IEA

Geothermal Energy
Annual Report
2007

International Energy Agency
Implementing Agreement
for
Cooperation in
Geothermal Research & Technology

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IEA-GIA Website: http://www.iea-gia.org/

Cover Photograph: At Hveravellir, Iceland, a silica-rich hot spring is creating terraces by depositing silica on the surrounding ground. (Photo by Sigurður S. Jónsson)

Message from the Chair

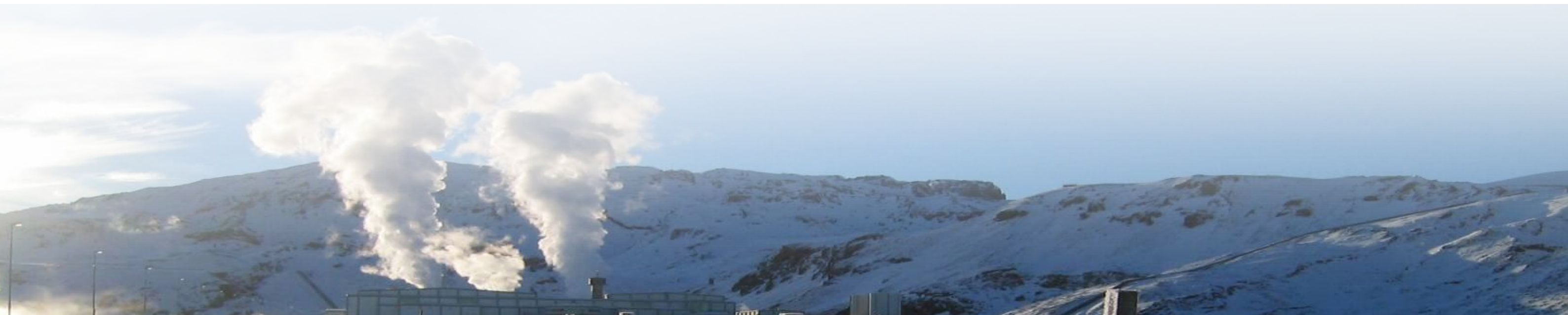
The Geothermal Implementing Agreement (GIA) has vigorously launched into its third five-year term, building on past accomplishments, addressing key issues, and promoting the global deployment of geothermal as a sustainable renewable energy resource. Added impetus has come from the growing concern for climate changes arising from global warming due to carbon emissions, as documented by the Intergovernmental Panel on Climate Change (IPCC). By increasing awareness of geothermal resources, and breaking down some of the barriers that had previously restricted investment by risk-averse players, we are beginning to see a pay-off in terms of a global renaissance in geothermal exploration and development drilling.

Membership of the IEA-GIA continues to grow, with France having joined in 2007 and considerable interest shown by industry and associations. There is an eagerness to collaborate, to share past experiences and to avoid mistakes from the past. The GIA core membership includes most of the geothermal pioneers, including Italy, New Zealand, Mexico, Iceland and the USA; plus the largest geothermal electric power producers, leading users of geothermal heat for direct applications, and companies, countries and institutions associated with advanced geothermal research programmes. The work of the GIA is well represented in its Web site, its publications and presentations by members at key conferences, and by its contributions to the material produced by the IEA Secretariat which helps publicize reliable statistics and general information on geothermal technology.

I would like to pay special tribute to our former Chair, David Nieva, who contributed significantly to the growth and reputation of the GIA during his four-year term. I concur with his concerns, expressed last year, that there is still a wide gulf in knowledge and understanding of geothermal resource development opportunities between those countries where geothermal is a mature industry and those that have yet to develop their indigenous geothermal resources. The continent of South America is a prime example of the latter. In these times of global financial turmoil, and energy supply uncertainty, we are challenged to work together even more closely to tackle the barriers that continue to suppress geothermal development, particularly in these countries. Cooperation and open sharing of knowledge will go a long way to overcome the public suspicion and miss-information that often accompany a competitive resource allocation. Improving the awareness of geothermal technology, its environmental benefits and its economic advantages, amongst decision-makers around the world (both at government policy and commercial investment levels) is high on my list of priorities.

In conclusion, I recommend to you this comprehensive annual report on the GIA activities for 2007. The Executive Summary provides a synopsis of the current world-wide status of geothermal energy development, its continuing acceleration and promising future. With concerted efforts to remove barriers, both real and perceived, the next few years should see geothermal taking an even more prominent position in global renewable energy portfolios.

Chris Bromley
Chair, IEA-GIA Executive Committee



Executive Summary

Figure 13.13 Travertine terrace in the Sipoholon geothermal field, Sumatra, Indonesia, 1 September 2006 (courtesy of H. Muraoka).

INTRODUCTION

2007 proved to be another very successful year for the IEA Geothermal Implementing Agreement (GIA). The year was also an especially auspicious one, as it began with the IEA Committee on Energy Research and Technology (CERT) approving the GIA's third 5-year term of operation, taking its activities to March 2012.

This 2007 Annual Report describes the activities and the major achievements of IEA Geothermal and its Country and Sponsor (industry) Members for the first year of its third term. The current status of the Member Countries' geothermal energy policies, uses, market situation, economics, research activities, education and international activities is presented, and the business and geothermal activities of our three Sponsor Members are described. Membership again grew, with France becoming the 11th Country Member, bringing total GIA membership to 15.

This Executive Summary begins by setting the context in which the IEA-GIA operates. It provides an introduction to the world's present energy situation, describes the contribution that geothermal resources are now making to the global energy supply, and discusses the potential significant contribution that geothermal energy could make in the future. It includes a brief description of the GIA and a summary of the information described in detail in the Annex, Country and Sponsor reports provided in Chapters 2-5, 7-18 and 19-21, respectively. A few highlights of GIA Members' 2007 activities are provided and the major achievements of the GIA's pursuits are presented. Finally, the GIA's plans for 2008 are outlined.

The World Energy Situation

The global demand for energy continues to grow, with fossil fuels expected to remain the dominant source well into the future, especially in the emerging "giants", India and China. The IEA Reference Scenario, which assumes the continuation of current government policies, indicates that the total global primary energy need will grow by 55 % between 2005 and 2030 (IEA, 2007), and the demand will reach 17.7 billion [10^9]tonnes of oil equivalent (Btoe) (744 EJ_{th} or 206,500 TWh_{th}), compared to the 2005 value of 11.4 Btoe (479 EJ_{th} or 133,000 TWh_{th}) (*ibid.*) and the 2006 value of 11.7 Btoe (492 EJ_{th} or 136,600 TWh_{th}) (IEA, 2008a); with 2006 electricity generation amounting to 18,930 TWh, or 68 EJ_e (*ibid.*). Continuation of the current, unregulated growth will likely result in energy security problems and a sharp increase in CO_2 emissions with related significant climate change effects. Even worse is the High Growth Scenario, in which primary energy use amounts to 6 % above that of the Reference Scenario, with CO_2 emissions 7 % higher! However, in the more positive Alternative Policy Scenario, whereby governments implement energy saving and renewable energy options, oil demand drops, coal use falls and energy related CO_2 emissions are about 20 % lower than in the Reference Scenario (IEA, 2007). Awareness of these possible outcomes provides a strong incentive for expanding the use of clean, renewable energy resources. Providing affordable, reliable and clean energy to meet these needs is an enormous challenge, and geothermal energy can make a very important contribution.

Geothermal Energy in the World Energy Scene

In 2006, the worldwide total primary energy use was 11,741 Mtoe (IEA, 2008a), equivalent to about 492 EJ_{th}, or 136,600 TWh_{th}. This energy utilization corresponds to an average annual power consumption of 15.6 TW_{th}, assuming 24 hour per day usage. The *most likely* worldwide total technical potential for geothermal (hydrothermal) resources located along tectonic plate boundaries and volcanic hot spots has been estimated to be about 6.5 TW_{th} (205 EJ_{th}/yr) (Stefansson, 2005), about 40 % of the 2006 average annual consumption. Hydrothermal resources capable of development for electricity generation using conventional methods (T > 130 °C) make up about 210 GW_e (6.5 EJ_e/yr, or 65 EJ_{th}/yr) of this total, assuming a 10 % electrical conversion efficiency, which may range up to 20 %. The remaining 4.4 TWh_{th} (140 EJ_{th}/yr), comprise lower temperature resources ($T \leq 130$ °C) considered useful mainly for direct heat applications. More optimistic estimates increase these numbers by factors of 5 to 10; the range arising from the uncertainty associated with determining the number of hidden/unidentified resources (*ibid*.).

In addition to the abovementioned hydrothermal resources, there are several other significant geothermal sources, including: 1) the contribution binary generation can add by utilizing the hot water discharged from conventional plants (co-generation) and that available from the lower temperature geothermal resources (75 - 130 °C); 2) the cascaded use of hot water discharged from geothermal power stations for direct heat applications; 3) the huge geothermal energy potential available within drilling depths (3 - 10 km) in the earth's crust via enhanced geothermal systems (EGS) development; 4) the large energy resources in the form of super critical fluids inferred to exist deep (3 - 5 km) beneath hydrothermal systems; 5) hot water produced from oil and gas wells; 6) hot water present in deep sedimentary basins; 7) off-shore (under-sea) hydrothermal resources identified by the presence of hydrothermal vents and 8) the ubiquitous shallow geothermal resources utilized by geothermal heat pumps for heating and cooling and available almost anywhere on the earth's surface. Recent estimates indicate that the USA has over 200,000 EJ extractable via EGS techniques (about 2,000 times its 2005 annual primary energy consumption), with approximately 100 GW_e of cost-competitive generating capacity developable within the next 50 years given reasonable R&D investment (MIT, 2006).

Estimates of EGS potential for the Rehai and Yangbajing geothermal fields of China (Wan, *et al*., 2005) and for regions across India (Chandrasekhar and Chandrasekharam, 2007) also show capacities on the order of 100 GW_e. The other mentioned geothermal sources still require assessment to produce reasonable estimates for their contributions.

Consequently, there is the potential for geothermal resources to make a considerable contribution towards meeting the world's current and future energy needs, both for electricity generation and direct heat applications. In addition, geothermal energy has characteristics which make it extremely valuable for both electricity generation and direct heat use, including its: extensive global distribution, environmentally friendly character, independence of season, immunity from weather effects, indigenous nature, contribution to development of diversified power, effectiveness for distributed application and sustainable development capabilities. Though geothermal usually operates as a baseload provider of electricity with availability and load factors typically well above 90%, it can also operate in a load-following capacity, albeit at lesser efficiency.

Status of Worldwide Geothermal Energy in 2007

Globally, in 2007, 24 countries were generating electricity from geothermal resources, with a total installed capacity greater than 10,026 MW_e (data from Bertani (2007), revised with 2007 GIA data) (Figure ES1). The worldwide electricity generation was not updated in 2007, but using data from 2005, updated with 2007 GIA data, a "minimum" estimate of about 56,782 GWh/yr is obtained for 2007. Worldwide generation data is updated every 5 years and will next be available in 2010, when it is produced for the World Geothermal Congress 2010. In 2007, about 62 % of the global geothermal installed capacity was located in GIA Member Countries, and they generated some 66% of the total geothermal power.

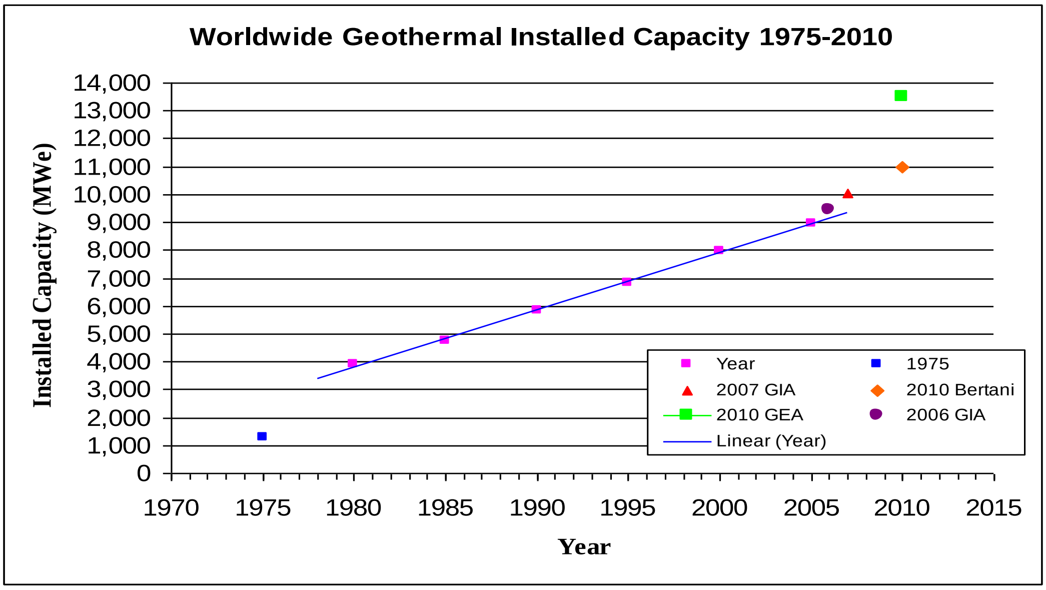


Figure ES1 Worldwide geothermal installed capacity for the period 1975-2010. The 2006 data [star] includes GIA data for 2006 and data for 16 other countries (Bertani, 2005); the 2007 data [triangle] includes 2007 GIA data and data for 15 other countries (Bertani, 2007); the trendline was calculated using data for 1980-2005 and has a slope of 200 MW_e/yr; the 2010 estimates are from Bertani (2007) [diamond] and GEA (2007) [square].

During the period 1980-2005, the worldwide geothermal installed capacity increased by a factor of about 2.3, at a very steady rate of 200 MW_e/yr (Figure ES1). However, geothermal development has begun to accelerate in the past few years. In the period 2005-2006, the global geothermal installed capacity is estimated to have increased by about 520 MW_e (5.8 %), to 9,452 MW_e; and in 2006-2007, the increase was approximately 574 MW_e (6.1 %), taking the total to about 10,026 MW_e. For GIA Countries, the corresponding increases were: 2005-2006: 520 MW_e (9.5 %) and for 2006-2007: 195 MW_e (3.3 %). The generation in GIA Member Countries increased by about 1,674 GWh over the latter period; and using this data a "minimum" estimate for global generation becomes: 56,782 GWh, or an increase of about 1,573 GWh (2.9 %). Note that the "decrease" of ~ 100 GWh from non-GIA Member countries in 2007 arises from France becoming a GIA Member. Table ES1 presents the 2007 data for GIA Member Countries and 2007 updates for many of the other 15 countries (Bertani, 2007), and Table ES2 illustrates the growth in installed capacity and generation since 1975, with the 2006 and 2007 results representing minimum values.

Table ES1 Geothermal power installed capacity and electricity generation for GIA Member Countries in 2007, plus 2007 installed capacity data for 15 other countries (Bertani, 2007) and 2005 generation data for the 15 non-GIA countries (Bertani, 2005).

Country	**Installed Capacity (2007) [MW]**	**Annual Energy Produced (GIA- 2007) (Others- 2005) [GWh/yr]**	**% of National Capacity**	**% of National Energy**
Australia*	***0.12***	***1.8***	***Negligible***	***Negligible***
Austria	1.1	3.2	Negligible	Negligible
China (Tibet)	28	95.7	30	30
Costa Rica	163	1,145	8.4	15
El Salvador	204	967	14	24
Ethiopia	7	na	1	n/a
France* (Guadeloupe Island)	***15***	***95***	***~9 (for Island[¶])***	***~9 (for Island[¶])***
Germany*	***3.23***	***0.4***	***Negligible***	***Negligible***
Guatemala	53	212	1.7	3
Iceland*	***485***	***3,600***	***20.5***	***29.9***
Indonesia	992	6,085	2.2	6.7
Italy*	***810***	***5,233***	***1.0***	***1.8***
Japan*	***535.26***	***3,102***	***0.2***	***0.3***
Kenya	129	1,088	11.2	19.2
Mexico*	***958***	***7,393***	***1.9***	***3.3***
New Zealand*	***452***	***3,272***	***4.9***	***7.7***
Nicaragua	87	270.7	11.2	9.8
Papua New Guinea (Lihir Island)	56	17	10.9	n/a
Philippines	1,970	9,419	12.7	19.1
Portugal (San Miguel Island)	23	90	25	n/a
Russia	79	85	Negligible	Negligible
Thailand	0.3	1.8	Negligible	Negligible
Turkey	38	105	Negligible	Negligible
USA*	***2,936.5***	***14,500***	***0.3***	***0.3***
Total	**10,026**	**56,782**	**9.2****	**11.9****
Total GIA Countries	***6,195***	***37,197***	***5.4*****	***7.5*****

na = not available, **** GIA Member Country (includes Guadeloupe Island); [¶] % from Bertani (2007)***
** Average values exclude negligible contributions, but include Guadeloupe, Lihir and San Miguel Islands since this has been the procedure for World Geothermal Congresses.

Geothermal energy provides a major contribution to the national generation of many countries. For eight countries (including Lihir and San Miguel Islands), the geothermal installed capacity now exceeds 10 % of their national capacity, and six obtain more than 15 % of their electricity from geothermal (Table ES1). The average contribution to national installed capacity for GIA Member Countries with "non-negligible" installation/generation was 5.4 %, with the corresponding average contribution to national generation being about 7.5 %. The corresponding worldwide values were 9.2 % and 11.9 %, respectively (Table ES1).

The total GIA geothermal generation of 37,197 GWh/yr is "equivalent" to a savings of about 9.4 Mtoe (using GIA conversion (Mongillo, 2005)) and avoided CO_2 emissions of 30.4 Mt. The equivalent savings for the worldwide total generation of 56,782 GWh/yr is about 14.4 Mtoe and avoided CO_2 emissions of some 46.4 Mt (*ibid.*).

Table ES2 Worldwide installed geothermal capacity (1975-2007) and electricity generation (1995-2007). The generation changes for 2006 and 2007 only reflect changes from GIA Countries.

Year	1975	1980	1985	1990	1995	2000	2005**	2006***	2007
Geothermal Installed Generating Capacity (MW_e)	1,300	3,887	4,764	5,832	6,798	7,974	8,930	9,452	10,026 ¶
Increase Over Previous Five-Year Period MW_e (Percent)	-	2,587 (99)	877 (22.6)	1,068 (22.42)	966 (16.6)	1,176 (17.3)	956 (12.0)	522* (5.9*)	574* (6.1)
Electricity Generation GWh/yr	-	-	-	-	37,744	49,261	53,649	55,209	56,782 #
Increase Over Previous Five-Year Period GWh/yr (Percent)	-	-	-	-	-	11,517 (30.5)	4,388 (8.9)	1,560* (2.9)	1,573* (2.9)

* Change from previous year (For 2005 only changes in GIA Member Country data included)
** 2005 values incorporate corrections for Iceland and USA GIA 2005 data
*** The 2006 values are indicative and consist of 2006 data for 8 GIA Members with corrected USA data, and 2005 data for the other 16 countries with geothermal power (Bertani, 2005)
¶ Includes 2007 updated installed capacity data for 15 countries from Bertani (2007) plus GIA 2007 data
# The 2007 generation data is from 2005 (Bertani, 2005) with updated 2007 GIA Country data

The true contributions that renewable energy resources make are determined by the amount of power they provide for a given installed capacity, i.e. their "contribution efficiency" or the ratio of the energy generated to the installed capacity. This ratio takes into account the amount of time that the renewable generator is available to produce power, i.e. the "availability factor". For geothermal, this can be divided into resource availability (usually sustained by make-up drilling) and plant availability (affected by repairs, maintenance, transmission and load-following constraints). As shown in Table ES3, the contribution efficiencies for the various renewables in the 30 OECD countries in 2007 were: 7.1 GWh/MW_e for geothermal (6.0 for GIA Member Countries in 2007), 5.2 GWh/MW_e for solid biomass, 3.7 GWh/MW_e for hydro, 1.8 GWh/MW_e for tide/wave/ocean, 1.8 GWh/MW_e for wind and 0.6 GWh/MW_e for solar PV (IEA 2008b). Geothermal's very high availability factor makes it valuable for baseload generation. It is interesting to note that geothermal is 3.4 to 4 times more "efficient" than wind in its generation, i.e. geothermal provides 3.4 to 4 times more electricity per installed megawatt.

A major effort is undertaken to collect and report worldwide geothermal direct use data every five years for the World Geothermal Congresses (as for electricity generation), and this will next be done in 2010. Therefore, the most current data available is based upon that reported by Lund, *et al.* (2005), and updated using the 2007 GIA country data reported in this Annual Report plus other information for Europe provided by Antics and Sanner (2007).

Table ES3 Installed capacity, electricity generation and contribution efficiency for renewable resources in OECD Countries for 2006 (data from IEA (2008b)) and GIA Members for 2007.

Resource	Installed Capacity (MW_e)	Generation (GWh)	Contribution Efficiency (GWh/MW_e)
Geothermal			
GIA Members 2007	*6,195*	*37,197*	*6.0*
OECD 2006	5,400	38,100	7.1
Solid Biomass	22,500	115,900	5.2
Hydro	344,600	1,286,300	3.7
Tide, Wave, Ocean	300	550	1.8
Wind	63,700	116,200	1.8
Solar PV	4,100	2,626	0.6

As of May 2005, 72 countries were utilizing geothermal energy for direct use applications, including: geothermal heat pumps (GHPs); space, greenhouse and aquaculture pond heating; agricultural drying; industrial uses; bathing and swimming; cooling; and snow melting (Lund *et. al*, 2005). The total installed capacity at the end of 2007 was estimated to be about 35,570 MW_{th}, by incorporating 2007 updates to the 2005 total of 28,269 MW_{th} (Table ES4), or a 26 % increase. The total thermal energy usage for 2007 was similarly estimated to be about 329,270 TJ/yr, more than 20 % higher than the 2005 value of 273,372 TJ/yr (*ibid.*) (Table ES4, Figure ES2). In 2007, the 11 GIA Member Countries had a total installed thermal power capacity of 20,547 MW_{th} and utilized 154,560 TJ/yr, or 58 % of global capacity and 47 % of total utilization. In 2005, an estimated 1.3 million geothermal heat pumps (GHPs) installed in 33 countries contributed over 54 % (15,384 MW_{th}) of direct use installed capacity, with a usage of 87,503 TJ. Estimates for 2007 show continued significant growth in the GHP market; about 1.6 million GHP units installed globally with > 19,000 MW_{th} of capacity and > 105,000 TJ utilization (Mongillo, 2008).

Table ES4 Worldwide direct use categories and their development 1995-2005 (from Lund, *et al.*, 2005), with 2007 total and GHP updates from GIA and Antics and Sanner (2007).

Category	Capacity (MW_{th})				Utilization (TJ/yr)			
	1995	**2000**	**2005**	**2007**	**1995**	**2000**	**2005**	**2007**
Geothermal heat pumps	1,854	5,275	15,384	19,010	14,617	23,275	87,503	105,000
Space heating	2,579	3,263	4,366	-	38,230	42,926	55,256	-
Greenhouse heating	1,085	1,246	1,404	-	15,742	17,864	20,661	-
Aquaculture pond heating	1,097	605	616	-	13,493	11,733	10,976	-
Agricultural drying	67	74	157	-	1,124	1,038	2,013	-
Industrial uses	544	474	484	-	10,120	10,220	10,868	-
Bathing and swimming	1,085	3,957	5,401	-	15,742	79,546	83,018	-
Cooling/snow melting	115	114	371	-	1,124	1,063	2,032	-
Others	238	137	86	-	2,249	3,034	1,045	-
Total	**8,664**	**15,145**	**28,269**	**35,570**	**112,441**	**190,699**	**273,372**	**329,270**
Total GIA Countries	-	-	-	***20,547***	-	-	-	***154,560***

Worldwide direct use installed capacity has nearly doubled every 5 years since 1995 and based upon the 2007 estimates, which are about 25 % higher than 2005, high growth is continuing. The estimated 2007 direct energy use has increased by about 20 % since 2005, a slightly higher average annual rate than for the 2000-2005 period. The total 2007 use of about 329,270 TJ, is equivalent to an annual savings of about 11.6 Mtoe in fuel oil and 37.4 Mt in avoided CO_2 emissions (GIA conversion (Mongillo, 2005)). GIA Member Country utilization in 2007 was equivalent to an annual savings of 5.4 Mtoe and avoided CO_2 emissions of 17.6 Mt (*ibid.*).

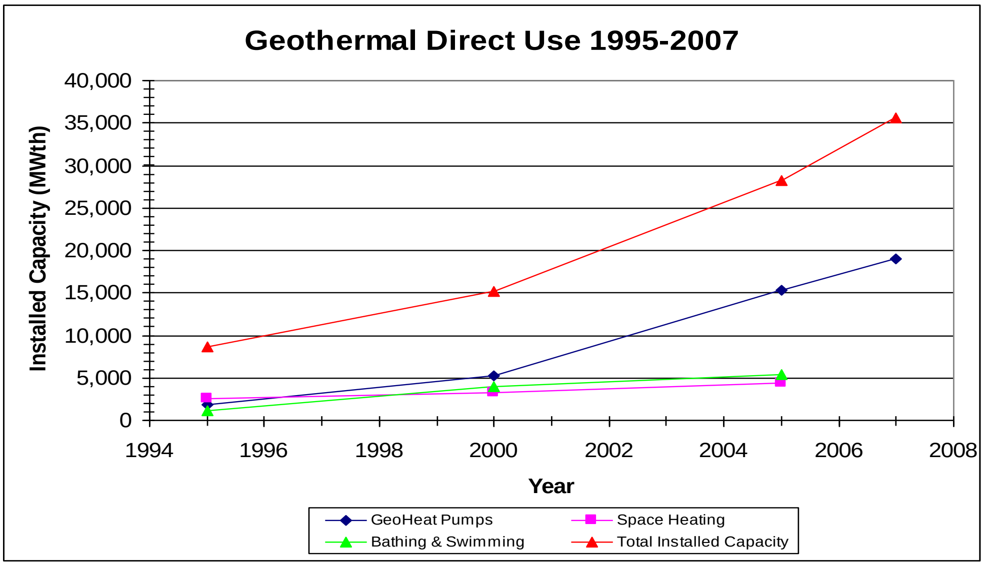


Figure ES2 Worldwide geothermal direct use installed capacity for the three largest applications and totals for the period 1975-2007 (1995-2005 data from Lund, *et al.* (2005), with estimates for 2007 based on GIA data (Mongillo, 2008)).

