominant contribution is from geothermal heat pumps (GHP).

Among these the borehole heat exchanger (BHE)-coupled systems predominate. They are now increasingly installed in larger complexes like Science City at ETH Zurich Hönggerberg Campus.

In Zurich city/Triemli area a major hydrogeothermal project (=deep aquifer) has been launched, with a first exploratory well to a maximum depth of 3.0 km. Builder-owner is EWZ, the electric utility company of Zurich.

c) Energy savings

The increasing use of GHP systems in new buildings avoids the additional burning of fossil fuels; GHPs are also increasingly installed in renovation.

Nearly 60 % of the total BHE length was installed for renovation in 2007.

4. Market development, constraints, economy

No significant changes took place;

the rate of fossil fuel price changes (a major stimulus for heat pump application in case of increase) remains unpredictable;

significant electricity price rise (up to 25 % at places) must be expected in the near future.

5. Research activities

a) National

Numerous research projects are been financed by the Swiss Federal Office of Energy (SFOE) currently.

Dr. Rudolf Minder (former IEA GIA ExCo Alternate) is the SFOE Geothermal Research Program Leader.

Federal Government sponsored R&D activities

- Heat pumps: detailed measurement campaigns, thermal response tests, conceptual resource studies, utilization of tunnel waters
- Hydrothermal projects: site specific explorations studies, data bases
- EGS: seismic risk analysis in Basel, support of the EU-Project at Soultz-sous-Forêts (France)

The ongoing deep R&D activities include a new project *BDFGeotherm-Google* about implementation of the Swiss geothermal fluid data base into Google Earth.

It is a specific Swiss contribution to GIA Annex VIII, under the leadership of Dr. F.-D. Vuataz (Center of Geothermal Reasearch CREGE, Neuchâtel).

b) International

Switzerland continues its GIA participation, especially in Annexes I, III and VIII.

Within the R&D programs of European Union, in which numerous Swiss specialists have cooperated, the following geothermal projects came to an end in 2008 or are nearing completion:

- EGS Scientific Pilot Plant Soultz/F
- ENGINE
- I-GET
- GROUNDHIT
- GROUND-REACH.

5. Geothermal education

a) University level teaching

A new full professorship in applied geothermics has been established at Neuchâtel University.

The elected professor, Eva Schill, will be responsible to organize the Master of Advanced Studies in Geothermal Energy course starting in fall 2009.

Her research shall be coordinated with that of CREGE.

b) Basic and post-graduate training for professionals

Basic and post-graduate teaching is organized by the Swiss Geothermal Association SVG, mandated by the SFOE.

The courses are distributed over whole Switzerland, i.e. courses are held in the German, French, and Italian parts of Switzerland.

The following educational events have been organized in 2008 until end of July:

- Basic education: 6 courses with 176 participants
- Post-graduate events: 5 courses with 234 participants. 1 excursion with 15 participants.

Reference:

Signorelli, S., Sonnenfroh, F., Kohl, T., Rybach, L. (2008): Statistik der geothermischen Nutzung in der Schweiz – Ausgabe 2007. Report to the Swiss Federal Office of Energy.

Geothermal websites in Switzerland

SVG/GEOTHERMIE.CH	www.geothermal-energy.ch
BFE (SFOE)	www.bfe.admin.ch
CREGE	www.crege.ch
FWS/Heat Pump Promotion Association	www.fws.ch
Geopower Basel AG	www.geopower-basel.ch
Geothermal Explorers Ltd.	www.geothermal.ch
Geowatt AG	www.geowatt.ch

Acknowledgement

The participation of Switzerland in the IEA GIA is financed by the Swiss Federal Office of Energy (SFOE), Berne. The support is gratefully acknowledged.