THE IEA-GIA: AN OVERVIEW

The IEA-GIA provides a flexible framework for wide-ranging international cooperation in geothermal R&D. In February 2007, the IEA Committee on Energy Research Technology (CERT) extended GIA's operation for a 3rd 5-year term, taking its activities to 2012. To guide the GIA's international cooperative activities through its third term, a new Strategic Plan (GIA, 2006) was developed, with the **Mission**:

To promote the sustainable utilization of geothermal energy throughout the world by improving existing technologies 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.

The IEA-GIA brings together national and industry programmes for exploration, development and utilization of geothermal resources, with a focus on assembling expertise and enhancing effectiveness by establishing direct cooperative links among geothermal experts in the participating countries and industries. Current GIA activities are directed mainly toward the coordination of ongoing national programmes, with contributions from industry members. New studies and activities are implemented when needs are established.

The GIA's general scope of action, as specified in its operational document, the IEA Implementing Agreement for a Cooperative Programme on Geothermal Energy Research and Technology (GIA), consists of international scientific collaborative efforts to: *compile and exchange improved information* on worldwide geothermal energy research and development 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 methods to avoid or minimize its environmental drawbacks. Six new strategic objectives were set for the 2007-2012 Term to target GIA's activities:

- To actively promote effective cooperation on geothermal RD&D through collaborative work programmes, workshops and seminars
- To collect, improve/develop and disseminate geothermal RD&D policy information for IEA Member and non-Member Countries
- To identify geothermal energy RD&D issues and opportunities and improve conventional and develop new geothermal energy technologies and methods to deal with them
- To increase membership in the GIA
- To encourage collaboration with other international organizations and appropriate implementing agreements
- To broaden and increase the dissemination of information on geothermal energy and the GIA's activities and outputs to decision makers, financiers, researchers and the general public

Project activities, called "tasks", are defined and organized in "Annexes", which are appended to the IEA-GIA document. Participants must take part in at least one Annex. Table 1.2 in Chapter 1 lists the Annex titles and involvement of the participants in them. An Executive Committee (ExCo) supervises the GIA and its decisions are binding on all Members. The ExCo consists of one voting Member from each Member Country and Sponsor.

Since the GIA's beginning, the Annexes have operated under the "task-sharing" mode of financing, whereby participants allocate specified resources and personnel to conduct their portion of the work at their own expense. Though exact figures are not available, the total Annex work conducted under the auspices of the GIA is estimated to have been well over US$ 310,000/yr plus several man-years (GIA, 2006a).

A GIA Secretariat was established in March 2003 to provide the GIA ExCo with administrative and other assistance. It is funded through "cost-sharing"- all Members contribute to a Common Fund according to the number of "shares" they have been allocated by the ExCo.

As of December 2007, membership of the IEA-GIA included: the European Commission; 11 countries: Australia, France, Germany, Iceland, Italy, Japan, Mexico, New Zealand, the Republic of Korea, Switzerland and the United States; and 3 industry Sponsors: Geodynamics, Green Rock Energy and ORMAT Technologies.

COLLABORATIVE ACTIVITIES

The Annexes

In 2007, the participants in the IEA-GIA worked on four broad research topics, specified in the following Annexes:

- Annex I- Environmental Impacts of Geothermal Energy Development
- Annex III- Enhanced Geothermal Systems
- Annex VII- Advanced Geothermal Drilling Techniques

- Annex VIII- Direct Use of Geothermal Energy

Annexes I and III were initiated in the original implementing agreement in 1997, and have continued programmes into the current term, as has Annex VII, which was started in 2001. In September 2006, Annexes I, III and VII were extended by the ExCo for a further 4 years, to 2009. Annex VIII, which officially started in 2003, completed its first term of operation in 2007, and was unanimously continued by the ExCo for another 4 years to 2011. Four other Annexes were drafted in previous years, with II- Shallow Geothermal Resources and IX- Geothermal Market Acceleration subsequently closed. The possibility of initiating draft Annexes: V- Sustainability of Geothermal Energy Utilization and VI- Geothermal Power Generation Cycles remains open. The status of the Annexes is presented in Table 1.2 (Chapter 1).

A brief discussion of some of the GIA's activities and major highlights for the Annexes active in 2007 is presented below. Details are available in Chapter 1 and in the Annex Reports included in Chapters 2-5.

IEA-GIA Secretariat to Continue in New Zealand

At the 17th ExCo Meeting held on 22-23 March 2007 in Nice, France, the GIA ExCo unanimously agreed to accept the GNS Science bid to continue operating the IEA-GIA Secretariat in New Zealand for the GIA's 3rd Term.

The European Geothermal Congress 2007

The European Branch Forum of the International Geothermal Association (IGA) held the European Geothermal Congress EGC 2007 at Unterhaching, Germany, on 30 May to 1 June 2007. The GIA participated with Vice-Chair Rybach presenting a paper: *The IEA Geothermal Implementing Agreement (GIA) Advancing into its Third Term* (Mongillo and Rybach, 2007).

First European Geothermal Review 2007

The 18th Executive Committee Meeting was held in Kandel, Germany, on 25-26 October 2007, in conjunction with the First European Geothermal Review meeting, held on 29-31 October 2007 in Mainz, Germany (http://www.soc.nii.ac.jp/grsj/FEGR_ENGLISH.pdf). Several GIA ExCo Members gave invited presentations.

GIA Participation in IEA Activities

The GIA had an especially active participation with the IEA in 2007, through participation at IEA workshops and meetings, and by providing information and comments on IEA reports.

In February 2007, Chairman David Nieva made an invited presentation at the **46th IEA CERT Meeting** in Paris, France, *Review of the 2002-2007 End of Term Report & Strategy for 3rd 5-Year Term (2007-2012)*, in representation of the GIA ExCo's request to extend the GIA IA for a 3rd 5-year term. The CERT unanimously approved the ExCo's request. Vice-Chair Ladsi Rybach represented the GIA at the October 2007 **IEA Deploying Demand Side Energy Technologies Workshop** (Paris, France) with a presentation: *Geothermal Heating and Cooling of Buildings* (Rybach, 2007). In October, GIA Secretary, Mike Mongillo, participated in the **IEA Network of Expertise in Energy Technology (NEET) Workshop** held in Beijing, China, with a presentation: *The IEA Geothermal Implementing Agreement (GIA) Advancing into its Third Term*.

In addition, the GIA provided several documents plus two posters for the **IEA Ministerial Technology Fair** held in Paris, on 14-15 May 2007 (Figure ES3); and contributions for the **IEA Energy Technologies at the Cutting Edge 2007** (*Tapping into vast, unused heat resources*), the **IEA Energy Technology Perspectives 2008**, the **IEA Global Renewable Energy Heating & Cooling** report, the **IEA Global Renewable Energy Markets & Policies (GREMP)** report, and commented on the **IEA Contribution of Renewable Energy Technologies to Energy Security** report.

Geothermal Energy Utilization and the Environment

The various types of energy utilization cause a range of environmental impacts which can be of concern on the global scale. Geothermal is a relatively benign renewable energy source, with significant advantages over fossil fuels, especially as regards carbon emissions. However, there are some environmental effects associated with its use that require attention. Annex I- Environmental Impacts of Geothermal Energy Development encourages the sustainable development of geothermal resources while identifying and quantifying possible adverse and beneficial environmental impacts, and determining ways to avoid, remedy or minimize the adverse ones, while encouraging the beneficial.

Geothermal development may affect natural surface features like hot springs. Such impacts and strategies to mitigate them were collected and compared for New Zealand, the USA and the Philippines; and recommended policies were designed to assist regulators to sensibly manage the effects. The disposal of waste fluids and the small quantities of chemicals (e.g. arsenic) and gases (H_2S and CO_2) contained in them is an important issue, and various methods for dealing with them (e.g. injection and chemical treatment) were investigated and addressed at several conferences, including the GRC 2007 (USA), First European Review (Germany), Chile-Invest 2007 (Chile).

The possible causes of subsidence associated with some geothermal developments were investigated and predictive models further developed, with the use of satellite-based interferometric synthetic aperture radar (INSAR) for subsidence monitoring investigated and a paper published (Hole, *et al*., 2007). International collaboration continued to develop a better understanding of induced seismicity mechanisms and develop strategies and robust hazard assessment methods, and a paper published (Major, *et al*., 2007).

A new activity, Task E: Sustainable Utilization Strategies, was initiated in 2007, with a comprehensive reference list posted on the GIA website and an international workshop planned for 2008.

Artificial Stimulation to Access Geothermal Resources

Huge heat resources consisting of high temperature, water-poor rock are available within current drilling depths (>3 km) almost anywhere on the globe. To utilize the vast amount of geothermal energy in this hot rock, Annex III- Enhanced Geothermal Systems (EGS) is investigating the development of new and improved technologies to artificially stimulate these resources (e.g. hydraulically fracture the rock) to enable commercial heat extraction for electricity production and, in some cases, co-generation of heat for direct use applications. These techniques can also be used to help sustain and even enhance energy production at existing conventional hydrothermal developments through reinjection and by increasing permeability. Successful development of EGS is currently one of the major challenges facing the geothermal community The EGS R&D investigations conducted over the past 30 years have led to the 2007 commissioning of the first EGS-assisted operating plant in Landau, Germany; and completion of plants at Soultz-sous-Forêts, France and Cooper Basin, Australia, within the next 2 years.

In 2007, many of the activities of this Annex were revised. An economic modelling task was re-activated to more clearly define and quantify EGS resources and to develop a standardized model that can take account of local incentives, labour and environmental requirements and be used to raise capital on the market. Actions are being prepared to coordinate how conventional technology like horizontal drilling, fracture detection and mapping and pumping can be modified for EGS applications; and related projects funded by the US DOE have been summarized in the "EGS Program Review" (EERE, 2006) and discussed at the GRC meeting (GRC, 2007) and the Stanford workshop (SGW, 2007).

The difficulties in accessing the data, results and reports from the previous 30 years of EGS studies are being addressed, including the development of a new search engine to more easily access the large resources collected by the US DOE developed "Legacy Project". A "handbook", Enhanced Geothermal System Project Management Decision Assistant or EGS-PMDA (2005) that defines the data needed for and helps guide the developer through all phases of an EGS power development continues to be distributed.

A new EGS reservoir management task is being designed, now that the first EGS developments are nearing completion.

Reducing Geothermal Drilling Costs

One of the essential and most expensive parts of geothermal exploration, development and utilization is the drilling of wells. Significant benefits can be had by reducing well drilling and completion costs, which can account for more than 50 % of the capital cost of a geothermal power project. Annex VII- Advanced Geothermal Drilling Technology is working to identify, develop and promote ways to reduce the costs of drilling, logging and completing geothermal wells.

Due to the loss of task leaders and reduced funding of the Annex Leader, the effort in Annex VII was severely restricted in 2007. New data from several of the Annex participants was obtained and incorporated into the well cost database which is being developed. Requests for collaboration were received and information exchanged, and deployment of a downhole high temperature tool was postponed at the last minute due to well problems. Contact was made between Annex VII and the ENGINE and HITEN projects, with links established through the GIA website. An Annex meeting was held in March 2007 at which future activities were discussed and planned; and results on drilling and completion technology and laboratory simulation of drill bit dynamics were presented at GRC (Blankenship, *et al.*, 2007) and the Offshore Mechanics and Arctic Engineering workshop (Raymond, *et al.*, 2007).

Direct Use of Geothermal Heat

For millennia, geothermal heat and water have been used directly for bathing, cooking and therapeutic purposes. Direct use continues today for many applications, including: building and district heating; industrial process heating; greenhouse heating; crop drying, temperature control for fish farming, bathing and swimming; and snow melting. In fact, heat from the earth's shallowest depths (< 100 m depth) can be used practically anywhere on earth for heating and cooling homes and buildings through the application of geothermal heat pumps. Geothermal direct use has experienced outstanding growth, almost doubling every 5 years since 1995, and its scope for continued expansion remains great.

Many direct use applications are now well developed and economically viable. However, implementation difficulties and unfavourable economics still provide major challenges. Annex VIII- Direct Use of Geothermal Resources addresses all aspects of the direct use technology, with emphasis on improving implementation, reducing costs and enhancing use.

The collection, evaluation and comparison of physical and chemical data from natural features of the participating countries continue as part of the characterization of geothermal resources. Evaluation of information obtained from a questionnaire for direct use of geothermal energy has been completed and a revised questionnaire is been developed to acquire realistic cost and performance information. In addition, the collection of available information related to engineering standards for designs, equipment and controls has begun and a comprehensive reference list compiled and available.

GIS-type methods to access and present direct use data are being investigated, with promising results obtained through the use of Google Earth being further developed.

NATIONAL ACTIVITIES

The geothermal programmes of the GIA Country Members provide the basis for the cooperative IEA geothermal activities. These programmes focus on the exploration, development and utilization of geothermal resources. A synopsis of Country Member activities is provided in Chapter 6, with a comprehensive description of the current status of geothermal activities for each of the participating countries and the EC provided in Chapters 7-18.

In 2007, Contracting Parties from 11 countries and the European Commission (EC) participated in the IEA-GIA. The Member Countries were: Australia, France, Germany, Iceland, Italy, Japan, Mexico, New Zealand, the Republic of Korea, Switzerland and the United States.

Contributions of GIA Members to Power Generation and Direct Use

In 2007, the 9 GIA Member Countries with geothermal generation had an installed capacity of about 6,200 MW_e, or about 62% of the total global geothermal capacity of 10,026 MW_e; and generated 37,200 GWh/yr, or about 66% of the total geothermal generation of 56,780 GWh/yr (Tables ES5 and 6.1). The United States was by far the largest producer, generating about 14,500 GWh/yr, with Mexico second with 7,393 GWh/yr and Italy third with 5,233 GWh/yr. The percent of national installed capacity provided by geothermal in the 7 IEA-GIA Member Countries with non-negligible power development ranged from 0.2 % for Japan to 20.5 % for Iceland, with an average of about 5.4 %. The contribution of geothermal to national generation in Member Countries ranged from 0.3 % for Japan to 29.9 % for Iceland, with an average of 7.2 %.

All 11 GIA Member Countries utilized geothermal in direct applications, with a total installed capacity of about 20,547 MW_{th} and total thermal energy used approximately 154,560 TJ/yr (42,936 GWh/yr) (Table 6.2). The three largest users of geothermal heat by far were the USA (41,817 TJ/yr), Japan (41,518 TJ/yr), and Iceland (26,000 TJ/yr). However, the non-high enthalpy geothermal countries, Germany (8,280 TJ/yr) and Switzerland (6,063 TJ/yr) also had very high utilization, mainly due to the large and growing geothermal heat pump usage.

Table ES5 Total geothermal installed capacity, electricity generation and direct use in GIA Member Countries in 2007.

Country	Electrical Installed Capacity (MW)	Annual Energy Generated (GWh/yr)	% of National Capacity	% of National Energy	Installed Thermal Power (MW_{th})	Annual Energy Used (TJ/yr)
GIA Member Countries	6,195	37,197	5.4*	7.2*	20,547	154,560
Worldwide Total**	10,0026	56,782	9.2	11.9	35,570	329,270
GIA % of Worldwide Total	62	66	-	-	58	47

* Average % of 7 GIA Member Countries with non-negligible generation, including Guadeloupe Island.
** For sources of worldwide total data see Tables ES1 and ES4

The equivalent fuel oil savings by GIA Member Countries for geothermal power generation and direct use amounted to about 14.8 Mtoe using GIA conversions (Mongillo, 2005), or approximately 39.4 Mtoe based upon IEA assumptions (1 GWh ~ 860 toe; 1 TJ ~ 47.8 toe). The avoided CO_2 emissions were about 48 Mt (Mongillo, 2005).

SPONSOR ACTIVITIES

At the end of 2007, the GIA had 3 industry Sponsor Members: Geodynamics Limited and Green Rock Energy Limited, both from Australia, and Ormat Technologies, Inc. from the USA.

Geodynamics Limited

Geodynamics is the largest geothermal company in Australia and specifically focuses on the use of enhanced geothermal systems (EGS) technology for the economic removal of heat from hot rocks. In 2007, Geodynamics raised AUS$ 49.8 M through a rights issue, AUS$37.4 M from shareholder options and completed an AUS$ 105.6 M joint venture farm-in agreement with Origin Energy. The company is currently concentrating on EGS development in the Cooper Basin, South Australia, where they hold tenements covering 2,000 km^2 and where they have proven temperatures > 250 °C at depths of 3.6-4 km and produced the first high temperature (> 200 °C) geothermal flows in Australia. To circumvent problems associated with the global drill rig shortage, Geodynamics purchased a Tourneau "Lightning Rig" in 2007, capable of drilling to depths ~ 6 km. Well Habanero #3 was begun in August 2007 and is expected to be completed to ~ 4,200 m in early 2008. Geodynamics is also exploring in the Hunter Valley area of New South Wales, Australia, where their shallow drilling has indicated elevated temperature gradients of > 50 °C /km, justifying deeper drilling.

Green Rock Energy Limited

Green Rock Energy Limited is a public listed company whose aim is to explore, develop and produce geothermal energy from both hydrothermal systems and EGS for electricity and direct use. Green Rock's main activities are in Australia and Hungary. In 2007, the company participated in a joint venture with Hungarian Oil and Gas Company (MOL) and Enex to develop geothermal in Hungary for power and direct use using hot water available from existing oil wells. Though the two wells tested had non-commercial flow rates, the knowledge gained encouraged the formation of a new joint venture geothermal company with MOL and Enex hf, called Central European Geothermal Energy Private Company Limited (CEGE), which is initially focussing on two areas where existing wells encountered substantial hot water. Green Rock also holds exploration licences for three project areas in South Australia: Olympic Dam, Patchawarra Trough area (1,483 km^2) and Upper Spencer Gulf (1,938 km^2). The company owns 100 % interest in a 3,000 km^2 area at BHP Billiton's Olympic Dam mine, where hot granites at ~ 2 km depth have been located; and is investigating the use of geothermal for a distillation desalination plant in the Upper Spencer Gulf coast.

Ormat Technologies, Inc.

Ormat Technologies Inc. is based in the USA, and is a leading company involved in the geothermal and recovered energy (i.e. electricity generation from "waste heat") business. In addition to designing, manufacturing and selling equipment (e.g. binary power generators), the company develops, builds, owns and operates geothermal and recovered energy power plants. Ormat has built over 900 MW_e of geothermal power installations worldwide, and in 2007 had revenues of US$ 296 M, an increase of 10 % on 2006. The company has almost 1,000 employees, with some 100 geologists, resource managers and drilling engineers working to confirm and develop new geothermal fields. In 2007, Ormat established its wholly-owned drilling company, Geodrill, with 4 rigs to assist with increasing its geothermal production. During the past two years, Ormat has obtained leases for about ~ 560 km^2 of land in California, Nevada and Alaska. A successful joint project with US DOE at the Rocky Mountain Oil Test Centre validated the feasibility of commercially producing electricity using hot water produced *with* oil and gas- the first project of this type to provide free on-site power that will increase productivity and possibly longevity of existing US oil fields. Ormat is also pursuing joint EGS investigations at their Desert Peak geothermal field and their Brady facility in Nevada, USA; and at the end of 2007, a combined heat and power station (with EGS injection) utilizing a 3.2 MW_e Ormat unit, was commissioned at Landau, Germany.

PLANS FOR 2008 AND BEYOND

In early 2007, the IEA CERT approved the extension of GIA's operation for a 3rd 5-year term, taking its activities to 2012. At the end of 2007, three-quarters of the way through the first year of its 3rd term, the GIA has already enthusiastically embraced its new Mission and objectives (GIA, 2006), having revised and extended Annex I, III and VIII activities, acquired new Country Membership (France), participated at several international workshops and conferences, and increased efforts in our information dissemination about geothermal energy and the GIA.

The GIA foresees continued growth in these efforts into 2008, and further into the future. The GIA plans to enhance its visibility and that of geothermal by producing stand-alone Executive Summaries for its Annual Reports and distributing them along with CD-Roms containing all of GIA's Annual Reports and other information. Efforts aimed at growing and broadening GIA membership will be actively continued, with consideration being given to inviting international geothermal organizations, from where it is expected that different perspectives and ideas will be contributed. Participation at IEA workshops and other international renewable energy and geothermal conferences is already planned, and an Annex I organized Geothermal Sustainability Workshop will be held in association with the 50th Anniversary of the Wairakei Geothermal Power Station in New Zealand at the end of 2008.

Worldwide development of geothermal energy for power generation has begun to accelerate and direct utilization continues along its large growth path. Geothermal energy has the potential to make a considerable contribution towards meeting the future global energy needs, and the GIA sees the organization and its activities continuing and growing into the future in order to help ensure that geothermal provides its maximum sustainable contribution.

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IEA GEOTHERMAL R&D PROGRAMME

Chapter 1

The Implementing Agreement

The production test in the Minase geothermal field, Akita Prefecture, Japan (courtesy of H. Muraoka).

1.0 The IEA Geothermal Research and Technology Programme

The IEA began its involvement in geothermal energy in 1978, with the launching of two 3-year long studies which were completed in 1981. Then followed a 16-year lull in IEA geothermal activities, until the IEA Implementing Agreement for a Cooperative Programme on Geothermal Research and Technology, or Geothermal Implementing Agreement (GIA), was officially established on 7 March 1997, with an initial term of five years. In November 2001, the GIA's operation was extended for a 2nd 5-year term. A major highlight for GIA in 2007, was the approval by the IEA Committee on Energy Research and Technology (CERT) to extend the GIA for a 3rd 5-year term, taking its activities to 31 March 2012.

The GIA provides a versatile framework for extensive international cooperation in geothermal research, development and deployment. It brings together national and industry geothermal programmes for exploration, development and utilization of geothermal resources; and focuses on assembling specific expertise, enhancing effectiveness by establishing direct cooperative links among geothermal experts in the participating countries and industries, and information exchange.

The general scope of the GIA's activities as defined in Article 1 of its Implementing Agreement document is to provide basic guidance for the organization and consists of international scientific collaborative efforts to:

- **Compile and exchange improved information** on worldwide geothermal energy research and development concerning existing and potential technologies and practices

- **Develop improved technologies** for geothermal energy utilization

- **Improve the understanding of the environmental benefits** of geothermal energy and methods to avoid or ameliorate its environmental drawbacks

The GIA's present efforts are directed primarily towards coordination of ongoing national programmes, with contributions from industry (Sponsor) members. Activities encompass a range of geothermal topics from "traditional" power generation and direct use of heat, to leading-edge technologies pertinent to enhanced geothermal systems (EGS), advanced geothermal drilling techniques and sustainable utilization strategies. New studies are also encouraged and implemented when the needs are established.

As of December 2007, the IEA-GIA had 15 Members: 12 Contracting Parties from 11 countries: Australia, France, Germany, Iceland, Italy, Japan, Mexico, New Zealand, the Republic of Korea, Switzerland, the United States, and the European Commission (EC); and three industry Sponsor Members: Geodynamics, Green Rock Energy Limited and ORMAT Technologies Inc. See Table 1.1 for details.

1.1 Strategy and Objectives

The potential of geothermal energy is vast and its development can contribute significantly towards meeting the growing global renewable energy demand. Geothermal development is beginning a rapid growth phase worldwide, and 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 began its 3rd 5-year term of operation in April 2007, with these objectives strongly in mind, aiming to use its extensive international cooperation to focus particularly on disseminating information, improving environmental outcomes, enhancing EGS prospects, reducing drilling costs, promoting direct use applications, and encouraging long-term sustainable development strategies that will also contribute to the mitigation of climate change. To these ends, the IEA-GIA set its ***3rd Term (2007-2012) Mission (GIA, 2006b):***

To promote the sustainable utilization of geothermal energy throughout the world by improving existing technologies, by 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, the GIA has developed six ***Strategic Objectives:***

- To actively promote effective cooperation on geothermal RD&D through collaborative work programmes, workshops and seminars

- To collect, improve/develop and disseminate geothermal energy RD&D policy information for IEA Member and non-Member countries

- To identify geothermal energy RD&D issues and opportunities and improve conventional and develop new geothermal energy technologies and methods to deal with them

- To increase membership in the GIA

- To encourage collaboration with other international organizations and appropriate implementing agreements

- To broaden and increase the dissemination of information on geothermal energy and the GIA's activities and outputs to decision makers, financiers, researchers and the general public

1.2 Collaborative Activities

The GIA's programme operates through participation in collaborative projects called "tasks", which are specific investigations included within the more general "topic" areas, called Annexes. After approval by the ExCo, detailed descriptions of new tasks, or of completely new Annexes including many new tasks, are appended to the IA by inclusion within existing Annexes, or as new Annexes, respectively (Chapters 2-5). Each Annex, referred to by its annex number, is managed by an Operating Agent organization from one of the Member Countries or industry Sponsor Members.

In 2007, participants worked on four broad research tasks, specified in Annexes: I- Environmental Impacts of Geothermal Energy Development; III- Enhanced Geothermal Systems; VII- Advanced Geothermal Drilling Techniques; and Annex VIII- Direct Use of Geothermal Energy.

Annexes I and III were part of the original GIA, and have continued programmes into the 3rd Term, as have Annexes VII (started in 2001) and VIII (begun in 2003). In addition, Annex VIII was extended by a unanimous ExCo vote in December 2007 for a further 4 years, to 2011. Annex V has been placed on hold, with a new Task- Sustainable Utilization Strategies included in Annex I. Annex VI remains in its original draft form, though it may be revised for future consideration.

A list of Annexes, Operating Agents and indication of Annex status as of December 2007 is provided in Table 1.2; more complete details of objectives, results and work planned for 2008 for the active Annexes are presented in the Annex Reports included in Chapters 2-5. Table 1.3 presents brief summaries of the current draft and the closed Annexes.

Participants must take part in at least one Annex, with their involvement defined by activities relevant to their current research and development programmes. Each Annex is divided into Tasks, and not all participants are necessarily active in all Tasks in those Annexes in which they participate. The involvement of the participants in the Annexes is shown in Table 1.1.

To date, GIA Annexes have operated under the "task-sharing" mode of financing, whereby participants allocate specified resources and personnel to conduct their portion of the work at their own expense. Though precise figures are not available, the "costs" associated with the total Annex work conducted under the auspices of the GIA during the 2nd Term are estimated to be well over US$ 310,000 per year plus several man-years (GIA, 2006a).

Table 1.1 Contracting Parties, Sponsors, funding sources and periods of operation for the Annexes active to the end of December 2007.