ANHANG VI

Workshop announcement „Geothermal Energy - Its Global Development Potential & Contribution to the Mitigation of Climate Change”

Joint GIA-IGA Workshop

Geothermal Energy-
Its Global Development Potential
&
Contribution to the Mitigation of Climate Change

The International Energy Agency- Geothermal Implementing Agreement (IEA-GIA) and the IGA are holding a joint 2-day workshop in Madrid, Spain, on 5-6 May 2009, to discuss the global potential of geothermal energy and its possible contribution to the mitigation of climate change. The results will contribute to the geothermal chapter of the Intergovernmental Panel on Climate Change (IPCC) Special Report on Renewable Energy and Climate Change to be published in 2010.

Though still in the planning stages, the current draft Workshop discussion topics includes: Definitions of Geothermal Potential; Geothermal Potential for Power Generation and for Direct Use; Challenges and Barriers to Attaining Geothermal Potentials; and the Potential Contribution to Mitigation of Climate Change. The plan is to have a limited number of experts from the GIA and IGA, and possibly other invited experts, make short presentations on these topics based upon their current work and/or published (peer reviewed) papers, to be followed by in-depth discussions. A "wrap-up session" will firm up conclusions, assign actions and set deadlines for completion of outputs, which are expected to include: a formal "Madrid" statement on geothermal's potential contribution to climate change and final reviewed summary documents presenting the participants' agreed conclusions.

For the IEA GIA: Mike Mongillo, Secretary
For IGA: Ladislaus Rybach, President

ANHANG VII

Bromley, C.J., Mongillo, M., Rybach, L., Song, Y. (2008): Geothermal Energy - IEA-GIA’s Efforts Towards Accelerating Development of this Global, Under-utilized Renewable Resource. Proc. RE 2008 (CD-ROM).

GEOTHERMAL ENERGY- IEA-GIA's EFFORTS TOWARDS ACCELERATING DEVELOPMENT OF THIS GLOBAL, UNDER-UTILIZED RENEWABLE RESOURCE

Chris J. Bromley[1], Mike Mongillo[2], Ladislaus Rybach[3], Yoonho Song[4],
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The International Energy Agency (IEA) Implementing Agreement for a Cooperative Programme on Geothermal Research and Technology (GIA) is now in its 11th year, with a growing membership (17) of participating countries and industry partners. The wide-ranging and expanding efforts of the IEA-GIA are targeted towards accelerating sustainable development of the world's vast geothermal energy resources and thereby contributing to the mitigation of climate change. Geothermal energy development is in a rapid growth phase worldwide and has characteristics of significant importance for both generating electricity and for direct heating applications. Geothermal is a renewable indigenous energy resource, it is suitable for diversified and distributed power generation, it can be managed in an environmental friendly manner, it can be utilized in a sustainable manner, and it provides "base-load" electricity and heat supply independent of seasonal or weather effects. The potential is vast, and geothermal energy can contribute significantly towards meeting the growing global renewable energy demand. To maintain this accelerated development it is essential to improve and develop new technologies, promote the benefits of sustainable geothermal utilization, and better educate the public, financial, and policy sectors. The GIA provides the means to do this through its extensive international cooperation in geothermal R&D, focusing particularly on disseminating information, improving environmental outcomes, enhancing EGS prospects, reducing drilling costs, promoting direct use applications, and encouraging long-term sustainable development strategies.

Keywords: geothermal energy, Geothermal Implementing Agreement, enhanced geothermal systems, sustainable utilization