Annex		I	III	VII	VIII
Country/Industry	**Contracting Party/Sponsor**	**Environmental Impacts of Geothermal Development**	**Enhanced Geothermal Systems**	**Advanced Geothermal Drilling Techniques**	**Direct Use of Geothermal Energy**
Australia	Primary Industries & Resources- South Australia (PIRSA)	G	G		
EC	The Commission of the European Communities	G	G	G	
France	Bureau de recherches géologiques et miniéres (BRGM)	G	G		G
Germany	Forschungszentrum Jülich GmbH		G		
Geodynamics	Geodynamics Limited, Australia		OA, I		
Green Rock Energy	Green Rock Energy Limited, Australia		I		
Iceland	Orkustofnun	G, I		G	OA, G
Italy	ENEL Produzione	I	I		
Japan	National Institute of Advanced Industrial Science and Technology (AIST)	R	R		R
Mexico	Instituto de Investigaciones Electricas (IIE)	G		G	
New Zealand	GNS Science	OA, R, I		I	R
ORMAT Technologies	ORMAT Technologies, Inc United States.		I		
Republic of Korea	Korea Institute of Geoscience & Mineral Resources (KIGAM)				R
Switzerland	Swiss Federal Office of Energy	G	G		G
USA	United States Department of Energy (US DOE)	N	N	OA, N	U
Annex Start Date		1997	1997	2001	2003
Date Current Term of Annex Continuing To		2009	2009	2009	2011
End Date*		Ongoing	Ongoing	Ongoing	Ongoing

G = Government; I = Industry; R = Research Institute (government funded); N = National Laboratory (government funded); U= University; OA = Operating Agent; * = Ongoing means no fixed end date yet determined

Table 1.2 Annex Title, Operating Agent and Status of GIA Annexes at December 2007.

Annex Number	Title Operating Agent (OA) Task Leader (TL); Affiliation; Contact E-mail Participants	Status
I	Environmental Impacts of Geothermal Development OA: GNS Science (GNS), New Zealand TL: Chris Bromley; GNS, New Zealand; c.bromley@gns.cri.nz Participants: Australia, EC, France, Iceland, Italy, Japan, Mexico, New Zealand, Switzerland, USA	Active since 1997, Continuing through 2009
II	Shallow Geothermal Resources	Closed
III	Enhanced Geothermal Systems OA: Geodynamics Limited, Australia TL: Roy Baria, MIL-TECH UK (for Geodynamics); roybaria@onetel.com Participants: Australia, EC, France, Geodynamics, Germany, Green Rock Energy, Italy, Japan, ORMAT, Switzerland, USA	Active since 1997, Continuing through 2009
IV	Deep Geothermal Resources	Closed September 2006
V	Sustainability of Geothermal Energy Utilization	Draft
VI	Geothermal Power Generation Cycles	Draft
VII	Advanced Geothermal Drilling Techniques OA: Sandia National Laboratories, United States TL: Steven Bauer; Sandia National Laboratories, USA; sjbauer@sandia.gov Participants: EC, Iceland, Mexico, New Zealand, USA	Active since 2001, Continuing through 2009
VIII	Direct Use of Geothermal Energy OA: The Federation of Icelandic Energy and Waterworks, Iceland TL: Einar Gunnlaugsson; The Federation of Icelandic Energy and Waterworks, Iceland; einar.gunnlaugsson@or.is Participants: France, Iceland, Japan, New Zealand, Republic of Korea, Switzerland, USA	Active since 2003, Continuing through 2011
IX	Geothermal Market Acceleration	Closed

In March 2003, the GIA Secretariat was established to provide the ExCo with administrative and other assistance, as well as to assist with expanding its activities. It is funded through "cost-sharing", whereby all Members contribute to a Common Fund according to the number of "shares" they have been allocated (see Section 1.4 for details).

A brief review of the geothermal situation, activities and achievements made by each Member Country and a company profile and description of activities for each Sponsor (industry) Member are provided in Chapter 6, with details reported in the individual Country and Sponsor Reports making-up Chapters 7-18 and 19-21, respectively.

More information about the GIA's activities may be obtained by contacting the GIA Secretary at: mongillom@reap.org.nz or by visiting the GIA website: www.iea-gia.org.

1.3 Structure of the GIA

The GIA is supervised by an Executive Committee (ExCo), which consists of one Member and one Alternate Member designated by each Contracting Party and each Sponsor. There is one Contracting Party for each country, usually a government department or agency. The ExCo meets regularly twice each year to exchange information, discuss activities and progress in each of the Annexes and in each of the participating countries and industries, and to plan future activities of the organization. Decisions are made by majority vote (unless otherwise specified in the IA), with each Contracting Party and each Sponsor allowed one vote. In 2002, the GIA ExCo decided to increase the scope of its activities. Consequently, it created a dedicated Secretariat, which began operations in March 2003 and is funded by a cost-shared Common Fund.

Table 1.3 Annex number, name, description and status for draft and completed Annexes as of December 2007.

Annex Number	Title Description	Status
II	**Shallow Geothermal Resources** The GIA ExCo made the decision in October 2000 to close this Annex after it reached the draft stage. Its major topic, which was associated with the application of geothermal heat pumps, is now included in Annex VIII- Direct Use of Geothermal Energy, which was initiated in September 2003.	Closed
IV	**Deep Geothermal Resources** The GIA ExCo decided to close this Annex in September 2006 after the successful completion of much of its work, and because of the overlap of the remaining activities with those in Annexes III and VII. The unfinished studies were transferred to Annexes III and VII.	Closed September 2006
V	**Sustainability of Geothermal Energy Utilization** This proposed Annex would investigate alternative scenarios for energy production from representative geothermal resources with the goals of (1) defining methods and requirements for sustaining production from these resources, and (2) of estimating the long-term economic sustainability of such production not only for representative resources but for the worldwide geothermal resource as a whole. The issue of "sustainable" energy production has grown in recognition and importance over the past few years. Consequently, during 2006, the GIA ExCo made a preliminary decision to initiate a sustainability Task in Annex I. However, if activities expand in the future, it is possible that this Annex would be activated.	Draft
VI	**Geothermal Power Generation Cycles** This proposed Annex would develop scenarios as a basis for comparison of cycles, plant performance and availability, economics and environmental impact and mitigation. The output would be a database and guidelines of best practice. A draft of this Annex was prepared in 2001, and it is currently being updated and revised due to growing interest in the topic.	Draft
IX	**Geothermal Market Acceleration** Geothermal electricity production and direct heat use are well developed and economically viable in many parts of the world, however, there are large untapped resources in many countries. The ExCo explored ways to hasten geothermal energy development, or market acceleration, in these countries during the last few years, and decided that a more pro-active approach was needed, possibly including: identifying a few regions with high geothermal potential, collating resource assessments on a few sites and discussing with key players (government, utilities, developers, financiers, *etc*.) the barriers to progress in their regions. Consequently, this market acceleration Annex was drafted. In October 2004, following the IEA's decision to initiate its own market acceleration type of IA, the ExCo made the unanimous decision to close this Annex.	Closed

GIA research results are disseminated through participation at international conferences and workshops, and publication in scientific and technical journals and conference proceedings (details in Chapters 2-6). In addition, information is made more widely available on the GIA's public website, through promotional material produced by the GIA Secretariat, and via IEA publications and the IEA website (www.iea.org).

In 2007, 11 countries, one international organization and three industries formally participated in this programme (Table 1.1).

1.4 The Executive Committee

Officers

In 2007, Chris Bromley (New Zealand) was elected as Chairman, to replace Dr David Nieva (Mexico) who desired to step-down from an Officer role. Dr Ladislaus Rybach (Switzerland) and Dr Allan Jelacic (USA) continued to serve as Vice-Chairs for Policy and Administration, respectively.

Membership

There were several changes in the ExCo composition in 2006. The EC Member, Dr Jeroen Schuppers, was replaced by Mr Andreas Piontek; the Iceland Member, Dr Helgi Torfason, was replaced by Dr Jonas Ketilsson; the Alternate Member from Japan (NEDO), Mr Chitoshi Akasaka transferred from NEDO, so was replaced by Mr Yoshinori Makino (NEDO); Dr Rudolf Minder replaced Dr Thomas Mégel as Alternate Member for Switzerland; Dr Lothar Wissing became the ExCo Member from Germany, exchanging positions with Dr Dieter Rathjen, who became Alternate member. France joined the GIA in 2007, with Dr Patrick Ledru appointed as ExCo Member and Dr Fabrice Bossier as Alternate Member.

The list of ExCo Members and Alternates as at December 2007 is provided in Appendix B.

Meetings

The ExCo held two Meetings in 2007 to conduct business, including the discussion and review of ongoing tasks and planning of future activities.

17th ExCo Meeting 22-23 March 2007, Nice, France

The 17th ExCo Meeting was held on 22-23 March 2007, at the Hotel La Perouse, Nice, France, with the support of ADEME and BRGM. Nice was the chosen location to celebrate France becoming the GIA's newest Member. There were 31 participants, including 12 ExCo Members and 6 Alternate Members, 7 Observers, 5 invited Guests and the GIA Secretary.

The ExCo unanimously approved the election of Chris Bromley as the new Chair (replacing David Nieva), and Allan Jelacic and Ladislaus Rybach as Vice-Chairmen.

Chair David Nieva reported that his invited presentation to the CERT at IEA Headquarters in Paris in support of the GIA's application for extension for a 3rd 5-year Term was well received and that the CERT had approved the extension. The GNS Science (New Zealand) contract for operating the GIA Secretariat was unanimously continued for the GIA's 3rd Term.

All four GIA Annexes held meetings on Wednesday 21 March 2007. The four Annexes reported on their activities at the ExCo meeting, as did the European Commission, 10 Country Members and the 3 Sponsor (industry) Members. France presented their first Country report, noting the renewed activity in geothermal research and creation of a new geothermal department in BRGM to structure all French geothermal activities. EGS projects are proceeding, with Soultz (France) and Cooper Basin (Australia) progressing well and Landau (Germany) planning a combined electricity generation (2.58 MW_e, with 1.5 MW_e production) and heat use (5.1 MW_t) project to come on-line in late 2007.

The ExCo decided to begin the geothermal sustainability studies as a new Task in Annex I, rather than start an entire new Annex V, though the draft Annex V- Sustainable Geothermal Energy Production was kept "open" for possible future initiation. It was also decided to add a new Annex VIII Task on geographic representation of direct use data using Google Earth. Geodynamics was conditionally approved as the new Operating Agent for Annex III- EGS.

The importance of induced seismicity was stressed as the result of the events experienced at Basel, Switzerland, in December 2006. The ExCo approved the production of a GIA document to be submitted to the IEA OPEN Bulletin, which explains induced seismicity and emphasizes that there are still several R&D questions needing investigation.

The Secretary provided a report on the operation (work accomplished and budgets) of the Secretariat for the 2006-year and the 2007-year to March 2007, presented a work plan and revised budget for the remainder of 2007, and gave an update on the Common Fund. Continued growth in GIA membership was discussed, with interest from Hungary and Spain reported.

The IEA Secretariat report was presented and the GIA confirmed its participation in the IEA Ministerial Fair being held in Paris, in May 2007.

The ExCo agreed to hold the 18th ExCo Meeting in Mainz, Germany, on 25-26 October 2007, in association with the First European Geothermal Review conference. However, a later offer from BESTEC to host the Meeting at their offices in Kandel, Germany was later accepted by the ExCo.

18th ExCo Meeting 25-26 October 2007, Kandel, Germany

The 18th ExCo Meeting was hosted by BESTEC, and held at their offices in Kandel, Germany, on 25-26 October 2007. The meeting was held in conjunction with the First European Geothermal Review, Mainz, Germany, thus allowing ExCo Meeting participants to take part (five papers were presented by GIA participants). Twenty-three people attended, including: 10 ExCo Members, 4 Alternate Members, 8 Observers and the GIA Secretary. A fieldtrip to the Landau EGS site was also provided by BESTEC.

ExCo approved production of a standalone Executive Summary of the 2006 Annual Report and CD-Rom with all GIA Annual Reports (1997-2006) for information dissemination and promotion purposes. The importance of producing geothermal costs information was stressed, with the ExCo deciding to design a "cost table" to which Members can contribute data.

The GIA continued to pursue the Membership of the major geothermal countries not yet Members, and the Secretary would be participating in the IEA NEET Workshop in Beijing, China, as part of this effort. ORME Jeotermal (Turkey) confirmed its interest in joining as a Sponsor Member, and the ExCo agreed to invite them. Membership interest on the part of Hungary and Spain are to be followed-up.

Annexes I and III held meetings on 24 October 2007. Reports from Annexes I, III, VII and VIII, the EC, and 10 Country and 3 Sponsor reports were presented and discussed. Draft "best practices environmental procedures" developed in Annex I were discussed. Revisions in the Tasks for Annex III were presented for consideration and new Task Leaders provisionally accepted.

Secretariat work plans and budgets for the remainder of 2007 and for 2008 were submitted along with the Common Fund report, and these were unanimously accepted by the attending ExCo Members.

It was recognized that the GIA had continued its active relations with the IEA Secretariat, having contributed a geothermal section for the IEA ETP 2008 book, provided documents and posters for the IEA Ministerial Fair (Paris, France), participated in the IEA Demand Side Technology Workshop (Paris, France) and confirmed its participation in the IEA NEET Workshop in Beijing, China, on 1-2 November.

The IEA Secretariat representative presented a report which included information on IEA activities and publications. They thanked the GIA for its input into IEA publications and activities, and especially for participating at the IEA Ministerial Fair and Demand Side Technology Workshop.

The ExCo reiterated the importance of disseminating information on geothermal energy and promoting the IEA-GIA and its activities for educational purposes, to encourage geothermal energy utilization and to increase the organization's membership. In 2007, the GIA ExCo was very active in support of these goals.

GIA Participation in IEA Activities in 2007

The GIA had an especially active participation with the IEA in 2007. The GIA provided a brief article for the **IEA Energy Technologies at the Cutting Edge 2007** (*Tapping into vast, unused heat resources*); commented on the **IEA Contribution of Renewable Energy Technologies to Energy Security;** provided geothermal data for the **IEA Global Renewable Energy Markets & Policies (GREMP)** document; significant effort in reviewing and providing information on geothermal costs, markets, policies and heating & cooling for two **IEA Global Renewable Energy Heating & Cooling** documents (which were eventually merged into one report); major contribution in reviewing and providing data and text for the IEA Energy Technology Perspectives 2008 book; submitted material (2 posters and copies of 3 documents) for the **IEA Ministerial Fair**; participated in the **IEA Deploying Demand Side Energy Technologies Workshop** (Paris, France) with a presentation by Rybach (2007): *Geothermal Heating and Cooling of Buildings*; made a presentation at the February 2007 CERT Meeting in support of extending the IEA-GIA for a 3rd 5-year Term; participated in the IEA provided revisions for the GIA portion of the IEA Technologies website; and participated in the **IEA NEET Workshop in Beijing**, China.

GIA posters at IEA Ministerial Fair, 14-15 May 2007, Paris, France
(courtesy of Nobu Hara, IEA Secretariat).

Other GIA Activities

The GIA participated in the European Geothermal Congress (30 May-1 June 2007), presenting a paper by Mongillo and Rybach: *The IEA Geothermal Implementing Agreement (GIA)- Advancing into Its Third Term.*

The GIA's public website (www.iea-gia.org), continued to grow as a source for information dissemination and discussion.

Costs of the Agreement

The GIA has a dedicated GIA Secretariat, currently located in New Zealand, which is supported by a part-time Secretary. The Secretary deals with the ongoing administration, assists with the management of the organization and provides a significant part of the information dissemination, including the preparation of GIA documents and publications, the GIA annual reports and development and maintenance of the GIA website.

The expenses for operating the GIA Secretariat, including the Secretary's salary and travel, and other common costs of the ExCo, are met from an Executive Committee Common Fund. In 2007, these costs amounted to a total of US$ 93,050. The Fund is administered by a Custodian, currently the National Renewable Energy Laboratory (NREL), based in Golden, Colorado, USA, who also conducts an annual review of its financial operations.

The Common Fund is supported through cost-sharing, with each GIA Member paying an annual contribution based upon a fair apportionment in the form of an allocated number of shares. The number of shares assigned to new Members is determined by the ExCo acting in unanimity. The apportionment for the current GIA Membership is shown in Table 1.4.

The cost per Common Fund share, set by unanimous ExCo decision, was US$ 3,500/yr in 2007. The addition of new members, or the withdrawal of current ones, will cause the total number of shares to vary, and may affect the share value, hence Members' contributions. Contributions are made annually on a calendar year basis.

Table 1.4 Common fund share apportionment among the GIA Members as of December 2007.

Australia	2	New Zealand	1
European Commission	4	Republic of Korea	2
France	4	Switzerland	2
Germany	4	United States	4
Iceland	1	Geodynamics	1
Italy	2	Green Rock Energy	1
Japan	4	ORMAT	2
Mexico	1	-	-
Total = 35 shares			

1.5 References

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Stefansson, V. (2005) World geothermal assessment. Proceedings World Geothermal Congress 2005, Antalya, Turkey, 24-29 April 2005, 6p.

IEA GEOTHERMAL R&D PROGRAMME

Chapter 2

Annex I- Environmental Impacts of Geothermal Energy Development

The Champagne Pool, Waiotapu geothermal field, New Zealand (photo courtesy GNS Science, New Zealand).

2.0 Introduction

Geothermal is a relatively benign renewable energy source, with significant advantages over fossil fuels with respect to carbon emissions, but there are some environmental problems associated with its utilization. To further the use of geothermal energy, possible adverse and beneficial environmental effects are identified, and measures devised and adopted to avoid or minimize adverse impacts, while encouraging the benefits.

The goals of Annex 1 are: to encourage the sustainable development of geothermal energy resources in an economic and environmentally responsible manner; to quantify and balance any adverse and beneficial impacts that geothermal energy development may have on the environment, and to identify ways of avoiding, remedying or mitigating adverse effects.

Participants in this Annex are: Australia, European Commission, Iceland, Italy, Japan, Mexico, New Zealand, Switzerland and the United States. Contributions have also been received from non-members: Turkey, the Philippines, and United Kingdom.

GNS Science, Wairakei Research Centre, New Zealand, is the Operating Agent. Chris Bromley, of GNS Science, is the Annex Leader.

2.1 Tasks of Annex I

Annex I has five Tasks, described below.

2.1.1 Task A- Impacts on Natural Features (Task Leader: Chris Bromley, GNS Science, New Zealand)

Focus on documenting known impacts of geothermal developments on natural geothermal features such as geysers, hot springs and fumaroles. The aim is to provide a sound historical and international basis on which to devise methods to accurately monitor changes and avoid or mitigate the impacts of development on these geothermal features, which often have significant cultural and economic value.

2.1.2 Task B- Discharge and Reinjection Problems (Task Leader: Trevor Hunt, New Zealand)

Focus on identifying and determining methods of overcoming the impacts of geothermal developments on other aspects of the environment. This includes the effects of gas emissions from geothermal power plants, effects of toxic chemicals in waste fluid that is discharged both into the ground and into rivers, and effects of ground subsidence. Projects examine the problems associated with disposal of waste geothermal fluids and the effects of CO_2, Hg and H_2S gas emissions, and subsidence.

Figure 2.1 Hydrothermal eruption crater at Mokai geothermal field, New Zealand

2.1.3 Task C- Methods of Impact Mitigation and Environmental Procedures (Task Leader: Chris Bromley, GNS Science, New Zealand)

The objective is to contribute to the future of geothermal energy utilisation by developing an effective, standard environmental analysis process. Field management strategies that result in improved environmental outcomes will be identified and promoted based on operational experience. Successful mitigation schemes that provide developers and regulators with options for compensating unavoidable effects are also identified, documented and promoted.

2.1.4 Task D- Seismic Risk from Fluid Injection into Geothermal Systems (Task Leaders: Ernie Majer, Lawrence Berkeley National Laboratories, USA; and Roy Baria, United Kingdom)

Address the issue of the occurrence of large (felt) induced seismic events, particularly in conjunction with EGS reservoir development, but also in connection with regular geothermal operations. The objective is to investigate these events to obtain a better understanding of why they occur so that they can either be avoided or mitigated. Objectives are to assess and generate an appropriate source parameter model, and test the model in relation to the hydraulic injection history, temperature gradients, stress field and the tectonic/geological background, using stress modelling, rock mechanics and source parameter calculations. Once various mechanisms of the events are understood, the injection process to engineer a geothermal reservoir, and the process of extracting heat over a prolonged period, may be modified to reduce or eliminate the occurrence of large events.

2.1.5 Task E- Sustainable Utilization Strategies (Task Leader: Guðni Axelsson, Iceland Geological Survey (ISOR), Iceland)

Collate case histories of models of geothermal developments to see what strategies have worked. Undertake modelling of long term reservoir behaviour to select optimum future strategies given different recharge and resource size scenarios. Compare environmental gains with economic gains from different sustainable development scenarios. Compare different conceptual and hypothetical reservoir model predictions. Investigate (with agreed scenarios) long term reservoir behaviour, recharge factors, recovery times, and optimised cyclic or staged operation strategies.

Figure 2.2 Geometricas Hot Spring in southern Chile.

2.2 Work Performed in 2007

2.2.1 Task A- Impacts on Natural Features

Thermal feature impacts due to geothermal development in New Zealand, USA and the Philippines were compared. Strategies to mitigate, recover or enhance thermal features were tabulated. Policies were designed to help regulators to manage effects on thermal features in a practical manner. Methods to quantify surface heat and gas flux changes through steaming ground were further refined. Results were presented at workshops in New Zealand, Germany and Chile.

2.2.2 Task B- Discharge and Reinjection Problems

Waste water disposal options, including groundwater disposal, deep injection, shallow injection, and chemical treatment were addressed at various conferences including, GRC 2007, Stanford 2007, NZGW 2007, Chile-Invest 2007 and the First European Geothermal Review. Methods of H_2S emission abatement, reduction of CO_2 emissions by injection into steam zones, and arsenic reduction through silica precipitation were also addressed.

Potential causes of subsidence in geothermal fields were investigated and methods to improve predictive capabilities of subsidence models were further investigated and published. The use of interferometric synthetic aperture radar (INSAR) for geothermal subsidence monitoring was investigated (jointly with Jessica Hole from the UK) and a paper published in Journal of Volcanology and Geothermal Research.

2.2.3 Task C- Methods of Impact mitigation and Environmental Procedures

A comparison of appropriate international geothermal policy and planning guidelines was undertaken. Tables of effects and avoidance strategies were prepared. Examples of mitigation costs were collated and discussed at Annex I meetings.

2.2.4 Task D- Seismic Risk from Fluid Injection into Geothermal Systems

Multi-party collaboration (mainly EC-France, USA, Australia, Switzerland and New Zealand) continued in order to advance understanding of induced seismicity mechanisms, provide strategies, and robust hazard assessment methods to address the issue of large induced earthquakes from injection/production activities. Completed Geothermics paper (Majer, *et al*., 2007) and modified induced seismicity protocol (posted on IEA-GIA website). Examples of improved seismic monitoring and processing methods were also presented.

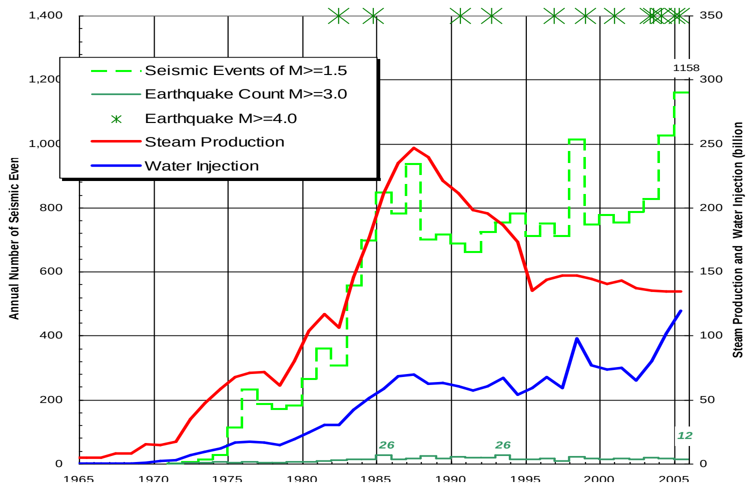

Figure 3
History of The Geysers geothermal field steam production, water injection and induced seismicity rates for various magnitude ranges. (From Majer *et al*., 2007)

Figure 2.3 History of Geysers steam production, injection and induced seismicity (from Majer, *et al*., 2007)

2.2.5 Task E- Sustainable Utilization Strategies

A reference list of papers addressing the issue of sustainability and related matters was compiled and posted on the IEA-GIA website. A first announcement brochure advertising a workshop (10 November 2008) to address reservoir modelling issues concerning long term sustainability was also prepared and circulated. Discussions took place at Annex meetings on the focus and objectives of this Task.