1. INTRODUCTION

Natural geothermal heat flow from the earth's surface is large, about 3 times the total energy use of humankind today, but it is not uniform. It is concentrated in regions around tectonic plate boundaries and volcanic hot spots, covering ~15% of the land surface, and home to about 15% of the world's population. The high-temperature hydrothermal resources located in these regions have been steadily developed using mature technology for electricity production over the past 100 years, with the current global installed capacity of ~10 GW_e estimated to be less than 4% of the total global potential from these naturally-fractured, high-temperature hydrothermal resources. Consequently, there is huge potential for increasing "conventional" geothermal development to help meet growing demand in these regions. In addition, the substantial heat resources available nearly everywhere at depths of 3-10 km are the targets for development with the emerging enhanced geothermal systems (EGS) technology. These could provide even more power and heat for direct use across the globe. Recent assessments of the deep heat resources for EGS development have been performed for the USA, Australia, Germany, Switzerland, India and China, and they indicate huge potentials: a total of ≥ 360,000 MW_e for these six countries alone. In addition, very large untapped resources may be available at depths of 3-5 km beneath conventional hydrothermal systems. Increased development of low temperature hydrothermal resources and better use of "waste" hot water can be achieved using binary cycle power plants. Direct uses of geothermal energy, including geothermal heat pumps and "cascade" applications for district/space heating and cooling, also have very large potential for growth.

The rate of investment in geothermal energy developments, worldwide, has increased significantly in recent years [1]. Many energy companies and policy makers now recognize that the global potential of geothermal energy, as a renewable resource, is vast and under-utilised. The IEA-GIA has been working collaboratively for 11 years to help improve knowledge of global geothermal resources and to overcome barriers to accelerating sustainable development.

2. IEA-GIA

The GIA was established in 1997, and is currently in its 3rd 5-year term. It provides a flexible framework for wide-ranging international cooperation in geothermal R&D by bringing together national and industry programmes for exploration, development and utilization of geothermal resources, with a focus on enhancing effectiveness through establishing direct cooperative links among geothermal experts in the participating countries and industries. The GIA's general scope of activity consists of international scientific collaborative efforts to: *compile and exchange improved information* on worldwide geothermal energy R&D concerning existing and potential technologies and practices, *develop improved technologies* for geothermal energy utilization, and *improve the understanding of the environmental benefits* of geothermal energy and ways to avoid or minimize its environmental impacts. GIA collaboration provides researchers with opportunities for information exchange via meetings, workshops and networking. Members can participate in R&D projects and develop databases, models and handbooks. Policy and decision makers can obtain an international perspective on geothermal issues, opportunities and environmentally-appropriate development strategies.

As of 2008, membership of the IEA-GIA included: the European Commission; 12 countries: Australia, France, Germany, Iceland, Italy, Japan, Mexico, New Zealand, the Republic of Korea, Spain, Switzerland and the United States; and 4 industry Sponsors: Geodynamics, GreenRock Energy, ORMAT Technologies and Orme Jeotermal.

2.1 Mission and Activities

The GIA's current Mission is: *To promote the sustainable utilization of geothermal energy throughout the* *world by improving existing and developing new technologies to render exploitable the vast and widespread global geothermal resources, by facilitating the transfer of know-how, by providing high quality information and by widely communicating geothermal energy's strategic, economic and environmental benefits.*

To accomplish this mission, GIA participants take part in one or more of the current four research areas (Annexes):

- *Annex I: Environmental Impacts of Geothermal Energy Development*- to identify environmental effects of geothermal development and devise and adopt methods to avoid or minimize their impact. Five tasks include: to investigate the impacts on natural features; to study the problems associated with discharge and reinjection of geothermal fluids; to examine methods of impact mitigation and produce environmental guidelines; to investigate seismic risk from EGS fluid injection; and to develop sustainable utilization strategies.
- *Annex III: Enhanced Geothermal Systems (EGS)*- to investigate new and improved technologies that can be used to artificially stimulate a geothermal resource to allow commercial heat extraction. Four tasks include: to develop EGS economic models; to review/modify application of conventional or new geothermal technologies; to collect information necessary for designing a commercial EGS plant; and to compile effective tools for reservoir evaluation that can be applied to new EGS sites.
- *Annex VII: Advanced Geothermal Drilling Techniques*- to pursue advanced geothermal drilling research and investigate all aspects of well construction with the aim of reducing costs. Three tasks include: the compilation of geothermal well drilling cost and performance information; production of a geothermal drilling "best practices" handbook; and exchange of information on drilling technology development and new applications.
- *Annex VIII: Direct Use of Geothermal Energy*- to address all aspects of direct use technology with emphasis on improving implementation, reducing costs and enhancing use. Six tasks include: to define and characterize geothermal resources for direct use applications; to collect, analyze and disseminate cost and performance data and validate improvements; to initiate research to remove barriers, enhance economics and promote implementation; to identify, test and characterize performance of innovative equipment; to develop engineering standards; and to develop methods for presenting geothermal data using Google Earth.