2.3 Highlights of Annex I Programme Work for 2007

The highlights for the 2007-year were:

- Papers were presented by participants on improved environmental sustainability strategies at the annual New Zealand Geothermal Workshop (November 2007) in Auckland, New Zealand, Stanford Geothermal Reservoir Workshop, the First European Geothermal Review in Mainz, Germany (October 2007) and at a renewable energy investment seminar in Santiago, Chile

- Interest in sustainability issues led to an agreement to hold a workshop on this topic in Taupo, New Zealand in November 2008

- Discussions on longer-term research and development needs were held with industry representatives at international conferences, including research into: induced seismicity, monitoring natural CO_2 and convective hear flux, using injection to reduce CO_2 and H2S emissions, classifying thermal feature vulnerability, testing mitigation and remedial methods and developing bio-remediation methods to remove toxic elements from geothermal water discharges

- Improved methods to monitor, avoid or mitigate environmental effects such as subsidence, gas and heat emissions and induced seismicity were published

- Geothermal environmental mitigation costs, best-practice government policy options and strategies to protect geysers from development effects were developed to assist countries that are new to geothermal development (e.g. Chile)

- Annex praticipants took part in discussions and Annex meetings in conjunction with the GIA Executive committee meetings in April 2007 (Nice, France) and in September (Kandel, Germany) to discuss progress on the existing Tasks and planning for new Tasks

2.4 Work Planned for 2008

2.4.1 Task A

- Distinguishing natural and induced variations in thermal discharges

- Modelling causes of groundwater effects from deep pressure change

- Methods of ranking thermal features and ecosystems for protection

- Classify vulnerability of thermal features to reservoir pressure changes

2.4.2 Task B

- Geothermal CO_2 capture for horticulture and bottling
- CO_2 sequestration by injection or chemical fixing
- Arsenic/boron removal from waste water by bio- or chemical processing
- Protection of potable water aquifers from out-field reinjection effects
- Improved prediction of subsidence and effects avoidance or mitigation

2.4.3 Task C

- Test the use of targeted injection to rejuvenate failed geysers
- Test the use of targeted injection to stop subsidence
- Review international geothermal environmental policies and procedures
- Review costs of mitigation options for environmental effects

2.4.4 Task D

- How to discriminate between EGS-related and natural seismic events- identifying and characterizing attributes typical of induced events (duration, frequency content, dominant frequency)
- Investigating possible seismic effects during long-term EGS operation (production phase). There is little experience regarding long-term thermo-elastic effects (cooling cracks). Will the level of seismicity due to hot fluid production be lower than that during stimulation?
- Defining how far relevant stress field pertubations can extend from EGS operations. What are the implications of this in terms of safe proximity of stimulated EGS reservoirs to major active faults?
- Further studies on post shut-in seismicity. Why do micro-seismic events continue to occur after suspension of injection?
- Designing downhole EGS operations to minimize ground shaking. The management scheme may involve adjusting volume, rate or temperature of fluid injection. Research should investigate the nature and degree of dependency of these factors on the local conditions at depth
- Predict likelihood of damaging induced earthquakes and devise avoidance or mitigation schemes

2.4.5 Task E

- Comparing simulations of >100 year continuous and periodic (30-50yr interval) production/injection scenarios, what are the optimum strategies?
- How rapidly and effectively do geothermal systems recover during breaks after periods of excessive production?
- What factors are most significant in controlling long-term behaviour/capacity; boundary conditions, inflow/recharge, reinjection, *etc*.?

- How significant and far-reaching are long-term production pressure drawdown and injection cooling effects, i.e. how significant is interference between adjacent geothermal areas?

- Using case histories, what is the reliability of long term predictions of reservoir behaviour using various methods (stored heat, simple analytical models, complex 3D models, *etc.*)?

- What information should be collected at pre-exploitation and early development stages to significantly reduce uncertainties in long-term resource sustainability assessments?

Each task is dependant on time and resources being made available by participants and the cooperation of geothermal development companies. Accelerated progress can be achieved through:

- An improvement in availability of funding, the availability of donated time of participants, and securing the interests and motivations of more people willing to collaborate

- Direct funding (through sponsorship) of expenses associated with specific activities such as bringing together researchers, enhancing websites, promotion of research results, and other means of information dissemination

Environmental tasks that would benefit from supportive direct or in-kind funding are:

- Preparation of an international geothermal environmental protocol document (improve on existing documents)

- Induced seismicity and sustainability workshops and publishing costs

- Field trials using targeted shallow reinjection of hot fluids to recover/enhance thermal features

- Field trials of injection as a means of suppressing subsidence

- Field trials of gas injection in geothermal wells

- Field trials of injection/production methods to influence the rate of induced seismicity

- Field trials of water treatment to remove toxic elements

2.5 Outputs for 2007

Reports and papers posted on the IEA-GIA website for comment and review:

- Sustainability of geothermal systems- a reference list

- Majer, E. and R. Baria (with revisions by C. Bromley, L. Rybach and B. Cummings) (2007) Draft Protocol for Induced Seismicity Associated with Enhanced Geothermal Systems

- Majer, E., *et al.* (2007) Induced Seismicity Associated with Enhanced Geothermal Systems

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Pascua, C., Minato, M, Yokoyama S. and T. Sato (2007) Uptake of dissolved arsenic during the retrieval of silica from spent geothermal brine. Geothermics, Vol 36, No.3, p 230.

Pruess K., Spycher N., and Kneafsey T. (2007) Water injection as a means for reducing non-condensible and corrosive gases in steam produced from vapor-dominated reservoirs. Proc. Stanford Geothermal Workshop, Stanford University, February 2007.

Shapiro S. (2007) Kinematic and dynamic features of earthquakes induced by borehole fluid Injections. In: *First European Geothermal Review: presentations, abstracts & papers - tagungsbeitrage*, October 29-31, 2007, Mainz, Germany.

Yeh A., O'Sullivan M. (2007) Modelling subsidence in geothermal fields. *Proc. 29th NZ Geothermal Workshop*, 19-21 November, Auckland University, New Zealand.

Yousefi, H., Ehara S. (2007) Environmental impact assessment for sustainable geothermal energy development. *Proc. 29th NZ Geothermal Workshop*, 19-21 November 2007, Auckland University, New Zealand.

2.6 Websites Related to Annex I Work

- IEA Geothermal Implementing Agreement hosting seismicity protocol, sustainability reference list, *etc*.: http://www.iea-gia.org
- Website hosting the results of three IEA-GIA convened induced seismicity workshops, containing presentations and links to sources of information and data: http://esd.lbl.gov/EGS/

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IEA GEOTHERMAL R&D PROGRAMME

Chapter 3

Annex III- Enhanced Geothermal Systems (EGS)

Flow test of Habanero #2 on May 2005, Cooper Basin, South Australia (courtesy of Geodynamics).

3.0 Introduction

Enhanced (aka Engineered) Geothermal Systems (EGS) energy technologies have been conceived to extract the natural heat contained in high temperature rocks which are not associated with hydrothermal systems and not dependent on special geological conditions. There is significantly more energy available in the form of heat from the earth which is not associated with hydrothermal energy and it is anticipated that EGS technology will allow the underground to be manipulated to extract the energy at commercially viable rates. Normally, EGS is associated with extraction of energy from water-poor rocks, in formations that are either too dry or too impermeable to allow extraction of available heat but EGS knowledge of flow and stress can also be used to target permeable faults using water as a heat transport medium at commercially viable rates. If necessary, permeability can be created by hydraulic stimulation of the existing fracture network, which involves high-pressure injection of a fluid into the potential reservoir to jack open pre-existing fractures.

The objective of this EGS Annex is to address new and improved technologies, which can be used to access the huge heat resources present in the majority of the continental land masses by engineering heat exchangers at depth in order to allow the extraction of geothermal energy at commercially viable rates. This technology will bring in to play a significant worldwide geothermal resource to generate base load power and reduce environmental pollution. It will also help sustain hydrothermal systems through the use of reinjection, which is an EGS technology.

The countries and organizations that participated in Annex III in 2007 were: Australia, the EC, Geodynamics Limited, Germany, Green Rock Energy, Italy, Japan, ORMAT Technologies, Switzerland and the USA.

In 2007, following the 17th GIA ExCo Meeting held in Nice, France on 22-23 March, the Operating Agent for Annex III changed from the New Energy and Industrial Technology Development Organization (NEDO), Japan, to Geodynamics Limited, Australia.

As a result of the change in Operating Agent, the Annex Leader changed from Isao Matsunaga (AIST, Japan) to Roy Baria (MIL-TECH, UK) and Doone Wyborn, of Geodynamics Limited, Australia.

3.1 Tasks of Annex III

Annex III has five Tasks, described below. Many of these Tasks were revised during 2007.

3.1.1 Task A- Economic Modelling (Task Leader: To be appointed)

Task A, which originally involved the evaluation of the economics of EGS systems, was successfully completed in 2001. However, it is being re-activated in order to incorporate the quantification and definition of EGS resources in a form that can be internationally accepted. Additionally, many commercially funded projects will start to come on line in the near future and will require a common terminology to make them comparable. It is becoming apparent that the development of EGS is moving from fundamental research to application. New EGS projects are likely to occur on different continents, with varying geological conditions and stress regimes, and *the knowledge gained in the past will need to be applied to new conditions.* It is important for the success of EGS that the processes developed through international research and cooperation are applicable in different stress and geological setting. With this in mind, details of this Task were reassessed and implementation sought. It is also becoming apparent that the flow of information is decreasing as privately funded projects regard the knowledge they obtain as the intellectual property rights associated with their investment.

In the past, economic models were used to evaluate what tasks or technologies were sensitive to economic viability, and those that were, were given preferential treatment for research and development. Today, the use of economic models has changed; they are now used to raise capital on the market.

There is concern that financiers may be disenchanted with some of the optimistic claims made and may not fulfil the requirements for the successful take up of this technology. A standardised economic model is needed that will take into consideration the local incentives, local labour and environmental requirements and conditions. It is believed that this will maintain the credibility of the technology and support those organisations that are experienced and can deliver on time and within budget. A part of this Task is the resource assessment, so that the market can compare like with like quantification of resource. A draft report has been prepared by the Australian Geothermal Association to address this aspect and is being reviewed.

3.1.2 Task B- Application of Conventional Geothermal Technology to EGS (Task Leader: Joel Renner, Idaho National laboratory, USA)

This Task is aimed to modify conventional hydrothermal development technology, such as horizontal drilling, fracture detecting and mapping, and pumping, for application to EGS energy development. A coordinated list of actions is under preparation to see how this can be put together to help EGS.

3.1.3 Task C- Data Acquisition and Processing (Task Leader: Thomas Mégel, Geowatt, Switzerland)

Task C involves the collection of information necessary for the realization of a commercial EGS energy producing plant at each stage of reservoir characterization, design and development and of construction and operation

Access to past data and reports from various projects has always been a difficult task. The US DOE developed the "Legacy project", which allows access to some of the reports from previous EGS projects. This needs reinforcing with additional missing reports and a better search engine, with the latter needing refining or replacing. The implementation of a search engine previously developed by Geowatt under this task may provide a good improvement.

Access to all the data is still a major problem as some of it will have been lost or may be regarded as confidential. The data, which is available, ought to be accessible to those who wish to work on it, gain from the past experience or develop new interpretation methods. Such data may be divided in to four categories:

- In-situ data: geology, stress profile, temperature with depth, *in-situ* fluid composition and pressure, joint network and orientation, *etc*.
- Hydraulic data: all hydraulic testing, stimulations and circulations of the wells
- Microseismic data: both located events and raw data
- Reports and papers

There are a number of ways to host the database: through a national institution, such as the US DOE, or as a shared database, which is supported and managed by a common fund or a pay as you go regime.

3.1.4 Task D- Reservoir Evaluation (Task Leader: Doone Wyborn, Geodynamics Limited, Australia)

The overall object of Task D is to compile and make clear what kind of methods, techniques, and tools are effective for reservoir evaluation; and then establish the evaluation method that can be applied to develop a new EGS site. Creation of an economically viable reservoir is the single most important item in EGS technology. There are methods which are used for evaluation of the data and some of them are borrowed from the oil and gas industry. The plan is to define agreed procedures to test and evaluate the reservoir parameters so that they can be compared. Some of the procedures that could be standardized are:

- Well testing models
    - Before stimulation
    - For stimulation
    - For circulation
- Borehole measurements
    - Temperature
    - Flow
    - Pressure

- Water management
  - Open system
  - Closed system
  - Over pressured system
- Review of numerical methods
  - Flac 3D
  - uDec
  - Geocrak
  - FRIP
  - Others
- Microseismic measurements
  - Design of network and errors
  - Automatic location of data
  - Interpretation of data
  - Quantification of stimulated area and hear transfer volume
- Tracer studies
  - Selection of tracers
  - Sampling, breakthrough time and modal volume
  - Heat transfer area
  - Identification of preferential paths
  - Life of a reservoir

3.1.5 Task E- Field Studies of EGS (Task Leaders: Peter Rose, EGI University of Utah, USA and Albert Genter, EEIG and EC)

The objective of Task E is to conduct Enhanced Geothermal Systems (EGS) research and development with an emphasis on reservoir management and reservoir enhancement technologies. This topic covers a broad area, including fracture and stress analyses, hydraulic and chemical stimulation, fluid flow modelling of hydraulic and chemical stimulation processes, tracer technologies and geophysical methods. This was a collaborative task between the EGS projects at Soultz-sous-Forêts (France) and Coso, California (USA).

This Task will now become part of a new reservoir management Task, a stage that is only now being reached for EGS systems. This includes things like scaling, corrosion, dissolution, precipitation, *etc*. The three EGS systems that were circulated for prolonged periods during early phases of EGS investigations were the Los Alamos, the Rosemanowes and the Hijiori sites. Some investigations were done at these sites, but this requires updating and integration with the limited experience at the Soultz site.

3.2 Work Performed in 2007

Many of the Task activities were revised during 2007. As a consequence of reduced funding from various participating organizations, efforts on Task projects were much reduced. It is expected that this will pick up in 2009 as more funding is released.

3.2.1 Task A- Economic Modelling

The major effort in this Task involved its re-establishment with new objectives (see Section 3.1.1 above).

3.2.2 Task B- Application of Conventional Geothermal Technology to EGS

The US Department of Energy continues to fund research projects bridging hydrothermal technology and technology that is more specific to Enhanced Geothermal Systems development. Results of these projects are summarized in "EGS Program Review" (http://www1.eere.energy.gov/geothermal/egs_prog_review.html), and described in the EGS sessions of the GRC (2007) and the SGERW (2007).

3.2.3 Task C- Data Acquisition and Processing

During the year 2007 no specific work was conducted within this Task. However, a handbook that facilitates the planning of specific EGS project steps and provides an overview to the state of art of commercially available services, which was completed in 2005: Enhanced Geothermal System Project Management Decision Assistant or EGS-PMDA (see IEA-GIA website under http://www.iea-gia.org/geothermal_information.asp) is still being distributed for a cost to cover reproduction and postage.

3.2.4 Task D- Reservoir Evaluation

A final report of Task D activities was compiled, made available on CD-Rom and distributed to many IEA-GIA Members in 2006. The final report consists of two sections: "Circulation and Heat Extraction" and "Monitoring". Both sections include the essence of experience and knowledge which has been obtained at the Japanese Hijiori and Ogachi HDR fields.

This task is being restructured to define and find a way to quantify these parameters. The process has started and information is being put together. See the details list in the previous section.

3.2.5 Task E- Field Studies of EGS Reservoir Performance

As stated above, this Task was being re-designed during 2007; consequently, no other activity was pursued.

3.3 Work Planned for 2008

The Operating Agent changed from New Energy and Industrial Technology Development Organization (NEDO), Japan, to Geodynamics Limited, Australia, following the GIA ExCo Meeting held in Nice, France, on 22-23 March 2007; with Roy Baria (MIL-TECH, UK) and Doone Wyborn (Geodynamics Limited, Australia) taking over the role of Annex Leader from Isao Matsunaga (AIST, Japan).

Following these changes, there was an assessment of Annex activities; with the remainder of the year taken-up with the re-development of most of the activities. Work is expected to continue in 2008.

3.4 Websites Related to Annex III Work

- Habanero project, Australia:
  http://www.geodynamics.com.au/IRM/content/default.htm
- Germany's Resources: http://www.tab.fzk.de/
- GeneSys-Project, Germany: http://www.bgr.de/
- Hijiori project, Japan: http://www.nedo.go.jp/chinetsu/hdr/hijiorinow/html
- Deep Heat Mining, Switzerland: http://www.dhm.ch
- EGS-PMDA promotion on: http://www.iea-gia.ch

- DOE technical projects: http://www.eere.energy.gov/geothermal
- EGS Program Review:
  http://www1.eere.energy.gov/geothermal/egs_prog_review.html
- Coso stimulation Project, USA: http://www.egs.egi.utah.edu
- Soultz European HDR Project: http://www.soultz.net/

3.5 References

GRC (2007) EGS Session. In: Transactions Geothermal Resources Council 2007, vol. 31, 265-327.

SGERW (2007) *32nd Workshop- Geothermal Reservoir Engineering*, Stanford University, USA.

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Chapter 4

Annex VII- Advanced Geothermal Drilling Technology

Drill rig at geothermal site in Landau, Germany (courtesy of Lothar Wissing).

4.0 Introduction

The objective of advanced drilling technology is to promote ways and means to reduce the cost of geothermal drilling through an integrated effort which involves developing an understanding of geothermal drilling needs, elucidating best practices, and fostering an environment and mechanisms to share methods and means to advance the state of the art. Drilling is an essential and expensive part of geothermal exploration, development, and utilization. Drilling, logging, and completing geothermal wells are expensive because of high temperatures and hard, fractured formations. The consequences of reducing cost are often impressive, because drilling and well completion can account for more than half of the capital cost for a geothermal power project.

Geothermal drilling cost reduction can take many forms, e.g., faster drilling rates, increased bit or tool life, less trouble (twist-offs, stuck pipe, *etc*.), higher per-well production through multi-laterals, and others. Activities in the Advanced Geothermal Drilling Technology Annex will address aspects of geothermal well construction, which include:

- Developing a detailed understanding of worldwide geothermal drilling costs
- Compiling a directory of geothermal drilling practices and how they vary across the globe
- Developing improved drilling technology.

The objectives of the Advanced Geothermal Drilling Task are to:

- Quantitatively understand geothermal drilling costs from around the world and identify ways to reduce those costs, while maintaining or enhancing productivity
- Identify and develop new and improved technologies for significantly reducing the cost of geothermal well construction to lower the cost of electricity and/or heat produced with geothermal resources
- Inform the international geothermal community about these drilling technologies
- Provide a vehicle for international cooperation, field tests, *etc*. toward the development and demonstration of improved geothermal drilling technology

Annex VII of the Geothermal Implementing Agreement has been developed to pursue advanced geothermal drilling research that will address all aspects of geothermal well construction.

Participants in this Annex are: Mexico, Iceland, the European Commission, New Zealand, and the United States.

Sandia National Laboratories (USA) is the Operating Agent for Annex VII. Stephen Bauer, from Sandia National Laboratories, is Annex Leader (sjbauer@sandia.gov).

4.1 Tasks of Annex VII

Annex VII has three Tasks, described below. As specified in the Annex VII charter, all participants in the Annex are considered to participate in all Tasks. Due to a reassignment of Jaime Vaca (Mexico), after a few years of dedicated and productive service, Steven Bauer has assumed responsibilities for Tasks A and B, until replacements can be found.

4.1.1 Task A- Compile Geothermal Well Drilling cost and Performance Information (Task Leader: Steven Bauer, Sandia National Laboratories (SNL), USA)

This activity is a compilation of drilling cost information associated with the development, construction and operation of geothermal wells. This information/data will be maintained in a single database, so that all participants can use it to identify key cost components that might be reduced by new technology or by different drilling practices. Data could include R&D cost, project cost, operation and maintenance cost and overall cost of energy. It will include information on wells for both electricity and direct-use applications (including geothermal heat pumps), and will include information from 1990 to date. The key modification sought in this time period, based on the realization that operators do not want to openly share costs, is to collect depth-time data, from which, performance may be estimated.

4.1.2 Task B- Identification and Publication of "Best Practices" for Geothermal Drilling (Task Leader: Steven Bauer, Sandia National Laboratories (SNL), USA)

The participants plan to identify and catalogue the technologies that have been most successful for drilling, logging and completing geothermal wells. A complete Handbook will contain drilling practices for both direct use (low temperature) and electrical generation (high temperature) wells. The complete Handbook will eventually include, but not be limited to: design criteria for the drilling and completion programs, drilling practices for cost avoidance, problem diagnosis and remediation during slimhole drilling, trouble avoidance, well testing, geophysical logging, and wellbore preservation.

4.1.3 Task C- Advanced Drilling Collaboration (Task Leader: Stephen Bauer, Sandia National Laboratories (SNL), USA)

The participants will monitor and exchange information on drilling technology development and new applications in their respective countries. The participants will also identify activities and projects for collaboration, and then collaboration plans will be developed. For example, the participants anticipate identifying opportunities to field test in one country a technology/system that is being developed in another participant's country.

4.2 Work Performed in 2007

4.2.1 General

- Completed written Annex VII reports for the spring and autumn ExCo Meetings, the spring Annex VII meeting and the 2006 GIA Annual Report
- Conducted spring Annex VII meeting in Nice, France

4.2.2 Review of Annex VII Meeting (Nice, France)

Annex VII met in Nice, France, on 21 March 2007. The following is an update of Annex VII activities presented and discussed at this meeting, plus those that took place to the end of the year. The US DOE Geothermal budget was diminished significantly; consequently, activities by the Annex Leader were limited primarily to reporting.

Key Points from Meeting:

- Each of the five active participants in the Annex was represented: Iceland, Mexico, New Zealand, European Commission and the United States
- Each Task was discussed, with a view towards maintaining a substantive path forward

Task A: At the meeting, it was announced that Jaime Vaca moved to a new position. A replacement for the CFE Task activities has not yet been appointed. A costing data base system has been partially developed by CFE. The system is spreadsheet based and includes details of cost components of wells as planned and constructed. New CFE wells were incorporated into the data base system first; and older wells will be entered into the data base in time. Work on the database is suspended until a new task leader is identified. The successful completion of the effort, however, requires time, thought and analysis. Notable progress in this Task was made with well data from Mexico, New Zealand and Ormat contributed to the data base.

Task B: The first draft of the Drilling Handbook was developed. Further work is required and assistance is being solicited.

Task C: Requests for collaboration have been received, discussed, and information exchanged between principal investigators. Potential for Technology sharing continues:

- Web Connection was made between ENGINE and GIA
- Web Connection was made between HITEN and GIA
- A collaborative effort between the US and Geodynamics (Australia) in the form of sharing a downhole high temperature tool was planned. At the last minute, deployment of the tool was cancelled for technical reasons
- Stephen Bauer visited Switzerland to discuss geothermal drilling considerations with Ladsi Rybach, Geowatt, and the Technical University

The Annex VII Nice meeting was extremely well attended, with 22 participants.

Technical and Programmatic Presentations at the Nice Meeting: During the Annex VII meeting, a presentation was made in the spirit of fostering international communications and technology sharing:

"US Geothermal Drilling Technologies Update", S. Bauer (SNL, USA). This presentation highlighted Sandia National Laboratories activities in high temperature electronics and drilling dynamics.

Notification of the ENGINE workshops and conferences: to be held during the next two years:

2007

- 08 November- Risk analysis for development of geothermal energy - Utrecht, The Netherland
- 13 September- Increasing policy makers awareness and the public acceptance - Milos Island, Greece

2008

- 13 February- Final conference - Vilnius, Lithuania

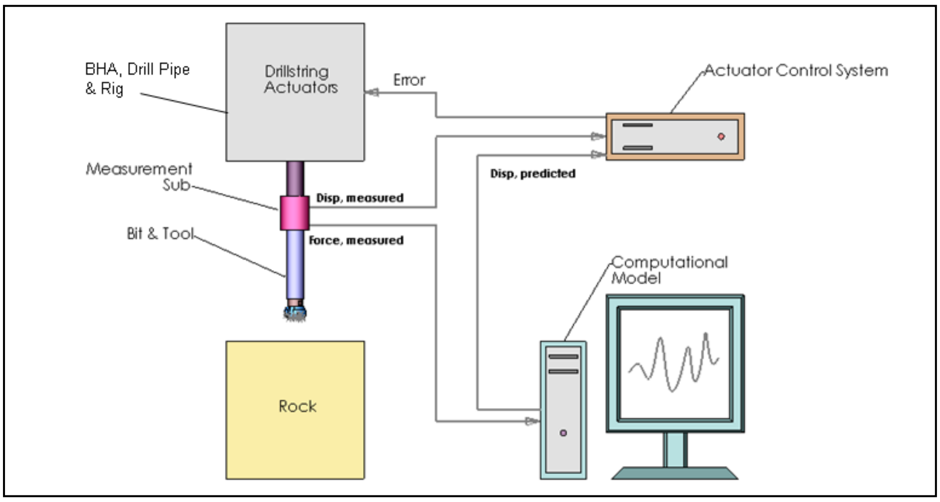

Figure 4.1 Drilling Dynamics Simulator Concept (Raymond, *et al.*, 2007).

Figure 4.2 First generation realization of Drilling Dynamics Simulator in Sandia's Hard-Rock Drilling Facility (Raymond, *et al.*, 2007).

4.3 Highlights of Annex Programme for 2007

Extreme interest in the Annex has developed as judged by attendance at Annex VII meetings; increased participation is anticipated.

4.4 Work Planned for 2008

Increased participation in the Annex is being solicited and is anticipated.

4.4.1 Task A- Compile Geothermal Well Drilling Cost and Performance Information

The US will continue to solicit drilling performance/cost data from operators. The Annex VII participants will begin to discuss, assimilate and analyze information. Reports will be made to the Executive Committee.

Output: A more comprehensive compilation of cost data received.

4.4.2 Task B- Identification and Publication of "Best Practices" for Geothermal Drilling

Develop full draft of the Handbook for review and comment to a limited set of reviewers.

Output: Report to Executive Committee.

4.4.3 Task C- Advanced Drilling Collaboration

Solicit, coordinate, and plan international collaborations of technology sharing. Examples of such collaborations include: instrumentation demonstrations and evaluations, information exchanges through visits to foreign sites (ongoing for each year). Organize international exchange program, possibly (and in part) in association with other international travel, for information exchange and sharing.

Output: Report to Executive Committee.

4.5 Outputs for 2007

Publications for 2007 included:

Blankenship, D. A., A. J. Mansure, J. T. Finger (2007) Drilling and Completion Technology for Geothermal Wells. *Geothermal Resources Council Transactions, Vol. 31*.

Raymond, David W., Y. Polsky, S. S. Kuszmaul, Sandia National Laboratories, and M. A. Elsayed (2007) Laboratory Simulation of Drill Bit Dynamics Using a Model-Based Servo-Hydraulic Controller. *Proceedings of the 26th International Conference on Offshore Mechanics and Arctic Engineering*, June 10-15, 2007, San Diego, California, USA.

4.6 Websites Related to Annex VII Work

- Sandia geothermal programme: http://www.sandia.gov/geothermal
- National Renewable Energy Laboratory: http://www.nrel.gov/geothermal/
- ENGINE: http://engine.brgm.fr

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IEA GEOTHERMAL R&D PROGRAMME

Chapter 5

Annex VIII- Direct Use of Geothermal Energy

Figure 5.1 Snorralaug in West Iceland, historical thermal pool from 13th century (Photo Einar Gunnlaugsson).

5.0 Introduction

The direct use of geothermal heat and water dates back thousands of years and direct use continues today. The Romans, Chinese and Native Americans used hot mineral springs for bathing, cooking and for therapeutic purposes. Today geothermal water is used for many applications that require heat such as heating buildings, either individually or whole towns, raising plants in greenhouses, drying crops, heating water at fish farms, and several industrial processes. To promote further direct use of geothermal water and to learn from each other it was decided to establish an Annex on this subject.

The Direct Use of Geothermal Energy Annex was initiated in 2003, when the agreement entered into force.

The objectives of Annex VIII are to:

- Define and characterize the direct use applications for geothermal energy, with emphasis on defining barriers to widespread application
- Identify and promote opportunities for new and innovative applications
- Define and initiate research to remove barriers, to enhance economics and to promote implementation
- Test and standardize equipment
- Develop engineering standards
- Define suitable forms to present data geographically on the web

The Contracting Parties who officially agreed to participate in this Annex as of the end of 2004 were: Iceland and Switzerland. In 2005, Japan, New Zealand, the USA and Korea confirmed their participation in the Annex, increasing the total participation to six countries. Non-GIA Members have shown interest in participating, however, the GIA is initially pursuing avenues for them to join the GIA before allowing participation.

The Operating Agent for Annex VIII is The Federation of Icelandic Energy and Waterworks, Reykjavik, Iceland, and the Annex Leader is Einar Gunnlaugsson.

5.1 Tasks of Annex VII

Initially five tasks were defined for this Annex and work has started for four of these tasks. In 2007 it was decided to add a new task, Task F, dealing with publication and availability of data presented geographically on the web.

5.1.1 Task A- Resource Characterization (Task Leader: Hirofumi Muraoka, National Institute of Advanced Industrial Science and Technology (AIST), Japan)

The aim of this task is to define the available geothermal resources in the various participating countries.

5.1.2 Task B- Cost and Performance Database (Task Leader: Yoonho Song, Korea Institute of Geoscience and Mineral Resources (KIGAM), Republic of Korea)

This task focuses on collecting, analyzing and disseminating the characteristic cost and performance data for installations in participating countries, with emphasis on establishing a baseline and then validating the improvements from innovative components and better designs.

5.1.3 Task C- Barrier and Opportunity Identification (Task Leader: Yoonho Song, Korea Institute of Geoscience and Mineral Resources (KIGAM), Republic of Korea)

Based on Tasks A and B, this task will define the barriers which must be overcome to gain widespread use of geothermal heat for various applications. The research activities necessary to take advantage of these opportunities will also be defined and initiated. This task has been operated in parallel with Task B.

5.1.4 Task D- Equipment Performance Validation (Task Leader: To be appointed)

The aim of this task is define and test critical and innovative equipment; such as submersible and line shaft pumps, compact heat exchangers, down-hole heat exchangers, non-metallic piping, heat pumps and other equipment to characterize performance for various applications and for various geothermal brines. Work in this task has not yet begun and no task leader has been appointed.

5.1.5 Task E- Design Configuration and Engineering Standards (Task Leader: John Lund, Oregon Institute of Technology (OIT), USA).

The work here is to develop and characterize standardized designs for various applications, with the goal of minimizing the engineering related to various applications. Develop engineering standards for designs, equipment and controls.

5.1.6 Task F- Publication and Geographical Presentation on the Web (Task Leader: Einar Gunnlaugsson, Orkuveita Reykjavikur, Iceland).

The aim of this task is to define a suitable form to present data on direct use of geothermal water geographically on the web.

5.1.7 Expected Results

The primary results of Annex VIII will be improvements in systems and equipment, reduction in cost of delivered heat and an increase in the number of direct use applications. Cooperation between the countries and increased exchange of technical and scientific information within the field of direct use of geothermal energy will be beneficial for all partners. Specifically, the results of this Annex shall include:

- Development of an international database on direct use applications by each of the participating countries. The database will be based on standardized instruments and reporting techniques
- Reports on state-of-the-art in direct use of geothermal energy, including areas needing improvement
- Cooperative research to accomplish the needed improvements
- Participant reports on the status of research and development in new and improved technology that shall be presented in appropriate journals and meetings

5.2 Work Performed in 2007

An Annex VIII meeting was held in 21 March 2007 in association with the 17th ExCo meeting held in Nice, France. Participants from all the countries attended the meeting. The work conducted is reported by Task.

5.2.1 Task A- Resource Characterization (Temperature and Chemistry)

First evaluation of data on temperature of the geothermal manifestations and chemistry from Korea, Iceland, Japan and USA has been made. The results show that differences in chemistry are related to the different rock types and geological environments. A paper derived from this work on discharge temperature of geothermal water in Japan has been published:

Muraoka, H., K. Sakaguchi, S. Nakao, and K. Kimbara (2006) Discharge temperature–discharge rate correlation of Japanese hot springs driven by buoyancy and its application to permeability mapping. *Geophys. Res. Lett*., 33, L10405, doi:10.1029/2006GL026078.

(http://www.agu.org/pubs/crossref/2006/2006GL026078.shtml).

5.2.2 Tasks B and C – Barriers and Opportunities (Costa and Performance)

The first evaluation of the Questionnaire for Direct Use of Geothermal Energy with data from Japan, Korea, New Zealand, USA, Iceland and Switzerland has been done. Revision of the questionnaire is needed especially to obtain realistic information regarding cost and performance.

5.2.3 Task E- Design Configuration (Engineering Standards)

The collection of available information has begun and a list of references regarding published material is available.

5.2.4 Task F- Publication and Geographical Presentation on the Web

The aim of this task is to define a suitable form to present data on direct use of geothermal water geographically on the web. Tests have been made to present data in files which can be opened on the web through Google Earth. This method looks promising and further work will be conducted to develop the method further.

5.3 Work Planned for 2008

5.3.1 Task A- Resource Characterization (Temperature and Chemistry)

Proposed next steps:

- Include data from New Zealand, Switzerland and the USA. The data will be evaluated similarly as other data
- Interim results to be presented at RE2008, Busan, Korea
- Define how resource characteristics are affecting direct use of the resources

5.3.2 Tasks B and C- Barriers and Opportunities (Costa and Performance)

The questionnaire requires revision and further evaluation of the data collected will be performed. If new participants join Annex VIII, they will be asked to complete the questionnaire and the new data will be compiled.

Proposed next steps:

- Finalize update of the questionnaire
- Further evaluation of the results of the questionnaire
- Send questionnaire to new countries participating in Annex VIII

5.3.3 Task E- Design Configuration (Engineering Standards)

Proposed next steps:

- Collection of available descriptions will continue and be listed, regardless of language
- Proposed next steps
- To compile a list of engineering standards and design configurations as well as guidelines for best practice regardless of languages
- Have the list available at the Web

5.3.4 Task F- Publication and Geographical Presentation on the Web

Proposed next steps:

- Continue the work in Iceland regarding Google Earth
- Guidelines regarding files for Google Earth
- Define minimum data for different files
- Try to get webpage on material selection related to the chemistry of water translated to English (Web: http://www.lagnaval.is)

5.3.5 Expected Outputs for 2008

- A simple standardized database will be identified that can be used to show the direct use applications by each of the participating countries
- Paper on resource characteristics to be presented at RE2008, Busan, Korea
- Annex VIII meetings are scheduled in association with the ExCo Meetings to be held in Paris, France (April 2008) and in Busan, Korea, in October 2008.

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NATIONAL & INDUSTRY ACTIVITIES

Chapter 6

A Synopsis of National and Industry Activities

Steamboat Yankee geothermal power plant, Nevada.

6.0 Introduction

This chapter provides a summary of the geothermal situation in the eleven Member Countries, the EC, and the three industry Sponsor Members; and is based on the reports presented in Chapters 7-21. The Member Country reports include information on national policy; current status of geothermal energy use, both for electricity generation and direct use; market development; stimulation and constraints; economics; research activities; education and international cooperation; while the Sponsor reports contain information on the companies and their activities.

The geothermal installed capacity and electricity generated in the GIA Member Countries and the EC in 2007 are provided in Table 6.1, and the geothermal direct use installed capacity and energy used are presented in Table 6.2. Estimates of equivalent fuel oil savings and avoided CO_2 emissions are presented in Table 6.3.

6.1 The Context

Geothermal energy is used for electricity generation and for direct heat applications such as bathing and swimming, district and space heating, industrial processes, agricultural drying, green house and aquaculture pond heating, and snow melting. In 2007, 24 countries generated electricity from geothermal resources, with a total installed capacity in excess of 10,026 MW_e (Bertani, 2007, revised with 2007 GIA data) generating about 56,782 GWh/yr (most current available generation data from Bertani (2005), revised using 2007 GIA data). Geothermal energy provided an average of about 9.2% of national capacity and 11.9 % of national generation in those 18 countries with non-negligible development, or approximately 0.3% of the 18,930 TWh of electricity generated worldwide in 2006 (IEA, 2008). Though worldwide geothermal capacity grew relatively steadily, at about 200 MW_e/yr (Figure ES1) for the 25-year period 1980-2005; growth has begun to accelerate in the past few years, and was approximately 265 MW_e for the 3-year period 2005-2007; and expectations are that the installed capacity could reach 11-13.5 GW_e by 2010 (Bertani, 2007; Gawell and Greenberg, 2007).

In 2007, GIA country members had almost 6,200 MW_e of installed capacity and generated about 37,200 GWh/yr (Table 6.1), or about 62 % and 66 % of total global geothermal capacity (2007) and generation (2005), respectively. Geothermal contributed an average of about 4.8 % of Member's national capacity (5.4 % including Guadeloupe Island) and 7.2 % (7.5 % if include Guadeloupe Island) of their generation.

Table 6.1 Geothermal power installed capacity and electricity generation in GIA Member Countries and EC for 2007.

Country	Installed Capacity [MW_e]	Annual Electricity Generated [GWh/yr]	% of National Capacity	% of National Energy
Australia	0.12	1.8	Negligible	Negligible
EC[a]	855	5,693[b]	-	-
France (Guadeloupe)	15	95	9 (for Island*)	~ 9 (for Island*)
Germany	3.23	0.4	Negligible	Negligible
Iceland	485	3,600	20.5	29.9
Italy	810	5,233	1.0	1.8
Japan[¶]	535.26	3,102	0.2	0.3
Mexico	958	7,393	1.9	3.3
New Zealand	452	3,272	4.9	7.7
USA	2,936.5	14,500	0.3 [e]	0.3
Total[d]	**6,195**	**37,197**	**5.4 [c]** **4.8[¥]**	**7.5 [c]** **7.2[¥]**

[a] Data for 2006, does not include Iceland; [b] Geothermal Energy Barometer EurObserv'er 49, Sept 2007); [c] Average % of 7 GIA Member Countries with non-negligible generation, including Guadeloupe Island; [d] Totals exclude EC values; [¶] Year to March 2007; * from Bertani (2007); [¥] Value excludes Guadeloupe Island; [e] USA total installed capacity as at 31 Dec 2007: 1,089,807 MW- http://www.eei.org/industry_issues/industry_overview_and_statistics/industry_statistics

There is huge potential for growth in geothermal electricity generation incorporating conventional development of hydrothermal systems and new methods for developing enhanced geothermal systems (EGS); deep (>3 km) very high temperature (400-600 ºC) and low temperature (70-170 ºC) resources. Interest is rapidly growing in geothermal as its capabilities as a renewable energy resource that can provide reliable, baseload electricity are becoming more widely recognized. Currently, development is accelerating, and it is possible that several percent of the total global electricity could be provided with geothermal energy by 2050.

As stated above, geothermal energy is used in a wide variety of direct heat applications. This diversity and especially the worldwide accessibility for utilizing the lower temperature range (heat pumps, space heating, hot pools, *etc*.), help explain the current very rapid growth in use. Access to reliable worldwide data on direct use is difficult to obtain, with the most comprehensive especially collected and published for the World Geothermal Congresses (WGC), which are held every 5 years. The most recent data, obtained for the WGC 2005, estimated the global installed thermal power to be about 28,269 MW_{th}, with 72 countries reporting the use of 273,372 TJ/yr, or 75,940 GWh/yr (Table ES4) (Lund, *et al*., 2005). The installed thermal power nearly doubled between 1995 and 2000, and again between 2000 and 2005 (*ibid.*), accompanied by correspondingly large increases in utilization (Table ES4). Significant growth has continued in GIA Member Countries through 2007, and major expansion is expected to carry on worldwide well into the future. Details will become available following the WGC 2010.

Data for 2007 are reported for GIA members in Table 6.2. In a few cases, the data presented are from 2005 (Lund, *et al*., 2005) or Antics and Sanner (2007), or has been estimated based on indicative rates of growth. The total installed capacity was about 20,057 MW_{th} with approximately 154,560 TJ/yr of energy used. This growth of about 23 % in installed thermal power and 12 % in energy use since 2006, can be partly explained by the addition of data from France, who became a Member Country in 2007. However, Germany, Iceland, Korea and the USA did experience noteworthy growth in utilization.

Table 6.2 Geothermal direct use in GIA Member Countries in 2007.

Country	Installed Thermal Power (MW_{th})	Annual Energy Used (TJ/yr)
Australia	130	3,672
EC[§,1]	2,236	19,470[¶]
EC[§,2]	7,328	na
France**	1,230	6,485[§]
Germany	[952]	8,280[4]
Iceland	(1,844)	26,000
Italy	[650]	8,000
Japan*	3,385	41,518
Mexico	164	(1,932)
New Zealand	(308)	9,800
Republic of Korea	107	993
Switzerland	880	6,063
USA***	10,897	41,817
Total for GIA[3]	**20,547**	**154,560**

[1] Excludes Switzerland and Iceland and excludes heat pumps;
[2] Heat pumps only, excludes Switzerland and Iceland; [3] Total excludes the EC;
( ) = from Lund, *et al*. (2005); [ ] = from Antics and Sanner (2007)
[4] From AGEE Stat (2008); [§] 2006 data, EU 25; * Year to March 2006;
[¶] GIA conversion factor: 1 TJ (heat) = 35.2 toe (Mongillo, 2005);
** Data for 2006 and includes heat pumps (922 MW_{th});
*** Estimated using 8%/yr increase on 2005 values; na = not available

In 2007, the GIA Member Countries are estimated to have saved the equivalent of approximately 14.8 Mtoe and avoided about 48 Mt of CO_2 emissions, assuming total fuel oil replacement (GIA conversions (Mongillo, 2005)) (Table 6.3). The very large "apparent decrease" in 2007 equivalent fuel oil savings for geothermal electricity generation compared to 2006 is mainly due to the use of the GIA relation (*ibid.*): 1 GWh = 253.4 toe, rather than that of the IEA: of 1 GWh = 860 toe. The decision to use the GIA value was based on the clarity of its derivation and agreement amongst the geothermal community (*ibid.*).

Table 6.3 Equivalent fuel oil savings and avoided CO_2 emissions in 2007.

Country	**Equivalent Fuel Oil Savings (Mtoe) §**			**Avoided CO_2 Emissions (Mt)¥**		
	Electricity Generation	Direct Use	Total	Electricity Generation	Direct Use	Total
Australia	negligible	0.13	0.09	negligible	0.42	0.44
EC#	1.44	0.69[1]	2.13[1]	4.65	2.21[1]	6.86[1]
France	0.02	0.23	0.28	0.08	0.74[1]	0.48[1]
Germany	negligible	0.29	0.33§	negligible	0.94	0.50
Iceland	0.91	0.92	1.83	2.94	2.95	5.89
Italy	1.33	0.23	1.50	4.28	0.91	3.00
Japan*	0.79	1.46	2.25	2.53	4.72*	7.25
Mexico	1.87	0.07	1.94	6.04	0.22	6.26
New Zealand	0.83	0.34	1.17	2.67	1.11	3.77
Republic of Korea	0	0.03	0.05	0	0.11	0.11
Switzerland	0	0.21	0.14	0	0.69	0. 45
USA	3.67	1.47	6.62	11.9	4.75	23.3
Total for GIA[2]	**9.42 [32.0]✱**	**5.38 [7.39]✱**	**14.8 [39.4]✱**	**30.4**	**17.6**	**48.0**

* Year to March 2006; [1] Excluding geothermal heat pumps; [2] Total excludes the EC
# Data for 2006
§ GIA conversions (Mongillo, 2005): for electricity generation: 1 GWh = 253.4 toe, assuming oil thermal power plants; conversion for direct use assuming oil thermal power plants: 1 TJ = 35.2 toe
¥ GIA conversions for direct use (*ibid.*): 1 GWh = 817 tonnes CO_2; 1 TJ = 113.6 tonnes CO_2 (*ibid.*)
na = not available; ✱ Totals using IEA conversion (1 GWh = 860 toe; 1 TJ ~ 47.8 toe)

Many of the characteristics of geothermal energy make it of significant importance for generating electricity and for direct use applications, including:

- *Extensive global distribution* makes it accessible to both developed and developing countries
- Can be *sustainably developed*
- *Provides baseload electricity supply*
- *Independent from weather and seasonal effects*
- *Low emissions of pollutants* such as particulates and greenhouse gases, especially CO_2
- *Indigenous*, so provides increased security and reduced dependence on imported fuels, hence lessens problems caused by their price fluctuations
- *Provides more diversity in energy supply*
- *Effective for distributed application* in both on and off grid developments, especially useful in *rural electrification* schemes

- *Contributes to more employment and opportunity for industry and the local population* through equipment supply and plant construction and servicing.

To maximize these benefits, the GIA recognizes the importance of disseminating information, improving environmental outcomes, improving conventional and developing new technologies (e.g., EGS), reducing drilling costs, promoting direct use applications, and encouraging long-term sustainable development strategies that will also contribute to the mitigation of climate change. Success will make geothermal a major provider of the world's future energy.

6.2 Review and Highlights of National Activities for 2007

6.2.1 Australia

Australia's potential electricity generating geothermal resources consist of hot sedimentary aquifers (HSA), e.g. hydrothermal groundwater resources, and hot rock (HR) plays, including hot dry rocks (HDR) and hot fractured rocks (HFR) that are likely to be fluid saturated. Geothermal generation in 2007 amounted to 1.8 GWh/yr from a 120 kW_e binary plant in Queensland. The total direct use installed capacity was about 130 MW_{th}, with an estimated use of 3,670 TJ.

Since 2001, when the first Geothermal Exploration Licence (GEL) in Australia was granted, to the end of 2007, 33 companies have joined the search for geothermal energy resources in 277 licence application areas covering ~219,000 km^2 (Figure 7.1a). This represents a 152 % increase in applications in the last year, though vast prospective areas still remain to be licensed. The associated work programs correspond to an estimated investment of AUS$ 852 million over the period 2002-2013, a 49 % increase since the end of 2006. In 2007, South Australia and Queensland Government state grants amounted to AUS$ 23.3 M. Federal Government funds committed to support meritorious Australian geothermal projects could exceed AUS$ 100 M in 2008. Nine Australian companies have reached a drilling phase in their geothermal projects to 31 December 2007 (Figure 7.2).

The Australian Geothermal Energy Group (AGEG) has a common interest in commercializing Australia's geothermal resources at maximum pace and minimum cost; and provides financial and intellectual support for Australia's membership in the IEA-GIA. At year-end 2007, the AGEG had 65 member organisations including: companies, Federal, State and Territory government agencies, and University experts. In 2007, the AGEG established 10 Technical Interest Groups (TIGs) (Table 7.2), whose activities correlate with the GIA's Annexes. The Australian Geothermal Energy Association (AGEA) was founded in 2007 to represent the geothermal power generation and direct use industries by providing a unified voice to key stakeholders, notably governments, on matters of policy affecting the geothermal industry.

6.2.2 European Commission

In March 2007, The European heads of state agreed to proceed with ambitious objectives to significantly reduce greenhouse gas emissions and increase renewable energy use. This agreement was based upon recognition that energy and climate change policies should operate together. The EU leaders agreed to a binding target of reduction of greenhouse gas emissions of 20 % by 2010 (compared to 1990 levels), 30 %, if other industrialized nations committed themselves to comparable reductions. Major elements of the plan include a binding target to raise the EU's share of renewables to 20 % by 2020, developing a European Strategic Energy Technology Plan to focus R&D efforts on low carbon technologies and boosting energy efficiency by saving 20 % of the EU's total primary energy consumption by 2020.

At the start of 2007, EU countries had 854.6 MW_e of installed power capacity and 9,564.6 MW_{th} thermal capacity, which included 7,328.3 MW_{th} of geothermal heat pumps.

The major new geothermal project is the High Temperature Tools and Instruments, HITI, project, which aims to develop geophysical and geochemical sensors and methods capable of working up to critical temperatures (> 380 °C). It is planned to test these new tools in the wells being drilled for the Iceland Deep Drilling Project (IDDP).

First power production began at the EC Soultz sous-Forêts project in France. A long period of testing of a 1.5 MW_e binary plant will begin, with fluid produced from GPK 2 and reinjected back into the reservoir through GPK 3.

6.2.3 France

As part of the new environmental consultation process on French environmental issues, "Grenelle de l'environnement", renewable energies will produce 20 % of energy consumption, consistent with the EC decision of March 2007 (see above).

BRGM created a new geothermal energy department to enhance its geothermal R&D activity and involvement. It will work together with the French Environment and Energy Management Agency (ADEME) to promote geothermal energy and its many uses.

The geothermal market experienced continued growth in geothermal heat pumps (GHPs), with 25 % installed in individual homes. New wells were drilled in the Paris Basin for Orly City's district heating scheme. The 1.5 MW_e binary power plant was delivered at Soultz.

The 15 MW_e power plant of Geothermie Bouillante in Guadeloupe provided France's total geothermal power of about 95 GWh. In 2006, 307 MW_{th} of direct use capacity and 922 MW_{th} of GHPs were operating.

The implementation of a global scheme for financial guarantees to cover investors against geological uncertainties has encouraged geothermal development in France. In addition, a new ADEME subsidy scheme for development of renewable energies was set up in 2007 (to go into action during 2008-2013), to provide up to 50 % of the cost of feasibility studies and up to 40 % for demonstration operations (i.e. operations with new concepts or less known technologies).

6.2.4 Germany

The German Government defined the basis of its integrated climate and energy package in 2007, in agreement with the EU's plans (see above). In 2007, renewables provided about 8.5 % of Germany's total final energy consumption, including 14 % of Germany's gross electricity use, exceeding the 2010 target of 12.5 %.

The development of combined geothermal heat (district heating) and power is currently essential for the economic success of a geothermal electricity generation project. The first industrial geothermal plant to provide heat (6,000 homes) and power (installed capacity 3 MW_e) year-round began operation in Landau, Pfalz, in November 2007. The total geothermal power generated in Germany in 2007 was about 0.4 GWh. The direct use of geothermal energy amounted to some 8,300 TJ (2,300 GWh) in 2007; about 2.6 % of Germany's heat supply, mainly from GHPs.

Due to the current demand for drill rigs by the petroleum industry, availability for geothermal development is poor, making prices high and even resulting in the postponement of projects.

Government funded R&D projects are being conducted at several locations. At Unterhaching, the stage was reached where a geothermal plant is planned to be connected in early 2008. At Groß Schönebeck, a new drilling fluid [water/oil mixture] was successfully used to drill the second well and successful hydro fracturing created a reservoir capable of providing flows required for the production of electricity. Experiments are being performed at Neustadt-Glewe to test materials and examine deposition. Germany has also been very active at Soultz with the EU and France, since 1986; and electricity production is scheduled to start in 2008.

6.2.5 Iceland

The policy of the Iceland Government is to increase the use of geothermal resources for power intensive industry and direct use, while keeping in harmony with the environment. A new Master Plan for potential power project will be presented to Parliament for consideration in 2010.

In 2007, a 33 MW_e low-pressure turbine was installed at Hellisheidi, increasing the total capacity to 123 MW_e; and at Svartsengi, a 30 MW_e turbine was installed raising the total capacity to 76 MW_e. Currently, 485 MW_e are installed on six geothermal fields, with 90 MW_e more to be installed at the Hellisheiði plant in 2008. Electricity production in 2007 amounted to about 3.6 TWh, or almost 30 % of Iceland's total generation. The high demand for favourably priced geothermal electricity (competitive with hydro) by power intensive industry has led to the current large-scale geothermal development in Iceland.

The total geothermal direct use was about 26 PJ, of which 19 PJ was for space heating of about 88 % of Iceland's homes!

One of Iceland's major research projects is the Iceland Deep Drilling Project (IDDP), which if successful, could usher in a new era with supercritical hydrothermal fluids being used for power generation and chemical extraction. The first IDDP well is expected to reach 800 m in 2008 and plans are to complete it to 3.5-4.5 km in 2009.

6.2.6 Italy

Electricity has been generated from geothermal resources in Italy since early in the 20th Century, with the first commercial unit installed at Larderello in 1914. In 2007, the installed capacity is 810 MW_e, and the generation amounted to some 5,230 GWh, which provides Tuscany with 25 % of its electricity. Geothermal energy is also used for heating applications, mainly for bathing, with about 8,000 TJ used in 2007.

AMIS plants, designed by Enel to remove H_2S and Hg, substantially reduce the environmental impacts of power development, making it more acceptable by the local people. In addition, new designs have been adopted to reduce noise and visual impacts of drill pads, gathering systems and power plants.

Research has focused on implementation of advanced techniques to reduced the exploration risk of deep wells (such as 3-D seismics) and methods for solving or mitigating the corrosion problems associated with chlorine present in the steam from deep wells.

6.2.7 Japan

Though Japan has abundant geothermal resources, their occurrence in national parks has restricted development, as had the removal of geothermal energy from Japan's "New Energy" category. However, the decision to reverse the last mentioned impediment was made in 2006, with binary plant developments being included back into "New Energy" starting in April 2008.

Since practical geothermal power generation began in 1966, Japan's installed capacity has reached 535.26 MW_e, increasing by 1.02 MW_e in 2007. The total generation (to March 2007) amounted to about 3,102 GWh. Direct use of geothermal energy in Japan is mainly for bathing, with the total installed capacity for all uses amounting to about 3,385 MW_{th}, and total use amounting to 41,518 TJ or 11,533 GWh.

NEDO's "Geothermal Development Promotion Surveys" in prospective geothermal areas is providing support and incentives by reducing survey risks, hence expediting private-sector development. In 2007, NEDO adopted two new fields, Ikedako (Kagoshima) and Sado (Niigata) for promotional surveying.

Though there are no current national full-scale R&D projects, research activities are supported by national universities, national institutes and the private sector with their own budgets. The major research areas include EGS and geothermal heat pumps. In 2007, phase 1 (feasibility) of the "Development of the Hot Spring Ecogene System", which will investigate the use of waste heat from high temperature hot springs, was adopted by NEDO in a competitive R&D grant competition.

As part of Japan's international cooperation, the Japan International Cooperation Agency (JICA) completed a master plan study for Indonesia's geothermal power development.