3. GLOBAL GEOTHERMAL RESOURCE POTENTIAL

Global geothermal resource potential has been discussed in a recent publication [2]. There are considerable uncertainties in estimating economically-exploitable heat resources, and updated estimates can be anticipated in the future as more information becomes available. The geothermal resource essentially consists of heat energy stored beneath the earth's surface and discharging from it. More than 99% of the earth's volume is at temperatures >1000 ^{o}C. Within the earth's crust, the heat is transferred slowly towards the surface by conduction and transmitted convectively by fluid (water or steam) through fractures and pores. The principal sources of geothermal energy are the heat flow from the earth's core and mantle (~40%), and that generated by the gradual decay of radioactive isotopes in the earth's crust (~60%). The total heat content of the earth is estimated to be about 10^{13} EJ and would take over a billion years to exhaust at today's global terrestrial heat flow rate of 44 million MW_t (1,400 EJ/year). This natural heat flow rate is almost three times the world's primary energy consumption rate (479 EJ/yr in 2005). The key to tapping and using this renewable energy flow, both efficiently and economically, is to locate or create fractures in high temperature rock to allow rapid heat transfer to the surface using water and steam. Where fractures are not naturally abundant, it is technically feasible to stimulate new fractures or re-activate existing ones through high pressure injection, a practice developed for enhanced geothermal systems (EGS).

3.1 Hydrothermal Resource Potential

High temperature hydrothermal resources located in regions of elevated natural seismic and volcanic activity have been steadily developed for electricity production for 100 years. The current worldwide geothermal installed capacity of ~10 GW_e (mid-2007, Fig. 1) is distributed across 24 countries, but is mostly located in the USA, Philippines, Italy, Japan, Mexico, Indonesia, New Zealand, Iceland, Kenya and Central America [1]. Almost 50% of the installed capacity (~4.5 GWe) has been in operation for more than 25 years, providing a sound basis for long term assessments of sustainable resource utilisation strategies and operational costs. Present installed capacity amounts to only 4% of the estimated total global potential of 240 GW_e of identified hydrothermal ("technically feasible") resources, or ~0.5% of global geothermal resources if estimates of as yet "undiscovered" resources are included [3]. There is, therefore, still potential for a large increase in "conventional" geothermal development in the future to meet growing demand for renewable energy in these 'tectonically' or 'volcanically' active regions.

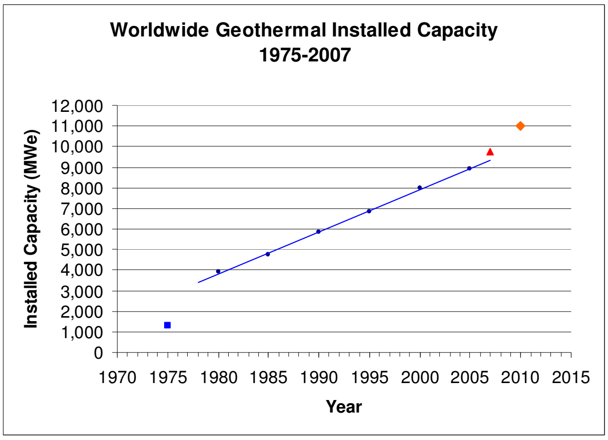

Fig. 1. Global geothermal power installed capacity 1975-2007. Red triangle is 2007 and orange diamond is forecast for 2010 ([4] and [1]).

Currently, the development of geothermal energy for electricity generation (Fig. 1) and direct use is in a new rapid growth phase worldwide, and its future prospects as a renewable, environmentally-friendly global energy resource are looking very positive. An advantage of geothermal energy relative to other renewable resources, is its very high availability factor (typically >90%) allowing "base-load" electricity generation. Comparison of the 'contribution efficiency' (GWh Produced)/(MW_e installed capacity) shows that, on average, geothermal out-performs hydro generation by a factor of 2, wind by a factor of about 3.5, and solar PV by a factor of about 20 [5]. The average geothermal power availability factor would be even greater if historical factors such as grid constraints and repairs to damaged power-plants, which are unrelated to resource availability, were removed.

3.2 EGS Resource Potential

Attention has recently been directed to the substantial heat resources available at depths of 3-10 km almost anywhere on earth for electricity production and direct use through the use of EGS techniques. These EGS resources are "created" by enhancing fracture permeability and/or providing the water to access the heat. The process of creating permeability involves high pressure pumping for the purpose of fracturing the rock. In these settings (away from plate boundaries), where naturally occurring earthquakes are less common, induced seismic events associated with EGS activities have been observed and may become an issue, so information dissemination and education of the public are necessary to address public perception of the risk that large induced seismic events could occur [6].

EGS investigations have been conducted in the past at several sites around the world, including: Fenton Hill (Los Alamos, USA); Rosemanowes (Cornwall, UK); Hijiori and Ogachi (Japan). Current projects (>1 MWe), at an advanced stage of development, are located at Soultz-sous-Forêts (France); Landau and Unterhaching (Germany); Basel (Switzerland); and Cooper Basin (Australia). In the USA, EGS investigations were recently conducted at Coso and Glass Mountain, and are now being pursued at Desert Peak. In Australia, 33 companies currently hold licenses for different EGS developments. The first EGS power plant (~3 MWe) was installed in late 2007 (Landau) and others are expected to be installed in 2008 at Soultz and Unterhaching, with Cooper Basin expected to come on-line in early 2009. Recent assessments of deep heat resources for EGS development have been performed for the USA [7], Germany, Switzerland, India, China and Australia. They indicate a huge potential: ≥100,000 MWe for the USA, and for parts of China and India; 35,000 MWe for Germany and 12,000 MWe for about 25% of Switzerland and 12,000 MWe for portions of Australia, making a total of ≥360,000 MWe for these six countries. Successful development of such resources can provide both electricity generation and direct heat applications (e.g. district heating).

Most EGS projects in 'continental' settings require drilling to depths of 4-5 km to reach adequate temperatures for economic electricity generation (≥ 170 ºC). Some sectors of conventional hydrothermal reservoirs have poor local permeability, despite high temperature, and these could benefit from EGS techniques at shallower depths. Reservoir stimulation techniques such as "hydro-fracing" and chemical stimulation are used to enhance permeability, and hence increase circulating flow rates and energy extraction rates. Heat recharge is supplied through conduction, so a large network of interconnecting fractures is required for an economically sustainable operation.

The reservoir permeability stimulation technique called "hydro-fracing" involves pumping water down wells at high pressure to hydraulically fracture the hot rock. This induces micro-seismic events, which can sometimes be felt at the surface. Typically, these are not sufficiently large enough, nor of the right vibration frequency, to cause structural damage. Hydraulic pressure decreases radially away from the well bore and dissipates with time, depending on the permeability (both natural and induced). Thus, an increasing volume (termed a 'cloud') of induced seismic events typically forms progressively about the injection point. The degree and extent of hydro-fracturing can depend on both pumping pressure and total volume of fluid injected. Other forms of stimulation are also possible including: chemical stimulation which creates permeability by leaching parts of the rock matrix; explosive fracturing and local thermal stress cracking (usually using colder water). These latter options are most useful in stimulating formations close to the wells.