6.2.8 Republic of Korea

Though Korea's geothermal resources are characteristically low-temperature hot springs associated with localized, deep fractures, a high heat flow anomaly was recently discovered and is being investigated in the Pohang geothermal development programme. Geothermal heat pump installations are accelerating, with the total heat produced about doubling every year. This is strongly supported by the "Mandatory Public Renewable Energy use Act" which states that for all public buildings with areas > 3,000 m^2, more than 5 % of the total budget must be used to install renewable energy equipment. In 2007, the total installed capacity for direct use was about 107 MW_{th}, with energy use amounting to > 993 TJ.

The Korean Government provides good support initiatives and incentives for renewables, with geothermal subsidies of about US$ 9.5 M paid in 2007.

A large database containing thermal and physical properties of 1,516 rock samples collected from the entire country has been created. This information has helped in producing the first geothermal assessment of Korea, indicating a geothermal potential of 100,000 EJ down to a depth of 5 km.

Korea's R&D activities are concentrated on exploration and exploitation of low-temperature geothermal water for district heating and characterization of geothermal resources among other topics.

6.2.9 Mexico

Geothermal energy is the most important non-conventional renewable used in Mexico; with power generation the major use. Geothermal power generation began in 1959, and in 2007 the installed capacity was 958 MW_e, fourth largest in the world. Total geothermal generation was 7,393 GWh, or 3.3 % of the national total. Direct use installed capacity was 164 MW_{th}, used mainly for balneological purposes.

There are currently no economic incentives to encourage geothermal development, since geothermal is considered "conventional" power.

Research is mainly aimed on development and exploitation of resources for electricity generation, so concentrate on improving knowledge of fields and the ability to predict future behaviour under continued exploitation.

Mexico continued a project for evaluating low and intermediate enthalpy geothermal resources in Mexico and Central America in 2007.

6.2.10 New Zealand

The geothermal scene in New Zealand is extremely active, with development of an additional 600 MW_e feasible and commercially attractive over the next few years. Contact Energy and Mighty River Power have stated that they each expect to spend about NZ$ 1 billion in developing geothermal resources over the next 10 years.

In 2007, an additional 13 MW_e was commissioned at Mokai field and construction of a new 100 MW_e plant at Kawerau field and a 15 MW_e binary plant at Ngawha are proceeding. In addition, there has been significant successful drilling, with 40 MW_e of make-up steam provided at Ohaaki and additional steam used to fully load (additional 25 MW_e) the Poihipi station at Wairakei. Approvals have also been granted for the 130 MW_e at Rotokawa, a 234 MW_e plant to replace Wairakei 164 MW_e station and a new 23 MW_e station at Tauhara. Geothermal power development is very competitive without subsidies or carbon credits.

In 2007, the total installed capacity was 452 MW_e and some 3,272 GWh was generated. Geothermal provides about 4.9 % of New Zealand's capacity, but generates 7.7 % of the national total. The thermal energy used from geothermal resources was about 9.8 PJ, about half of which was for industrial process heating at the Kawerau Pulp and Paper Mill.

Geothermal research is focused on environmental issues and resource delineation; with industry research aimed at H_2S and arsenic removal, geotechnical drilling and modelling to investigate subsidence.

6.2.11 Switzerland

Switzerland continues to have steady growth in geothermal direct use, mainly from the advancement of geothermal heat pumps. GHPs are increasingly being installed in larger complexes for space heating, cooling and hot water production.

The Swiss Government programme, SwissEnergy, provides the general strategic framework for geothermal R&D. National targets include the reduction of fossil energy use by 10 % and the reduction of CO_2 emissions by 10 % (relative to 1990) by 2010.

The first stage of the Swiss geothermal resource assessment has indicated that in the northern part of the country (23 % of total area) there is about 1,000 EJ of heat in the crystalline basement, with 11 EJ recoverable over 30 years. Switzerland's Basel EGS project for combined heat and power was suspended due to induced seismic events in 2006 and 2007 with plans to investigate the causes and means for mitigation, *etc*.

In 2007, the total installed capacity for direct use was 880 MW_{th}, with about 828 MW_{th} from heat pumps. GHPs continued to grow extremely rapidly. The total heat production was about 1,684 GWh, with 1,342 GWh from heat pumps. The total drilled depth for installation of bore hole heat exchangers was 1,500 km! There are some financial incentives available to encourage GHP installation.

The Swiss Federal Office of Energy provides funding for geothermal R&D, including for projects such as the investigations for operational experience and optimization of the Zürich Airport Terminal E geothermal heating/cooling system and a geothermal fluid chemistry database.

Switzerland is very active in the IEA-GIA and within several R&D programmes of the EU's FP6.

6.2.12 United States

Geothermal development in the US continues to advance, with the Geothermal Energy Association (GEA) reporting 2,936.5 MW_e capacity on line in 2007. Geothermal power amounting to about 14.5 TWh was generated in 5 states: Alaska, California, Hawaii, Nevada and Utah.

The estimated installed direct use capacity for 2007 was 10,897 MWth, with a total energy use of about 41,817 TJ (11,612 GWh).

Some 3,314 MW_e is currently under development, including projects in their initial stages. A 13 MW_e plant at Raft River, Idaho, was commissioned in December 2007, though commercial power generation did not begin until January 2008. Nine projects amounting to 373 MW_e were under construction in California and Nevada. A joint Ormat-US Department of Energy (DOE) EGS project has begun at Ormat's Desert Peak development. Production could be increased from current 11 MW_e to 50 MW_e through EGS techniques.

This accelerated growth in geothermal activity is strongly supported by the Federal Production Tax Credit and the state-specified Renewable Portfolio Standards. In addition, the Energy Independence and Security Act of 2007 (EISA) has authorized the spending of up to US$ 95 M for a wide range of geothermal activities, though the appropriation was less and directed mainly to EGS, resulting in a limited group of other activities being supported. The restoration of funding for the US DOE's Geothermal Technologies Program (GTP); US$ 20 M for October 2007-September 2008, has also stimulated geothermal R&D after the previous few years of very low budgets. The GTP EGS studies are mainly aimed at demonstration of stimulation techniques, R&D to develop tools and techniques for application at temperatures up to 300 ºC, and communications and outreach.

The leasing and development of federal geothermal resources should accelerate with new leasing and royalty regulations released by the US Department of Interior. A Programmatic Environmental Impact Statement (PEIS) under development should also result in more geothermal projects progressing.

6.3 Review and Highlights of Industry Activities

6.3.1 Geodynamics

Geodynamics is Australia's largest geothermal company, with a specific focus on using enhanced geothermal systems (EGS) methods to extract heat from hot rocks. The company has raised some AUS$ 142 M in the 5 years to December 2007. Efforts are focused in the Cooper Basin area in South Australia, where its tenements cover 2,000 km^2, and three wells (Habanero 1, 2 and 3 [completed February 2008]) have been drilled to depths of 3.6 - 4.2 km into fractured granite, where temperatures are about 235 - 250 ºC.

Geodynamics successfully raised AUS$ 49.8 M to purchase a new drill rig capable of drilling to 6 km and to drill Habanero 3, which became Australia's first commercial scale geothermal well when it was completed in February 2008. Plans are to install a 2.5 MW_e power plant in early 2009. Plans are to drill the fourth well, Jolokia #1, about 9 km west of the Habanero site. Shallow drilling (300-400 m) in the Hunter Valley, New South Wales, has produced good temperature gradient results, justifying deeper drilling.

In 2007, Geodynamics Power Systems merged with Exorka dhf to create Exorka International Limited, giving Geodynamics 46 % shareholding in Exorka International. In addition, a AUS$ 105.6 M joint venture farm-in agreement with Origin Energy was completed in December 2007.

6.3.2 Green Rock Energy

Green Rock Energy Limited is a public listed company whose aim is to explore, develop and produce geothermal energy from both hydrothermal systems and EGS for electricity and direct use.

Green Rock's main activities are in Australia and Hungary. In 2007, the company participated in a joint venture with Hungarian Oil and Gas Company (MOL) and Enex (an Icelandic geothermal consulting company) to develop geothermal in Hungary for power and direct use. Two existing oil wells, which produce hot water, and are owned by MOL, were re-entered and flow tested, but proved to have non-commercial flow rates. However, the knowledge gained has encouraged the joint venturers to consider new project sites. To pursue the new sites, Green Rock has established a new geothermal company with MOL and Enex hf, called Central European Geothermal Energy Private Company Limited (CEGE). CEGE has chosen two areas, where MOL's existing wells encountered substantial hot water, as their initial focus.

Green Rock held exploration licences for three major project areas in South Australia: Olympic Dam, Patchawarra and Upper Spencer Gulf. The company owns 100 % interest in a 3,000 km^2 area at BHP Billiton's Olympic Dam mine, where hot granites at ~ 2 km depth have been located. Successful hydro-fracing in early 2008 has confirmed a compressional stress regime favourable for creation of a large heat exchange reservoir. Information obtained is being used to design a drilling and stimulation programme for two new deeper wells.

Exploration licences for the Patchawarra Trough area (1,483 km^2) in Cooper Basin were obtained in 2007. The zones of interest are the sedimentary formations that could have high flows of hot water capable of power generation. The Spencer Gulf project (1,938 km^2) is looking at the potential of using geothermal resources for providing green, renewable power for a distillation desalination plant in the Upper Spencer Gulf coast of South Australia.

6.3.3 Ormat Technologies, Inc.

Ormat Technologies, Inc. currently owns and operates 410 MW_e of geothermal and recovered energy (REG) generation facilities in four countries, including 301 MW_e of geothermal in the USA. Ormat has built over 900 MW_e of geothermal power installations (in addition to REG and solar) worldwide, and in 2007 had revenues of US$ 296 M, an increase of 10 % on 2006, with continued growth foreseen. The company has almost 1,000 employees, 400 in the US alone. About 100 geologists, resource managers and drilling engineers work to confirm and develop new geothermal fields. In 2007, Ormat established Geodrill, a wholly-owned drilling company, with 4 rigs to assist with increasing its geothermal production. In the past two years, Ormat has obtained leases for about 140,000 acres of land in California, Nevada and Alaska.

In a joint project with the US DOE at the Rocky Mountain Oil Test Centre, Ormat validated the feasibility of producing commercial electricity using hot water produced during the production of oil and gas. This is the first project of its type to provide on-site free power that will increase productivity and possibly longevity of existing US oil fields.

Ormat is working with research institutions to create an EGS at their Desert Peak geothermal field in Nevada. This project will help advance scientific understanding and applied technology and if successful, increase the commercial generating capacity of the field. Ormat is also working with the US DOE, GeothemEx and others with a US$ 3.4 M DOE grant to apply EGS stimulation methods at Ormat's Brady facility near Reno, Nevada, to increase permeability within the productive reservoir and enhance generation. A combined heat and power station with EGS injection, which uses an Ormat 3.2 MW_e unit, was commissioned at Landau, Germany, at the end of 2007.

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National Activities

Chapter 7

Australia

Habanero 3 flow test, Cooper Basin, Australia (courtesy of Geodynamics).

7.0 Introduction

The concern about climate change, rising costs of fossil fuels, and evidence of enormous hot rock resources are key factors stimulating growth in geothermal energy research (exploration), proof-of-concept (appraisal) and demonstration (pilot development) projects in Australia.

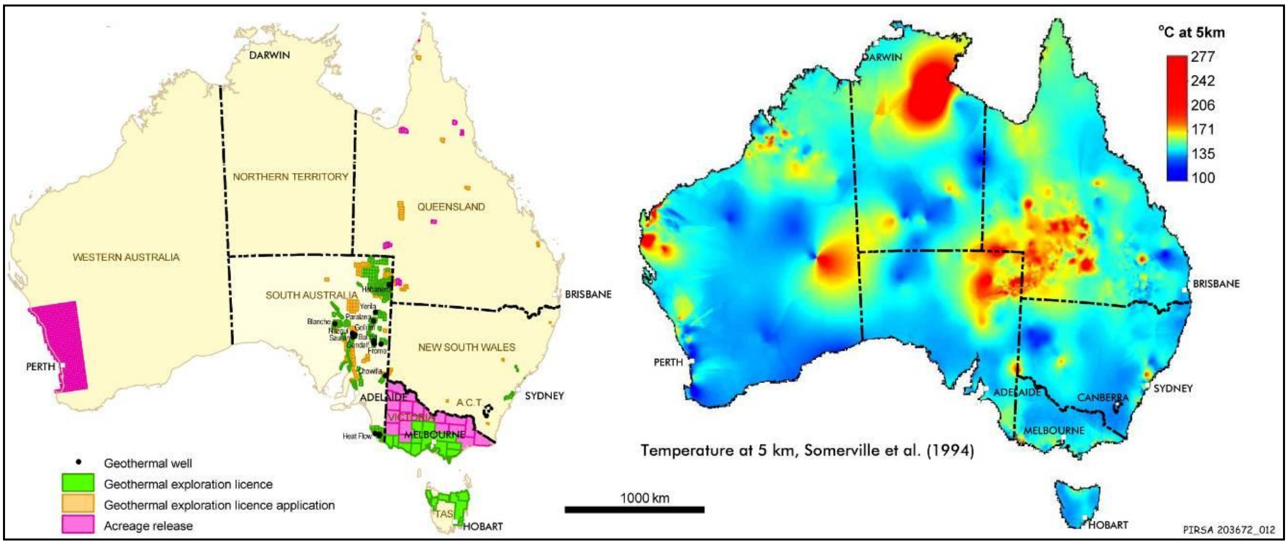

Figure 7.1a (left) Geothermal licenses, applications and gazettal areas as at 31 December 2007. **Figure 7.1b** (right) Extrapolated temperature at 5km. This map is based on available, in places sparse, data. See Section 7.2 for details.

Since the grant of the first Geothermal Exploration Licence (GEL) in Australia in 2001 through year-end 2007, 33 companies have joined the hunt for renewable and emissions-free geothermal energy resources in 277 licence application areas covering ~219,000 km^2 in Australia (Figure 7.1a). This represents a 152 % increase in applications in the last year, but leaves vast prospective areas still to be licensed for geothermal exploration energy (Figure 7.2). The associated work programs correspond to an estimated investment of AUS$852 million (49 % increase since year end 2006) over the period 2002-2013, and that tally excludes deployment projects assumed in the Energy Supply Association of Australia's scenario for 6.8 % (~5.5 GW_e) of Australia's baseload power sourced from geothermal resources by 2030. This progress follows encouraging geothermal drilling, temperature logging and flow testing programs in South Australia in the term 2004-2007, the dissemination of information that publicises the vast potential for Australia's geothermal resources, and the implementation of legislation to clarify investment frameworks to explore for and sell geothermal energy in a number of Australian jurisdictions.

Australia's geothermal resources that have considerable potential to fuel power generation fall into two categories: (1) Hot Sedimentary Aquifers (HSA) plays e.g. hydrothermal groundwater resources; and (2) Hot Rock (HR) plays, including Hot Dry Rocks (HDR) and Hot Fractured Rocks (HFR), which are likely to be fluid saturated. Where geothermal reservoirs are enhanced with fracture stimulation, HR resources constitute Engineered (Enhanced) Geothermal Systems (EGS). Currently, the only geothermal power in Australia is generated from a 120 kW geothermal energy plant located in Birdsville, Queensland; this sources hot hydrothermal waters at relatively shallow depths from the Great Artesian (Eromanga) Basin.

Current investment to explore for, and demonstrate the potential of, geothermal energy for power generation in Australia is focused on:

- HR EGS plays in the South Australian Heat Flow Anomaly (SAHFA) and the eastern half of Tasmania, and
- HSA plays in the Otway and Gippsland Basins in the States of South Australia and Victoria

Licences applied for (and yet to be granted), and further applications are expected to expand investment in HR EGS and HSA plays across Australia in 2008.

New companies (such as EnergyCore) were formed in 2007 to market and deploy direct use applications, ground-sourced heat pumps in particular.

In 2007, government grants from the Australian Federal South Australian State and Queensland State Governments for geothermal energy projects totalled AUS$23.3 million. In the term 1 January 2000-31 December 2007, the Australian Federal Government has awarded AUS$30.3 million to foster progress towards commercialising geothermal energy resources and cognate technologies. Details of these awards are provided in Table 7.2. Not reflected in these tallies is the Australian Federal Government's commitment made in 2007 to provide at least $50,000,000 in grants for meritorious proof-of-concept deep geothermal drilling and flow test projects as part of its $500,000,000 Renewable Energy Fund (REF). It is expected, that successful proof-of-concept HR projects will be eligible to compete on merit for further, material REF grants to cover a part of the costs to upscale and demonstrate HR power production. This will probably take government funds committed to support meritorious Australian geothermal projects to more than $100,000,000 in 2008.

In addition, the Australian Federal Government's five year funding (AUS$58.9 million) for an *Onshore Energy Security Program* (http://www.ga.gov.au/minerals/research/national/geothermal/index.jsp will enable the national geoscience and geospatial information agency (Geoscience Australia) to acquire precompetitive data and conduct research in support of geothermal energy exploitation. Geoscience Australia has consulted with industry, State and Territory governments and academic experts in developing its geothermal energy project plan.

To obtain a copy of a summary of Australian research and exploration projects as provided in the context of the AGEG's submission to Australia's stakeholder engagement assessment to inform the design of the national emissions cap and trading scheme, visit:
http://www.pir.sa.gov.au/__data/assets/pdf_file/0010/71389/AGEG_Submission_Garnaut_4April08.pdf

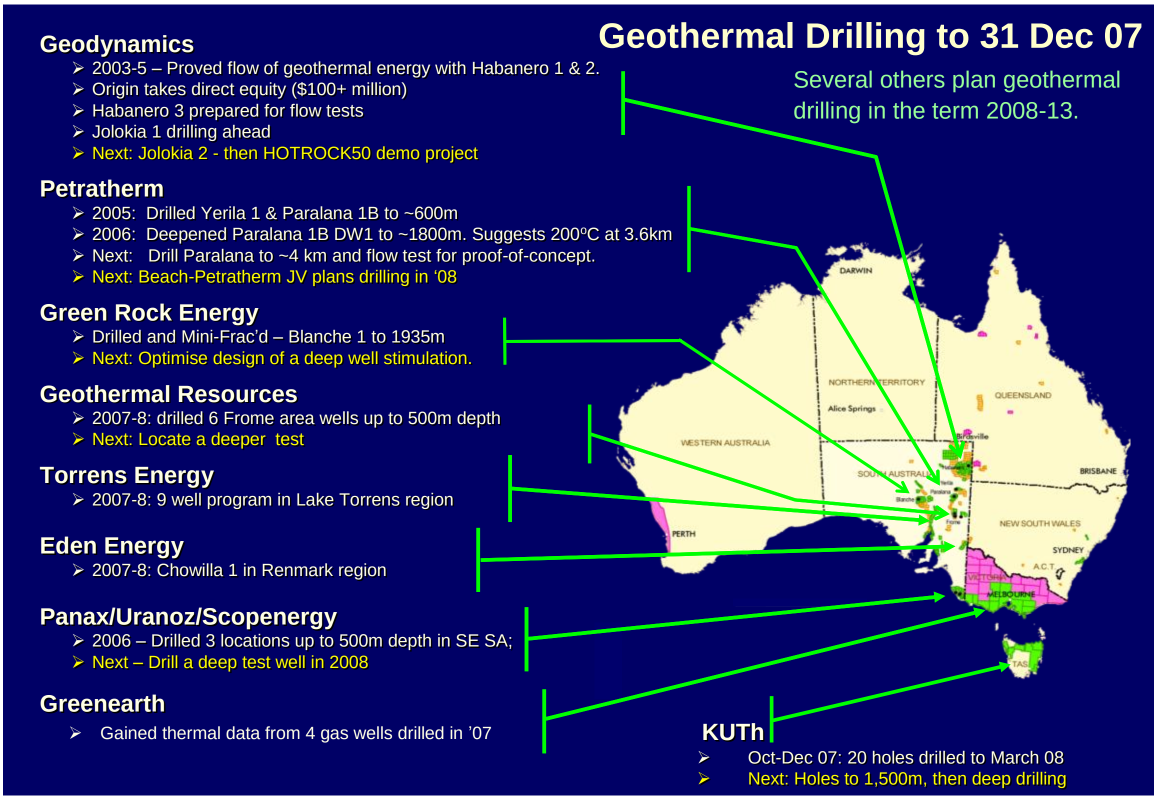

Figure 7.2 Geothermal drilling and downhole measurements to year-end 2007.

Nine Australian companies have reached a drilling phase in their geothermal projects to 31 December 2007. Several others have assessed pre-existing well and geophysical information as a precedent to drilling in their Geothermal Licences. Projects that have reached a drilling phase are summarised in the proceeding text and located in Figure 7.2.

7.1 Exploration and Proof-of-Concept Projects

7.1.1 Geodynamics Limited

The most significant advancement in terms of demonstrating the potential of Hot Fractured Rock (HFR) energy in Australia is Geodynamics' drilling, fracture stimulation and flow testing project near Innamincka in the Cooper Basin in northeast South Australia (Figure 7.2). To year-end 2007, Geodynamics had drilled two, is drilling a third, and has plans to drill a fourth well in early 2008. Habanero 1 and Habanero 2 were drilled to total depths of 4,421 m and 4,357 m, respectively. Well Habanero 3 was at a depth of 3,637 m at year-end 2007, with a planned total depth of 4,221 m. Jolokia 1, located 9.2 km WNW of Habanero 1 and beyond the extent of the fracture network drilled with Habanero 1, 2 and 3 (as defined during seismic monitoring during the stimulation of Habanero 1 and 2) has a planned total depth of 4,250 m. The granites in Jolokia 1 are expected to be about 10 °C hotter than at the same depths in the Habanero wells.

In 2005, flow of geothermal waters was achieved from Habanero 2 (20,000 ppm total dissolved solids) at a maximum rate of 25 l/s with a temperature of up to 210 ºC. The geothermal reservoir in the Habanero wells is a water-saturated, naturally fractured, basement granite (250 ºC at 4,300 m as reported by Geodynamics) with permeability that was effectively enhanced by fracture stimulation. Two fractured reservoir zones are present in the Habanero wells: a shallow, less permeable zone, at 4,200 m; and a deeper, more permeable zone, below 4,300 m. Geodynamics' Habanero 3 will have an 8 ½ inch hole through its HFR reservoirs (compared to 6 inch through reservoirs in Habanero 1 and 2).

The horizontal extension of stimulated reservoirs at the Cooper Basin site lends itself to multi-well developments. Geodynamics' HOTROCK 50 project entails a proposed 9-well, 50 MW_e power station. The 9 wells will be drilled 1 km apart at 4 km depth. This will entail 4 injection wells and 5 production wells forecast to yield 10 MW_e net per well from flows of 120 kg/s/well. This will be an important milestone for the demonstration of EGS from HFR in Australia and a stepping stone towards commercializing vast renewable and emissions-free geothermal energy supplies to meet Australia's future baseload energy requirements. Geodynamics believes that a successful flow test between Habanero 1 and 3 will lead to large-scale development of an extensive area of more than 1,000 km^2 where rock temperatures, stress conditions and rock properties are extensive and favourable for geothermal energy production.

To year-end 2007, two Australian Stock Exchange (ASX) listed companies with extensive upstream petroleum interests (Origin Energy and Woodside Limited) were cornerstone investors in Geodynamics. In November 2007, Origin agreed to take a 30 % equity in the Cooper Basin geothermal licences operated by Geodynamics, while it also retains roughly 10 % ownership of Geodynamics. Origin Energy's forecast expenditure in Geodynamics' Cooper Basin project is expected to be about AUS$100 million.

7.1.2 Petratherm Limited

Petratherm has drilled two wells to establish thermal gradients down to about 600 m above exceptionally high heat producing granites in South Australia. Results from both wells were encouraging, with the Callabonna and Paralana sites (Figure 7.2) respectively exhibiting 68 and 81°C/km thermal gradients. In June 2006, the phase-2 drilling program at Paralana was successfully completed with the geothermal test well being extended to 1,807 m. Temperature logging of the well suggests a world class thermal resource is located at Paralana, with extrapolations indicating 200 ºC at a depth of 3,600 m within insulating sedimentary rocks that are predicted to be susceptible to fracture stimulation. Petratherm refers to this play concept as Heat Exchange Within Insulator (HEWI). High heat producing basement rocks are a prerequisite for high quality HEWI plays.

Petratherm plans to create a HEWI system with the circulation of water between the two Paralana project wells to demonstrate hot rock EGS energy production from an initial small scale power plant that will supply up to 7.5 MW_e to a growing electricity market 10 km away at the Beverley Uranium Mine. This plan is the subject of a Memorandum of Understanding between Petratherm and the owners of the Beverley Mine, Heathgate Resources. An ASX-listed upstream oil and gas company (Beach Petroleum) has taken an equity position in the Paralana project. In November 2007, Petratherm signed a Letter of Intent for Ensign International Energy Services to secure a suitable rig and drill a deep Paralana well. Stimulation, flow testing and the drilling of a second well would follow, pending results of the first deep Paralana well.

7.1.3 Green Rock Energy Limited

Green Rock drilled Blanche 1 (Figure 7.2) to 1,935 m (718 m of sedimentary rocks and 1,216 m of homogenous hot granite) 8 km from the giant Olympic Dam mine in South Australia in 2005. The target granite is interpreted to persist to depths of 6,000 m over an area of about 400 km^2 and represents a potential geothermal resource in excess of 1,000 MW_e. Cores and wireline logs from Blanche No 1 suggested natural fractures exist. At year end 2007, Green Rock planned to undertake a mini-fracture stimulation program and then acoustic borehole imaging (to enable the analysis of fractures, post fracture stimulation) in Blanche 1 to inform the design of a deep well stimulation.

7.1.4 Geothermal Resources Limited

Geothermal Resources Limited is exploring a gravity low that could be a high heat producing granite associated with hot rock reservoirs predicted to be over 200 ºC at roughly 4,000 m depth in its Frome project area (Figure 7.2). Potential hot rock power markets for the Frome project are electricity consumers connected to the National Electricity Grid, some 120 km away at the township of Broken Hill. A number of active minerals exploration projects that lie between the Frome Project and Broken Hill are additional, potential future power markets. Frome 2, 3A, 5 and 9 were each drilled to depths of approximately 500 m in 2007, and have provided encouragement to commence a campaign of three shallow holes to be drilled in February 2008. Pending further encouraging results from the shallow drilling in 2008 and rig availability, Geothermal Resources will then drill deeper wells in the Frome area.