Stress redistribution into a larger volume of rock surrounding the well may also result from near-well hydraulic or thermal stress fracturing, and this can trigger fracturing events on more distant faults that are naturally pre-stressed to near failure conditions. The diffusion of pressure and the redistribution of stress can take a significant period of time (possibly weeks or months).

3.3 Other Sources of Geothermal Potential

In addition to the hydrothermal potential discussed in section 3.1, large energy resources are inferred to exist deeper (3-5 km) beneath these systems where temperatures up to ~600 ºC may be encountered. Wells drilled into such super-critical conditions could produce up to 10 times the output of typical geothermal wells, thus increasing the available energy for power generation considerably.

The use of binary–cycle power plants provide the opportunity to economically develop the more numerous lower temperature (75-170 ºC) hydrothermal resources as well as to utilize the hot "waste" water from conventional geothermal power developments. There may also be more opportunities for "cascaded" direct use of heat from the water discharged from all types of power developments.

3.4 Direct Use Geothermal Potential

Rapid world-wide escalation of geothermal heat pump installations for both heating and cooling of domestic buildings and other facilities has occurred over the past decade and this is set to continue. Significant potential also exists for wider commercial use of direct heat from geothermal fluids. More details can be found in companion papers in this publication (by L. Rybach and J. Lund).

4. RESEARCH DIRECTIONS

To maintain and accelerate geothermal development it is essential to improve and develop new technologies and to increase awareness of geothermal energy and the benefits of its sustainable utilization. The IEA-GIA provides one means to do this through its extensive international cooperation in geothermal R&D, focusing particularly on improving environmental outcomes, enhancing EGS prospects, reducing drilling costs, promoting direct use applications, encouraging long-term sustainable development strategies and information dissemination.

4.1 GIA Contributions - International Efforts

Examples of recent outcomes and discussions of ongoing research priorities are found at the IEA-GIA website: www.iea-gia.org. Environmental (Annex 1) research outputs include: a draft protocol for induced seismicity management; discussion papers on induced seismicity ([6] and [8]); and environmental enhancements and improved long-term sustainability strategies ([9] and [10]). The EGS research programme (Annex 3) has developed a Project Management Decision Assistant (PMDA) which incorporates 30 years of EGS project histories to guide new EGS developments, and an EGS economic model. The drilling research effort (Annex 7) has made progress on comparative costs, downhole logging tool improvements, and a best-practices drilling handbook. Direct-use research (Annex 8) has led to better understanding of controls on hot spring discharge rates and temperatures, improved public accessibility of web-based mapped information and technical information on optimizing heat pump designs.

4.2 Research Issues

Key research issues that are currently in need of focussed effort include: a) refining global assessments of geothermal resource potential, and cost projections, in order to assist investment decisions on energy projects to reduce atmospheric carbon emissions; b) improving sustainable fluid production and reinjection strategies to optimize long-term performance of resources, and c) devising cost-effective EGS reservoir stimulation technologies that minimize the potential effects of large induced seismic events.

5. CONCLUSIONS

Geothermal has an extremely bright future for both power generation and direct use applications. The potential is vast, for conventional geothermal power development, binary power applications, and for the now emerging EGS types of development, which extend the production of geothermal power and direct use well beyond plate boundary regions to most places in the world. Distributed direct use (including heat pumps), and "cascaded" use of waste heat from geothermal power plants can also make a considerable contribution. With additional investment in deep drilling, future development of vast deep hydrothermal resources may increase significantly. Geothermal energy has many characteristics that make it of significant importance for both generating electricity and for direct use applications. These include the fact that it is a renewable resource (recharged by crustal and subcrustal sources), it has extensive global distribution, it is suitable for diversified and distributed power generation, it is an indigenous energy resource, when appropriately managed it is environmental friendly, it can be utilized in a sustainable manner and it provides base-load electricity and heat supply independent of seasonal or weather effects. Geothermal energy can contribute significantly towards meeting the growing global renewable energy demand now and in the future while making substantial contributions toward climate change mitigation.

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