7.1.5 Panax Geothermal Limited

Scopenergy was acquired by Uranoz (an ASX-listed company changing its name to Panax Geothermal) in October 2007. In the first quarter of 2006, Scopenergy drilled 3 slim-hole wells in its Limestone Coast Project located near Millicent and Beachport in southeast South Australia (Figure 7.2) to determine geothermal gradients and confirm several large scale heat flow anomalies previously measured in 19 petroleum exploration wells and 26 water wells in the vicinity of its tenements. In mid-2006, the company completed temperature logging of its 3 wells: Heatflow 1A, 3A and 4. Poor recovery of core samples from unconsolidated sediments and highly variable lithology affected the reliability of thermal conductivity measurements and hence, estimates of heat flow. Panax is now considering whether to undertake a 3D seismic program to better define drilling targets prior to drilling its first production scale hole to reservoir depth in 2008.

7.1.6 Torrens Energy Limited

Torrens Energy drilled five wells of its nine well program in its Lake Torrens project area in late 2007 (Figure 7.2). Results from drilling those 5 wells to depths ranging 375 m to 601 m are encouraging, suggesting extrapolated temperatures of 248 °C (± 6 °C) to 202 °C (± 6 °C) at 5,000 m in the Lake Torrens project area. The aim of this program is to delineate heat flow trends as a precedent to locating deep proof-of-concept wells in proximity to the National Electricity Grid and power markets.

7.1.7 Eden Energy Limited

Chowilla 1 was drilled to 512 m in the Renmark-Tararra Trough, in the Riverland of South Australia, 40 km northeast of Renmark. Chowilla-1 is located to establish geothermal resources in proximity to transmission lines running to Adelaide and Broken Hill.

7.1.8 Greenearth Energy Limited

One of the cornerstone investors in Greenearth, Lakes Oil, is the operator of Petroleum Exploration Permits (PEPs) coincident with Greenearth's Geothermal Exploration Permits (GEPs) in the State of Victoria. Lakes Oil NL's Trifon-2 gas exploration well in 2004 (in PEP 157) in a petroleum exploration permit flowed 90 °C water to surface from 2,200 m within one of Greenearth's permits in the State of Victoria. Greenearth will also benefit from information obtained in four additional wells in petroleum permits coincident with its geothermal licences: Hazelwood-1 (PEP 166, total depth: 2,081 m) and Boola Boola-2 (PEP 166, suspended with a log total depth of 1,715 m); Alberton-1 (PEP 158, total depth: 998 m); and Napier High-1 (in an application area for a Petroleum Retention Licence, will be drilled after the grant of the relevant PRL). Greenearth has retained rights to deepen, core and log Boola Boola-2 from depths below 1,715 m.

7.1.9 KUTh Energy Limited

In October-December 2007, KUTh Energy started its systematic, shallow drilling program with up to 2 drill rigs on 3 shifts to drill a total of 33 wells in eastern Tasmania. To year-end 2007, five cored holes and a further three percussion pre-collars had been completed for a total of 1,203 m percussion and 762 m of diamond core. The shallow drilling campaign, when completed, will allow systematic down-hole temperature measurements across all of its +14,000 km^2 of tenements, leading to a high quality heat flow map. The heat flow map will allow optimal location of holes initially to 1,500 m, and then deep production holes into the thermal basement.

7.2 Highlights for 2007

Highlights and achievements to the end of 2007 include:

- Strong interest expressed by yet more new entrants into the geothermal sector bodes well for continued growth and competition. On 14 December 2007, Bell Potter Research published its review of the Australian geothermal energy sector and said, "*The geothermal energy sector of the Australia Stock Exchange (ASX) currently consists of nine stocks with a combined market capitalisation of over $700 m. The sector leader, Geodynamics (ASX code: GDY), represents $435 m of this total. GDY listed on the ASX in 2002 and has delivered to shareholders a capital return of just over 300 % - or a 30 % compounding average annual return - but is still a number of years away from full commercialisation. We expect a 10 th company to join these ranks in the March quarter of 2008 when Greenearth Energy (ASX code: GER) completes its IPO." "There are in fact 27 registered companies with geothermal exploration and development in Australia, collectively holding 179 geothermal exploration licenses and with expenditure plans of $700 m. The importance of South Australia's potential is highlighted by the fact that $570 m of these budgets will be spent in this State. The following table (Table 7.1) shows the nine listed companies, plus one imminent IPO, which we believe is about to close its fund raising, with a listing expected in January 2008. The table is ranked in order of market capitalization, which highlights the fact that Geodynamics was the pioneer in the sector, and has the most advanced project at Habanero in the Cooper Basin. However, a number of other* *companies are rapidly proving up their own particular projects, and it is impossible to predict which company will be the first to declare a commercially viable project, or indeed, when this will occur. As stated in the introduction of this report, the industry is at an early stage of development, and is speculative in nature. The report is for information purposes only, and should not be construed as a recommendation for the geothermal energy sector."*

- Passage of legislation in Western Australia (with acreage release planned for January 2008) and draft legislation for Northern Territory that will stoke the sectors' growth

- At year-end 2007, 33 companies have joined the hunt for renewable and emissions-free geothermal energy resources in 277 geothermal licence areas covering ~219,000 km^2 in Australia. This represents a 152 % increase in geothermal licences in the last year. Most (235 or 85 %) of the areas applied for are located in the state of South Australia. The balance include: 14 Geothermal Exploration Permits (GEPs) in the state of Queensland, 12 Geothermal Exploration Permits (GEPs) in the state of Victoria, 10 Exploration Licences (ELs) for geothermal exploration have been applied for in the state New South Wales; and 6 Special Exploration Licence (SEL) have been granted or applied for in the state of Tasmania

Table 7.1 The nine ASX listed companies, plus one imminent IPO.

Company	Code	Share Price AUS$	AUS$ Million Market Cap.	AUS$ Million Cash	Comment
Geodynamics	GDY	$2.04	$434.5	$16.5	Closest to proof of concept in South Australia
Eden Energy	EDE	$0.46	$112.5	$12	Focus on hydrogen R&D - Hot Rocks IPO in 2008
Petratherm	PTR	$1.15	$81.3	$7.4	South Australian heat anomaly, Spain & China
Torrens Energy	TEY	$0.63	$49	$5.6	South Australian heat anomaly
Geothermal Resources	GHT	$1.28	$44.6	$1.9	South Australian heat anomaly
Greenearth Energy	GRE	$0.30	$25	$14	Current IPO based on Victorian Hot Rocks
Panax Geothermal	PAX	$0.18	$22.9	$10	South Australian heat anomaly, India & Kyrgyzstan
Green Rock Energy	GRK	$0.11	$22.8	$1.7	South Australian heat anomaly & Hungary
KUTh Energy	KEN	$0.32	$17.2	$5.9	Tasmanian Hot Rocks play
Hot Rock	HRL	$0.22	$14.1	$4.9	Victorian Hot Rocks play

Source: Bell Potter

- Over AUS$852 million (US$783 million) in work program investment is forecast for the period 2002-2012. Approximately AUS$125 million (US$115 million) of this forecast was invested in the term 2002-07; 99 % of which was spent in South Australia. This current forecast (for the term 2002-2012) represents an increase of AUS$283 million (US$259 million) over the forecast for the same period stated in the 2006 annual report. These forecasts exclude capital expenditure associated with demonstration power plants.

- 136 exploration licences covering over 62,182 km^2 were applied-for in South Australia

- 13 tenements covering over 7,000 km^2 were released for tender in the state of Queensland in November 2007, with a closing date for work program bids in February 2008

- 19 permits covering 154,000 km^2 are set to be released for tender in Victoria offered in April 2008

- The *West Australian (WA) Petroleum and Geothermal Energy Resources Act 1967* was set for passage at year end 2007, leading to offers of 495 licence application areas for work program bidding in Western Australia in January 2008

- In February 2007, Geodynamics Ltd. purchased a purpose built rig to progress its geothermal operations. The ‘Lightening Rig” arrived in Brisbane in July 2007 and

  - Commenced drilling Habanero 3 in mid-2007

  - An AUS$17 million capital raising to progress its Habanero proof-of-concept project

- In the first quarter of 2007, Petratherm Ltd. announced a MoU with Heathgate Resources Ltd. to jointly evaluate the use of geothermal power from the Paralana project to meet the growing energy demand at Heathgate’s Beverley Mine in South Australia. Beach Petroleum Ltd is now a participant in the Paralana project.

- Upstream petroleum companies sustained interest in geothermal projects. To year-end 2007:

  - Woodside Ltd. and Origin Energy Ltd. sustained significant cornerstone equity in Geodynamics Ltd.

  - Origin Energy Limited has taken a 30 % equity position in Geodynamics’ South Australian geothermal tenements together with 30 % of the Lightning drilling rig. In addition to its 30 % share of on-going project expenditure, Origin will contribute up to AUS$105.6 million towards all project cash costs comprising $96 million plus an additional $9.6 million should Geodynamics, as Operator, complete its Stage One ‘proof of concept’ phase by 31 March 2008 within a defined budget

  - Beach Petroleum entered into a joint venture arrangement to participate in Petratherm’s Paralana project

  - Greenearth Energy Ltd. became the first geothermal energy licence holder to announce it had gained access to petroleum wells (to measure temperatures, *etc.*) and petroleum well samples (to measure conductivities, *etc.*) by paying some costs for relevant operations in a Hot Sedimentary Aquifer play. Mutually advantageous sharing of equipment, access to well bores and access to well samples are expected to become a standard steps towards to efficiency gains while reducing uncertainties for both geothermal and upstream petroleum proof-of-concept projects

  - Upstream petroleum companies bring considerable commercial and operational (especially deep drilling) experience to the geothermal sector

- As noted in the preceding text, drilling to test hot rock play concepts by geothermal licence holders was undertaken in 2007 by Geodynamics Limited., KUTh Energy Limited., Geothermal Resources Limited, Eden Energy Limited and Torrens Energy Limited

- Areas where significant, new subsurface temperature control was acquired in 2007 includes:

  - Geothermal Resources Limited’s four well shallow drilling programme in a Hot Rock play in its Frome Project area (Arrowie Basin, SA) in March 2007

- Eden Energy Limited’s 500 m well in a Hot Rock play in the Renmark area (Murray Basin, SA) in the fourth quarter of 2007

- Torrens Energy Limited’s five (of nine) well shallow drilling program in a Hot Rock play in its Lake Torrens project area (Arrowie Basin, South Australia) in the fourth quarter of 2007

- KUTh Energy Limited’s shallow, pattern drilling project in a Hot Rock play in eastern Tasmania (Tasmania Basin)

- Pacific Hydro Limited’s temperature measurements in three water bores to maximum depths of 1,500 m which suggests extrapolated temperatures of 133 ºC at 2,000 m in the Hot Sedimentary Aquifer play in the South Australian Eromanga Basin

- Hot Rock Ltd commenced a magneto-telluric survey of a Hot Sedimentary Aquifer play in its Otway Basin licences in Victoria in December 2007

- Following South Australia’s lead, Queensland, Victoria, Western Australia and the Northern Territory implemented reviews of geothermal legislation (ahead of gazettal of prospective geothermal acreage). Tasmania is reviewing production aspects of its legislation

- The Australian Federal Government’s five year AUS$58.9 million Onshore Energy Security Program conducted by the national geoscience and geospatial information agency (Geoscience Australia) continued to acquire precompetitive data and conduct research in support of geothermal energy exploitation. Geoscience Australia has consulted with industry, State and Territory governments and academic experts in developing its geothermal energy project plan. A nation-wide resource inventory was calculated from the Austherm temperature at 5 km dataset of Chopra and Holgate (2005). This work suggests a total thermal energy in place between a lower base of 5 km depth and an upper limit of the depth at which 150°C occurs of 1.9 x 10^{25} PJ. A map was produced that categorises outcropping granites by their radiogenic heat production and includes thickness of sedimentary basins. This map works as a first-pass geothermal play map.

- In the term 2000-2007, Australian Federal and State grants totalling ~AUS$43.3 million for geothermal research and exploration projects (Table 7.2). This includes:

  - The Queensland Government’s $15 million grant to the University of Queensland to establish the Queensland Geothermal Energy Centre of Excellence

  - The Federal Government’s $5 million grant to Petratherm to support its Paralana project in South Australia

  - The South Australian Government’s continued support as contracting party to the IEA-GIA’s Secretariat for the AGEG, and $300,000 in grants for geothermal research projects

- The AGEG formed in 2006 and provides financial and intellectual support for Australia's membership in the IEA-GIA. The members of the AGEG have a common interest in commercialising Australia’s geothermal resources at maximum pace and minimum cost. To year-end 2007, the AGEG had 65 member organisations including: representatives from: 48 companies with geothermal licences and pending application for licences in Australia; companies providing services to the geothermal sector; all Federal, State and Territory government agencies responsible for geoscience information provision, investment attraction and licence regulation for the geothermal sector; and University experts conducting research with implications for the geothermal energy sector

- To foster the achievement of these objectives, in 2007, the AGEG established ten Technical Interest Groups (TIGs) as outlined in Table 7.2
- The AGEG's TIGs will have active links to the International Energy Agency's (IEA's) research annexes, and will aim to attain strong linkages to all other reputable international geothermal research clusters, to ensure that Australia's comparative advantages in hot rock geothermal resources can be leveraged into international leadership in geothermal technologies, methods and development
- In November 2007, corporate members of the Australian Geothermal Energy Group (the AGEG) agreed to create a new peak geothermal industry directorate – the Australian Geothermal Energy Association (the AGEA). The aim of the AGEA is to provide a unified voice to key stakeholders, notably governments, on matters of policy affecting the geothermal industry. All company members of the AGEA are also members of the AGEG

Table 7.2 The AGEG's Technical Interest Groups

Australian Geothermal Energy Group (AGEG) Technical Interest Groups (TIGs)

AGEG Technical Interest Group (TIGs)		Purpose –Share Information to Learn-While-Doing with Maximum Effect & Efficiency	TIG Leaders / Members
☀ 1	Land Access Protocols (induced seismicity, emissions, native title, etc)	Management of environmental concerns and potential impacts of geothermal energy and devises protocols to avoid or minimize impacts.	**TIG Co-leaders:** Mike Malavazos / Barry Goldstein
2	Reserves and Resource (Definitions)	Align with similar International forums	**TIG Leader:** Adrian Williams, Geodynamics
3	Policy Issues *Industry Forum (AGEA) *Whole-of-Sector Forum (AGEG)	Industry advice to Governments – NOW AUSTRALIAN GEOTHERMAL ENERGY ASSOCIATION	**TIG Leader:** Susan Jeanes, AGEA
☀ 4	Engineered Geothermal Systems	Investigate technologies for enhancing geothermal reservoirs for commercial heat extraction.	**TIG Leader:** Doone Wyborn Geodynamics (also IEA Annex III leader).
5	Interconnection with Markets	Transmission, distribution, network, NEM issues	**TIG Co-Leaders:** Ian Stirling, Electranet and Terry Kallis, Petratherm
☀ 6	Geothermal Power Generation	Develop scenarios as a basis for comparison of cycles, plant performance and availability, economics and environmental impact and mitigation. The output would be a database and guidelines of best practice.	**TIG Co-Leaders:** Hal Gurgenci, U of Queensland Behdad Moghtaderi, U of Newcastle
☀ 7	Direct Use of Geothermal Energy (including geothermal heat pumps)	Direct use for heating and cooling, with emphasis on improving implementation, reducing costs and enhancing use	**TIG Co-Leaders:** Klaus Regenauer-Lieb, CSIRO / U WA Don Payne – CoreEnergy/U of Melbourne
8	Outreach (Including Website)	Create informed public through accessible information. Provide educational kits for media, K-12 and university education.	**TIG Leader:** Tony Hill, PIRSA
9	Data management	Database design, contents and ongoing enhancements.	**TIG Leader:** Anthony Budd, Geoscience Australia
☀ 10	Wellbore operations	Cover drilling, casing, logging, fracture stimulation, testing, etc	**TIG Leader:** Cam Selin, Clean Energy Australasia

☀ Parallels an IEA R&D Annex

Fed Government: $32,077,000 grants for company projects & University research to end March 07
SA Government: $1,350,000 grants for company projects & University research to end March 07
Qld Government: $15,000,000 grant to U of Queensland for geothermal research over 5 yrs
WA Government $2,300,00 grant to the U of WA for geothermal research

- The AGEA has stated its intentions to complement other major geothermal sector initiatives – notably the efforts of the Australian Geothermal Energy Group (AGEG). Along these lines:

    - The AGEG and the AGEA have agreed to coordinate research efforts through the AGEG's 10 Technical Interest Groups (TIGs). This will facilitate Australian companies, research experts and government agencies (including regulators) to convey and take note of international best practices for the full-cycle of below-ground and above-ground geothermal energy operations and stewardship

    - The AGEG and the AGEA have agreed that the AGEG should become the Australian affiliate for the International Geothermal Association. This will foster links to reputable international research

    - The AGEG and the AGEA have coordinated inputs to government program and policy development under the auspices of AGEG's TIG 3 (Policy) – with the Chief Executive of AGEA acting as the Chair of AGEG TIG 3

- The Australian Federal Government's Geothermal Industry Development Framework (GIDF) was instigated in March 2007, and will be published in 2008 (more information at: http://www.ret.gov.au/energy/clean_energy_technologies/energy_technology_framework_and_roadmaps/geothermal_industry_development_framework_and_technology_roadmap/Pages/GeothermalIndustryDevelopmentandTechnologyRoadmap.aspx). The GIDF sets out to identify the challenges for the Australian geothermal sector and to recommend actions, including high leverage national and international alliances, to encourage the development of a viable geothermal energy industry. The GIDF will be developed in parallel to a Council of Australian Government (CoAG) Technology Roadmap for the development of Australia's geothermal energy resources and technologies (due to be delivered to CoAG's consideration in 2008). Technology Roadmap will identify technology and research needs for the pre-competitive demonstration and subsequent development of geothermal energy resources. These initiatives follow-up the Australian Government's 2004 White Paper Securing Australia's Energy Future which classified hot dry rocks as a technology in which Australia had comparative advantages. Government support for geothermal exploration (research), appraisal (proof-of-concept) and demonstration projects manifest the view that geothermal energy has potential to contribute significantly to Australia's baseload electricity supplies, without generating greenhouse gas emissions. Initial drilling results indicate that Australia's Hot Rock resources are amongst the best in the world for the development of Engineered Geothermal Systems (EGS)

- Significant opportunities for the direct use of geothermal energy are gaining recognition, in parallel to growth internationally in the deployment of direct use applications. In particular, ground-sourced geothermal heat pumps, circulating hot water for heating and drying applications, and the use of geothermal steam for osmotic desalination are forms of direct use hold material potential for deployment in Australia

7.3 National Policy

7.3.1 Strategy

In March 2007, representatives from companies, the AGEG, universities and key Federal Government agencies were invited by the (then) Minister for the Environment and the Minister for Energy to a "Geothermal Roundtable" to contribute to the development of programs and policies that would efficiently and effectively attract investment in geothermal energy resources and technologies. In close consultation and agreement with its company members, the following vision and targets were posed by the AGEG at that time, and has not changed since:

- Vision: Geothermal power is safe, secure, reliable, competitively priced, emissions-free and renewable base load power for centuries
- Milestones for the Vision- Geothermal Energy Roadmap
  - Several successful research (exploration) and proof-of-concept (heat energy is flowed) geothermal projects- at least 10 by 2010
  - Several geothermal power generation demonstration projects in distinctively different geologic settings- at least 3 by 2012
  - Compelling success with geothermal power generation demonstration so the investment community is convinced geothermal energy is real- by 2012
  - Safe, secure, reliable, competitively priced, renewable and emissions-free base load power from geothermal energy for centuries to come- at least 7% of baseload demand from hot rock power by 2030

Since that March 2007, the AGEG and the AGEA have provided advice (welcomed by the Australian Federal Government) into the development of the Australian Federal Government's GIDF and CoAG Roadmap for Geothermal Technologies, as well as the design of the Australian Government's Renewable Energy Fund (REF, in part supplants the Low Emissions Technology Development Fund, see: http://www.ret.gov.au/energy/energy%20programs/RenewableEnergyFund/renewable_energy_demonstration_program/Pages/RenewableEnergyDemonstrationProgram.aspx), Energy Innovation Fund (EIF, which in part supplants the Renewable Energy Development Initiative [REDI] grant scheme: http://www.ret.gov.au/energy/energy%20programs/energy_innovation_fund/Pages/EnergyInnovationFund.aspx), the national emissions cap and trading scheme and reform of the National Electricity Market rules.

7.3.2 Legislation and Regulation

To end 2007, six states (New South Wales, Queensland, South Australia, Tasmania, Victoria and Western Australia) have legislation in place to regulate geothermal exploration and development. Relevant legislation is summarised below.

7.3.2.1 South Australia

A paper outlining proposed amendments to the *Petroleum Act 2000* closed for public comment on 29 June 2007. The Petroleum (Miscellaneous) Amendment Bill 2008 will be released in April 2008 for public consultation and it is expected that the *Petroleum and Geothermal Energy Act, 2008* will is expected to be enacted in late 2008. See: http://www.austlii.edu.au/au/legis/sa/consol_act/pa2000137/

7.3.2.2 Victoria

The *Geothermal Energy Resources Act* (GER Act) was passed in April 2005 and the *Regulatory Impact Statement and Geothermal Energy Resources Regulations 2006* (GE Regulations) came into effect during 2006. See: http://www.austlii.edu.au/au/legis/vic/consol_act/gera2005297/

The GER Act aims to encourage large-scale commercial and sustainable exploration and extraction of Victoria's geothermal energy resources. It does not apply to small-scale extraction operations or to exploration or extraction where the target in situ resource is less than 70 °C temperature or less than 1 km below the surface.

To facilitate the development of these potential resources, the Department of Primary Industries conducted a public tender process for geothermal exploration permits. A total of 5 companies accepted offers over 12 separate geothermal exploration permits in 2007. These permits cover 73,000 km^2 in southern Victoria with the companies committing over $64 million in expenditure over the five year term of the permits.

A further 19 permits, covering 154,000 km^2, are to be offered in April 2008.

7.3.2.3 New South Wales

The *Mining Act, 1992*, governing geothermal exploration in New South Wales is on its final review stage for a bill amendment. Currently geothermal exploration is considered Group 8 Geothermal Substances. Application for a Group 8 geothermal exploration licence requires the Minister's consent especially if it is under mineral allocation areas, usually within coal basins. If successful, a maximum 5-year term is granted based on work program commitments. See: http://www.austlii.edu.au/au/legis/nsw/consol_act/ma199281/

New South Wales will be introducing a tender process for geothermal exploration licences for Sydney Basin.

7.3.2.4 Queensland

The Geothermal Exploration Act 2004 is proposed to be repealed and replaced by the Geothermal Energy Bill 2008 (the Bill), a new Act to provide the framework for exploration and production of geothermal energy in Queensland. See:
http://www.legislation.qld.gov.au/LEGISLTN/CURRENT/G/GeoExpA04.pdf

The Geothermal Exploration Act 2004 was only intended to be interim legislation to enable geothermal exploration to commence in Queensland while production legislation was developed. Work on the production legislation has commenced and the proposed Bill will address the full geothermal energy regime.

The Bill is due to be passed in 2008. Commencement will be on a date to be nominated, most probably mid 2009. Some provisions may commence upon passage of the Bill. These may include declarations of restricted land, reporting requirements and retention tenure provisions. The Bill will include standard processes for accepting and considering applications, administering tenures, managing competitive application processes and registering dealings in the tenures.

The 2007 Geothermal Call for Tenders was gazetted on 2 November 2007 with a closing date of 18 February 2008. It comprised 13 areas throughout Queensland, totalling over 7000 km^2. An information booklet was prepared for the 2007 call for tenders to assist prospective tenderers. A native title process will be required prior to the grant of the Geothermal Exploration Permits.

None of the 14 geothermal exploration permits have been granted in Queensland to date as none of the preferred tenderers has yet obtained the necessary approvals.

7.3.2.5 Tasmania

Geothermal exploration and development has been covered for over a decade by the *Mineral Resources Development Act* (1995) and using this tried legislation, exploration has been able to be conducted with little regulatory impediment or uncertainty. See:
http://www.austlii.edu.au/au/legis/tas/consol_act/mrda1995320/

The MRD Act operates an "over the counter" system, where explorers can apply for those areas wanted to be explored, and these co-exist with existing or future minerals and petroleum exploration titles. Geothermal tenements are granted as 'Special Exploration Licences' which have cheap annual rentals and cover large areas. Initial grant is for 5 years, with annual reviews determining work programmes and mandated expenditures. An SEL can be renewed for an additional 5 years at the discretion of the Minister.

The MRD Act in its present form would allow a geothermal play to come into production via a Mining Lease but this is viewed as being impractical, due to the likely large size and exclusion of other resources exploration, and geothermal production aspects of the Act are currently under review.

To the end of 2007, 5 SELs for geothermal substances had been granted, totalling 22,663 km^2. See: http://www.mrt.tas.gov.au

7.3.2.6 Western Australia

The West Australian (WA) *Petroleum and Geothermal Energy Resources Act 1967* (PGERA67) was proclaimed on 15 January 2008, providing legislative coverage for both conventional (hydrothermal) geothermal energy and hot dry rock geothermal energy. The legislation provides a clear legal framework for companies to pursue large-scale geothermal energy projects in the State. The PGERA67 is under the portfolio of the Minister for Resources and will be administered by the Petroleum and Royalties Division of the Department of Industry and Resources (DoIR).

Following the proclamation of the legislation the Minister for Resources announced the State's inaugural open gazettal release of geothermal exploration acreage. The acreage comprises 495 exploration permit applications, each with an area of 320 km^2, situated predominately in the Perth Map Sheet. The release closes on 24 April 2008, and will be followed by sequential releases across the extent of Western Australia, over the proceeding twelve months. See: http://www.austlii.edu.au/au/legis/wa/consol_act/pagerfa1967603/.

Additional geothermal application areas are expected to be released for work program bidding in West Australia in 2008.

7.3.2.7 Northern Territory

The NT Government is in process of developing a *Geothermal Energy Bill* which will provide secure tenure for the controlled exploration and development of geothermal energy resources in the Northern Territory. The proposal is to develop stand alone legislation that will provide exploration tenure in a similar form to mineral exploration tenure but with the development securities more akin to the NT *Petroleum Act*. That is, the company that discovers and assesses the heat resource will have the right to develop the field.

The draft legislation is based on other State legislation and the Northern Territory's mining and petroleum legislation to ensure conformity and consistency for explorers and developers within the Territory. Details of the legislation have yet to be finalised but will draw strongly on existing State geothermal laws while attempting to keep the process as simple as possible.

The legislation will be developed and administered by the Titles Division of the Minerals & Energy Group of the Department of Primary Industry, Fisheries and Mines. It is hoped that the legislation will be passed this year and operative late in mid 2008 ahead of a Call for Bids for highly prospective geothermal acreage and over the counter provisions for the remainder of the Territory.

7.3.3 Progress Towards National Targets for Renewable Energy and Emissions

The Australian Federal Government has:

- Signed the Kyoto Protocol
- Set a target to reduce emissions by 60 % by 2050

- Clarified that the national Mandatory Renewable Energy Target (MRET, see: http://www.climatechange.gov.au/renewabletarget/publications/fs-ret.html) would supplant all pre-existing State-based equivalents, and be additive to the approximately 15,000 GWh of existing renewable capacity, so that electricity generated from renewable sources would meet 20% of power demand in Australia by 2020 (corresponding to a forecast of approximately 60,000 GWh in 2020). Renewable Energy Credits (RECs) correspond to one megawatt-hour of eligible renewable electricity under the MRET scheme, and the price of a REC has ranged between AUS$XX and AUS$YY in 2007

- Set 2011 as the date when a national emissions cap and trade scheme (see: http://www.climatechange.gov.au/emissionstrading/about.html) would be introduced, and

- Is designing criteria for a new AUS$500 million Renewable Energy Fund (REF) to underpin industry-backed research and demonstration of meritorious renewable energy technologies and methods with grants, including AUS$50 million specifically for proof of concept drilling projects via the Geothermal Drilling Program

7.3.4 Government Expenditure on Geothermal Research and Development

There has been a total of just more than AUS$43 million in Australian Federal and State grants for the period 2000 to end December 2007 (Table 7.3).

Table 7.3 Federal Australian, South Australian State (SA) and Queensland (Qld) State grants awarded for geothermal Research/Proof-of-Concept (including exploration geophysical surveys, drilling and well surveys/tests), and Demonstration projects in Australia 2000 – 2007

Grant	Date	Recipient	Project	Amount ($AUS)
Fed. RECP	2000	Pacific Power/ANU	Hunter Valley geothermal project	$ 790,000
Fed. START	2002	Geodynamics Ltd	Habanero project	$ 5,000,000
Fed. REEF	2002	Geodynamics Ltd	Habanero project	$ 1,800,000
Fed. GGAP	Mar 2005	Geodynamics Ltd	Waste heat fuel for Kalina Cycle power	$ 2,080,000
Fed. REDI	Dec 2005	Geodynamics Ltd	Habanero project, Cooper Basin, SA	$ 5,000,000
Fed. REDI	Dec 2005	Scopenergy Ltd	Limestone Coast geothermal project, SA	$ 3,982,855
SA PACE	Apr 2005	Petratherm Ltd	Paralana geothermal project, SA	$ 140,000
SA PACE	Apr 2005	Scopenergy Ltd	Limestone Coast geothermal project, SA	$ 130,000
SA PACE	Apr 2005	Eden Energy Ltd	Witchellina project, SA	$ 21,000
SA PACE	Dec 2005	Geothermal Resources Ltd	Curnamona geothermal project, SA	$ 100,000
SA PACE	Dec 2005	Green Rock Energy Ltd	Olympic Dam geothermal project, SA	$ 68,000
Fed. REDI	July 2006	Geothermal Resources Ltd	Frome Geothermal Project	$ 2,400,000
Fed. REDI	Dec 2006	Proactive Energy Developments Ltd	Novel regenerator for adapting supercritical cycles for power generation	$ 1,224,250
SA PACE	Dec 2006	Torrens Energy Ltd	Heatflow exploration, Adelaide Geosyncline	$ 100,000
SA PACE	Dec 2006	Eden Energy Ltd	Renmark (Chowilla) geothermal project	$ 100,000
SA PACE	Dec 2006	Geodynamics Ltd	High temperature borehole image logging,	$ 100,000
Fed. REDI	Feb 2007	Petratherm Ltd	Paralana geothermal project	$ 5,000,000
SA Grant	May 2007	Univ. of Adelaide	Induced seismicity protocols	$ 50,000
SA Grant	May 2007	Univ. of Adelaide	Research endorsed by the AGEG	$ 250,000
Qld Grant	Sep 2007	Univ. of Queensland	Geothermal energy research	$15,000,000
			Total to YE 2007	**$43,336,105**

7.3.4.1 Federal Government

The Australian Federal government provided a maximum AUS$5 million grant for industry-backed, geothermal exploration and proof-of-concept project in 2007. A total AUS$27.3 million in Federal Government grants have underpinned meritorious, industry-backed geothermal projects in the term 2000-2007. Descriptions of these grant programs are outlined in Section 4 under Support Initiatives and Market Stimulation Incentives.

A part of the Federal Government's AUS$58.9 million (US$46 million) funding over five years for Australia's Onshore Energy Security Program will be directed towards the advancement of geothermal energy projects. This program is discussed in greater detail in Section 7b. Approximately AUS$700,000 from this program has been spent directly on geothermal projects (including salaries) up until December 2007 and it is expected that a further AUS$300,000 will be spent in 2008.

The Australian Federal Government's Geothermal Industry Development Framework was instigated in March 2007. This will also result in the development of a Council of Australian Government (CoAG) Technology Roadmap for the development of Australia's geothermal energy resources and technologies (due to be delivered to CoAG and published in 2008). All Australian States and Territories are members of the CoAG, and will have the opportunity to contribute to this Technology Roadmap for the development of geothermal technologies. This roadmap will identify goals and milestones for the research, experimental development and demonstration of geothermal technologies. Furthermore, the Framework will support the development of a broader roadmap for the geothermal energy industry in Australia.

7.3.4.2 States and Northern Territory Governments

South Australia- A total of AUS$1.06 million in South Australian Plan to Accelerate Exploration (PACE) drilling and other research grants has been provided to underpin the advancement of geothermal energy projects since July 2004 (Table 7.3). A new round of funding for South Australia's PACE closed in September 2007 and an announcement of successful applicants will be made in January 2008. These grants assist in addressing critical uncertainties in frontier geothermal exploration regions and include partial funding of drilling, temperature logging and thermal conductivity analyses. The South Australian Government also provided the secretariat for the AGEG and is the Contracting Party to the IEA-GIA for Australia. Research projects supported by the South Australian government are summarised in Section 7**??** below.

Western Australia- The Department of Industry and Resources, Geological Survey published the "Geothermal Energy Potential in Selected Areas of Western Australia" report conducted in 2006 in February, 2007. In 2007, the survey has undertaken data gathering projects for researchers and geothermal explorers. This has involved collating all onshore petroleum well log data, scanning log headers and entering into the database bottom hole temperatures and other relevant data from the headers for calculating the equilibrium geothermal gradient at each location. This was completed for the Perth, Canning and Carnarvon Basins and the data made available via the web. Further temperature data was gathered from water bores in the Perth Basin and more water bore data will be collected for the other sedimentary basins in 2008. These data will provide the basis for further studies planned in 2008.

The Geological Survey has also collected seismic, magnetic and gravity data for the Perth Basin and produced a combined well and geophysical survey data package timed for release with the geothermal acreage release program in 2008.

At year-end 2007, the Western Australian Government was developing the basis for a $2.3 million grant to Universities in Perth to foster geothermal research into low-grade (up to 130 °C) heat in permeable sedimentary settings such as the Perth Basin.

New South Wales- In 2007, as part of its New Frontiers initiative programme, the NSW Department of Primary Industries, Petroleum Geoscience Group initiated a project focused on mapping and identification of prospective geothermal energy systems. A suite of scientific data such as: granite geochemistry, potential field data, heat flow units, bottom-hole temperatures from petroleum wells have been compiled and presented as an ArcGIS project and forms the main portion of a comprehensive geological and geophysical database called 'The Sydney Basin Geothermal Data Package'. This is a first geothermal data package prepared by the New South Wales Department of Primary Industries and it will be released in April 2008. A data package covering the whole state will be published later in 2008.

Tasmania- In 2006, Mineral Resources Tasmania launched its four year TasExplore initiative, which incorporates the acquisition of gravity and airborne magnetics and radiometrics, upgrading of the geology on north and northeast Tasmania and upgrading the 3D Geological Model of Tasmania. In focussing on the east and north-east granite terrain of Tasmania, this work will advance the understanding of the state's geothermal province

7.3.5 Industry Expenditure on Geothermal R&D

Australian geothermal industry field expenditure is classed as research and totalled AUS$39.2 million in 2007. This represents a 54% increase of AUS$13.7 million from the previous year. A 154% increase (to AUS$99.6 million is forecast to be expended in 2008. Historical, current and projected expenditure for 2008 are highlighted in Figure 7.3.

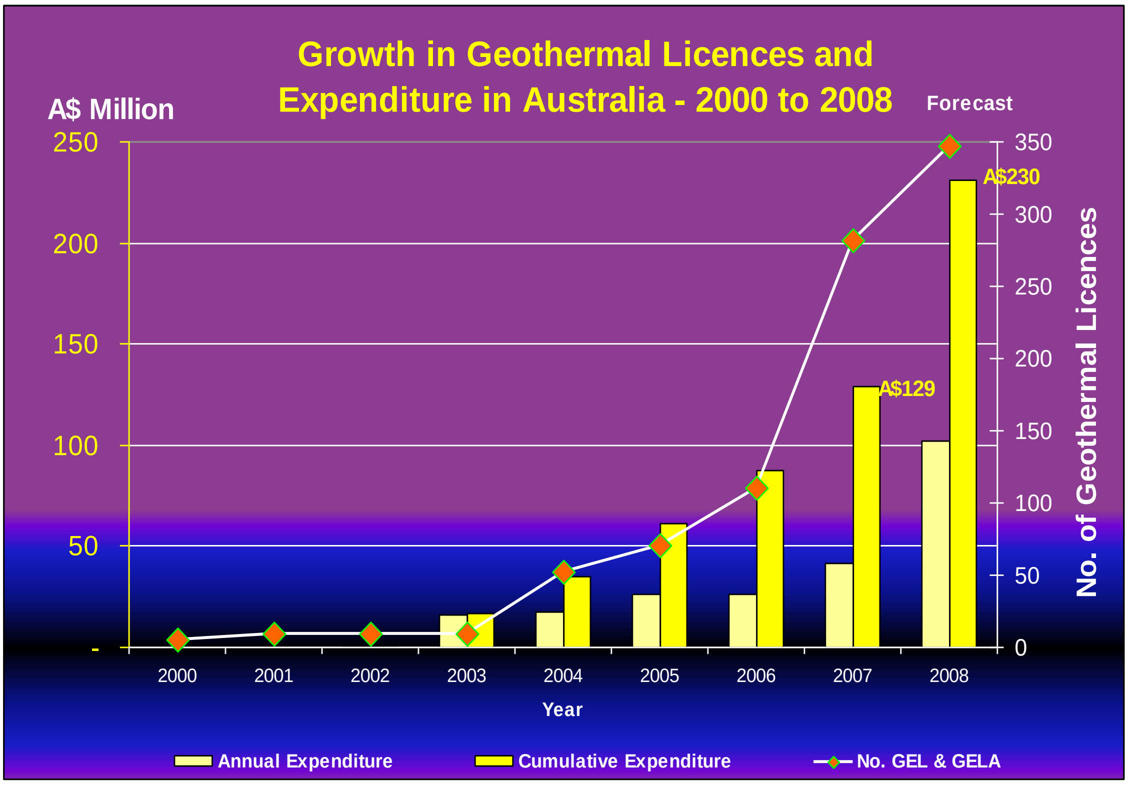

Figure 7.3 Geothermal licence applications and exploration expenditure from 2000 to 2007 actuals and forecast (in 2007) for 2008 (source: PIRSA).

7.4 Status of Geothermal Energy Use in 2007

7.4.1 Electricity Generation

Geothermal energy is currently produced at one small binary power station at Birdsville in western Queensland, which is supplemented by diesel powered generators. The fluid is 98 ^{o}C and derives from the Great Artesian Basin (also referred to as the Eromanga Basin) that overlies the Cooper Basin. The water is run through a gas filled Organic Rankine cycle heat exchanger which heats and pressurises the gas which drives a turbine and alternator to produce electricity. The partly cooled water is channelled into a pond for further cooling and reticulation into the town's water supply and the lagoon. The gross capacity of the plant is 120 kW_e and the plant power consumption is 40 kW_e, which equates to a net output of 80 kW_e. Total power generation in 2007 was 1,787,458 kWh of which 522,636 kWh was provided by the geothermal power plant. This equates to 29 % of total power output.

In late 2007, Ergon Energy completed a feasibility study into whether it can provide Birdsville's entire power requirements and relegate the existing LPG and diesel-fuelled generators to be used only as a back-up at peak times such as the annual Birdsville races which attract large crowds for several days. The company is reviewing which steps it should take forward as a result of the feasibility study.

7.4.2 Direct Use

7.4.2.1 Installed Thermal Power

Australia's total installed capacity in direct geothermal applications is estimated to be 130 MW_{th}. This is up from the 2005 estimate of 109.5 MW_{th} (Lund, *et al.*, 2005)

7.4.2.2 Thermal Energy Used

Following Lund, *et al*. (2005) with a capacity factor of 0.9, the thermal energy used is estimated to be 3,672 TJ/yr, up from the 2005 estimate of 2,968 TJ/yr.

7.4.2.3 Category Use

District heating (space heating) constitutes the majority with an estimated 98 MW_{th}. Bathing and swimming installations total 8 MW_{th}. Ground Source Heat Pumps (GSHPs) constitute the remaining 24 MW_{th}. The GSHP installations include over 300 residence and several commercial sites. See Chopra (2005) for an abridged list of significant sites. Some of these sites, not previously listed, have contributed to the increased estimate of total Australian installed thermal power.

Commercial water-loop GSHP installations include:

- New South Wales
  - Lithgow Hospital, Lithgow
  - NPWS Tourist and Information Centre, Jindabyne
  - Macquarie University, North Ryde
  - Detention Centre, Dubbo
  - Cowra Shire Council Offices, Cowra
  - Wagga Wagga Civic Centre, Wagga Wagga
  - Surry Hills Community Facility, Surry Hills

- Australian Capital Territory

- ACTEW Corporation, Canberra
- Geoscience Australia, Canberra
- Duntroon Headquarters, Canberra
- Airport Caltex, Pialligo
- ANU Research Laboratory, Canberra

➢ Tasmania

- ACTEW Corporation, Canberra
- Grand Chancellor Concert Hall, Hobart
- Queen Victoria Museum and Art Gallery, Launceston
- Southern Cross Homes/Aged Care, Moonah
- Antarctic Centre, Hobart
- Westpac Call Centre, Launceston

➢ Victoria

- ACTEW Corporation, Canberra
- Victoria University of Technology, Werribee
- Paynesville Pool, Paynesville
- Station Pier, Port Melbourne

➢ South Australia

- Royal Adelaide Hospital, North Terrace
- Bureau of Meteorology, Kent Town
- Garden East Apartments, Adelaide
- Coober Pedy Police Station, Coober Pedy
- Mt Barker TAFE, Mt Barker

➢ Queensland

- University of Southern Queensland swimming pool, Toowoomba
- Logan Institute of TAFE, Logan

➢ Northern Territory

- Bureau of Meteorology, Darwin

7.4.2.4 New Developments in 2007

The Australian Geothermal Energy Association (AGEA) was founded late in 2007 to represent Australian Geothermal power generation and direct use industries. For direct use geothermal applications including GSHPs, AGEA is calling for government incentives and rebates. Any progress here will substantially increase uptake of GSHPs. Regional Development Victoria launched the Four Seasons Pilot Program which funds up to 50 % of commercial and 100 % of public GSHP installations in regional areas without a natural gas supply. Further, Sustainability Victoria is funding 20 % of some commercial, innovative direct use installations through the Renewable Energy Support Fund (RESF).

New direct use installations include a resort in Warrnambool, which uses 45 ºC water drawn from a bore approximately 770 m deep with a flow rate of up to 50 l/s to provide domestic hot water, space heating, and pool and spa heating to a 122 room tourist facility. The estimated thermal capacity is 0.2 MW_{th} or 5.6 TJ/yr. This project can abate up to 412 t/yr of CO_2.

GSHPs can be broken into sub-categories: water-loop and refrigerant-loop or Direct Exchange (DX). Over the last two decades, only water-loop district heating and GSHPs have been installed in Australia. Over the last couple of years, DX GSHPs have been introduced to Australia. DX GSHPs are generally more viable for the residential and small-commercial markets: instead of 15-cm wide, 100 m deep bore holes (as required for water-loop systems), only 5-7-cm wide, 15-30 m deep bore holes are required, substantially reducing the drilling cost. There are now ten DX GSHP installations in Victoria with a total capacity of roughly 0.3 MW_{th}. These include seven residences, a factory, council offices and a ski chalet.

7.4.2.5 Rates and Trends in Development

In the face of increasing public and political will to act on climate change, rising energy prices, and an emerging GSHP industry, it is expected that the installation of GSHPs will accelerate.

7.4.2.6 Number of Wells Drilled

Based on the assumption that a 30 m bore for a DX GSHP has a 3.5 kW_{th} capacity and a 100 m bore for a water-loop GSHP has of order 10 kW_{th} capacity, the estimated number of wells is 13,000.

7.4.3 Energy Savings from Direct Use

The estimated fossil fuel savings is 87,440 toe (1 toe = 42 GJ).

Using the DTI/Carbon Trust/DEFRA/Ofgem recommended figure of 0.43kg CO_2/kWh saved, yields avoided emissions of CO_2 of 0.44 Mt/yr.

7.5 Market Development and Stimulation

7.5.1 Support Initiatives and Market Stimulation Incentives

There are a number of Federal and State government support initiatives designed to support and accelerate commercialisation of renewable energy technologies and R&D in general including geothermal energy. The following projects have been supported so far:

7.5.1.1 START Program

The R&D Start program was introduced in 2002 by the Federal government to assist Australian industry to undertake research and development and commercialisation. In 2002, Geodynamics received an R&D Start grant of $5 million to develop a deep underground heat exchanger to harness hot dry rock geothermal energy

7.5.1.2 Greenhouse Gas Abatement Program (GGAP)

In 2005, Geodynamics Power Systems Ltd received AUS$2.079 million under REDI to demonstrate the application of the Kalina Cycle to produce 13 MW from waste heat at the Mt Keith Nickel Mine in WA. This project has been deferred pending the instigation of related work by the operator (BHPB) of the Mt Keith Mine.

7.5.1.3 Renewable Energy Commercialization Program (RECP)

A grant of $0.79 million was awarded to the ANU and Pacific Power in March 2000 for shallow drilling in NSW Hunter Valley. See:
http://www.greenhouse.gov.au/renewable/recp/hotdryrock/one.html

7.5.1.4 Renewable Energy Certificates

The MRET Scheme operates through a system of tradable RECs that are created by renewable energy generators at the rate of 1 REC for each MWh of electricity generated from an eligible renewable source.

7.5.1.5 Renewable Energy Development Initiative (REDI) Program

This Federal government initiative is a competitive, merit based grants program supporting renewable energy innovation and its early stage commercialisation. The AUS$100 million program commenced in 2003 and will provide individual grants from AUS $50 000 to AUS $5 million over seven years. The REDI finishes on 28 April 2008, and will be supplanted with a number of new Government programs to support renewable and clean energy development in Australia. The following geothermal companies have been supported so far under the REDI scheme:

- In 2005, Geodynamics received AUS$5 million for the construction and operation of a high efficiency Kalina cycle generation plant based on existing geothermal wells near Innamincka, South Australia
- In 2005, Scopenergy Limited received AUS $3.98 million for a proof-of-concept geothermal energy project on the Limestone Coast
- In 2006, Geothermal Resources Ltd received AUS $2.4 million to identify (with geophysical methods and drilling) and map the composition of granites in the Curnamona Craton region of South Australia
- In 2006, Proactive Energy Developments Limited received AUS$1.22 million under REDI for the development of a novel regenerator for adapting supercritical cycles to geothermal power applications
- In February 2007, Petratherm Ltd received AUS$5 million under REDI for its Paralana project to supply electricity to the Beverley mine in South Australia and
- In August 2007, Torrens Energy Ltd received AUS$3,000,000 under REDI to undertake 3D modelling of hot rock resources in South Australia

7.5.1.6 Low Emissions Technology Demonstration Fund (LETDF)

The AUS$500 million LETDF is a merit based programme designed to demonstrate break-through technologies with significant long term greenhouse gas reduction potential in the energy sector. Key criteria for this award are the potential to reduce Australia's total CO_2 emissions by at least 2 %. The Fund was announced by the Federal government in June 2004 and was set to leverage at least AUS $1 billion in additional private investment in new low emission technologies. The Fund has been supplanted by a series of programs, including the $500 million Renewable Energy Fund, and the $500 million National Clean Coal Initiative.

7.5.1.7 Renewable Energy Equity Fund (REEF)

The REEF program was introduced by the Federal government in 1997 and is a specialist renewable energy technology research fund. In 2002, Geodynamics Ltd received an AUS$1.8 million grant from this fund to develop a deep underground heat exchanger to harness hot dry rock geothermal energy at its Habanero site in the Cooper Basin, South Australia.

7.5.1.8 Renewable Energy Fund (REF)

The REF initiatives include:

- Leveraging around AUS$ 1.5 billion worth of investment in renewable energy technologies through encouraging private investment with government funding

- Supporting a range of technologies across a range of geographic areas in Australia

- Taking technology from the laboratory to the field to help prove a project's viability on a technical and economic basis

Components of the REF relevant to geothermal include:

- The $435 million Renewable Energy Demonstration Program (REDP)- designed to fill the gap between post-research and commercial uptake for renewable energy technologies

- The $50 million Geothermal Drilling Program (GDP)- supporting companies in the geothermal energy sector

7.5.1.9 Energy Innovation Fund (EIF)

The EIF has been established by the Australian Government to provide $150 million over five years to support the development of clean energy technologies. The aspect of the EIF that may become relevant to geothermal technologies includes $50 million for competitive grants for research and development in clean energy technologies. Relevant objectives of the Energy Innovation Fund include:

- Accelerate the development of new and innovative clean energy technologies that will lead to medium to long term reductions in emissions from energy production and use

- Increase the level of collaboration within Australia and internationally on clean energy research and development

- Create clean energy technology development, growth and export opportunities for Australian businesses

7.5.1.10 Low Emissions Technology and Abatement (LETA)

The LETA initiative is a $26.9 million measure to reduce greenhouse gas emissions over the longer term by supporting the identification and implementation of cost effective abatement opportunities and the uptake of small scale low emission technologies in business, industry and local communities. Relevant aspects of LETA are:

- Increase the level of collaboration within Australia and internationally on clean energy research and development

- Strategic Abatement- Identification of Opportunities - Funds are available for industry on a sector wide basis to identify opportunities for emission reductions;

- Strategic Abatement- Local Government and Communities- The objective of this sub-programme is to achieve cost effective abatement at the community level

- Renewables- The LETA Renewables sub-programme will complement existing climate change measures by supporting broad industry development projects and national projects as set out in the Commonwealth/State Renewable Remote Power Generation Programme (RRPGP) Partnership Agreements. Projects supported under this sub-programme may be proposed by eligible State and Territory Government agencies, renewable energy industry associations or related institutions

Direct use advocates are expected to apply for a LETA grant to support expanded deployment of GSHPs in Australia.

7.5.1.11 PACE

The **P**lan for **AC**celerating **E**xploration was launched in April 2004 by the South Australian government and includes funding for collaborative exploration programs that will address critical uncertainties in mineral, petroleum and geothermal exploration. The AUS$22.5 million program (of which AUS$10 million has been designated for direct drilling initiatives) will be operative until at least 2009. A total of AUS$759,000 in South Australian PACE drilling grants has been provided to 7 geothermal explorers: Scopenergy (AUS$130,000), Petratherm (AUS$140,000), Green Rock (AUS$68,000), Geothermal Resources (AUS$100,000), Eden Energy (AUS$21,000 and AUS$100,000, Geodynamics (AUS$100,000) and Torrens Energy (AUS$100,000). A fifth round of grants closed in September 2007 and awards were made in 2008. For details, see: http://www.pir.sa.gov.au/minerals/pace/theme_2/current_round_of_pace_projects

7.5.1.12 Renewable Energy Support Fund

Sustainability Victoria offers a Renewable Energy Support Fund that helps to pay 50 % of the capital cost for new operations (such as fish farms, horticulture and swimming pool heating). See: http://www.sustainability.vic.gov.au/www/html/1517-home-page.asp

7.5.1.13 NSW Climate Change Fund

The NSW Climate Change Fund was established in July 2007. It includes $40 million Renewable Energy Development Grant (RED). The Climate Change Fund was established under the Energy and Utilities Administration Act 1987. It provides $40 million over five years to support projects which are expected to lead to large scale greenhouse gas emission savings in NSW by demonstrating renewable energy technologies in NSW and supporting the early commercialisation of renewable energy technologies in NSW. The Renewable Energy Development Program was open for Expressions of Interest for any renewable energy project, which will generate electricity or displace grid electricity use in NSW for stationary energy purposes.

7.5.2 Development Cost Trends

Drilling costs for high temperature non-sedimentary targets remain a challenge to be managed, especially while there is significant competition for a limited fleet of fit-for-purpose rigs. With each deep geothermal well drilled in Australia, “learnings” will be applied to foster more efficient operations in hostile, deep and hot hole conditions, including the development of increasingly resilient drilling assemblies. With increasing numbers of companies planning to drill deep wells, the opportunity will arise for one or more companies to commit to long-term arrangements for drilling rigs that can be expeditiously mobilised, commissioned, decommissioned and transported in a relatively low number of truck loads.

Substantial increases in the cost of consumables and steel casing are also a challenge to efficiency.

AGEG is compiling forecasts of trouble free geothermal well costs and actual well costs to gain an appreciation of expected drilling costs for the Australian geothermal sector.

7.6 Development Constraints

Whilst geothermal energy resources in Australia have vast potential, geothermal power generation is not yet price-competitive, and remains to be demonstrated to be economic at price levels that may be realised with the addition of costs to constrain greenhouse gas emissions in the cost of electricity from emissive fuels such as coal and natural gas.

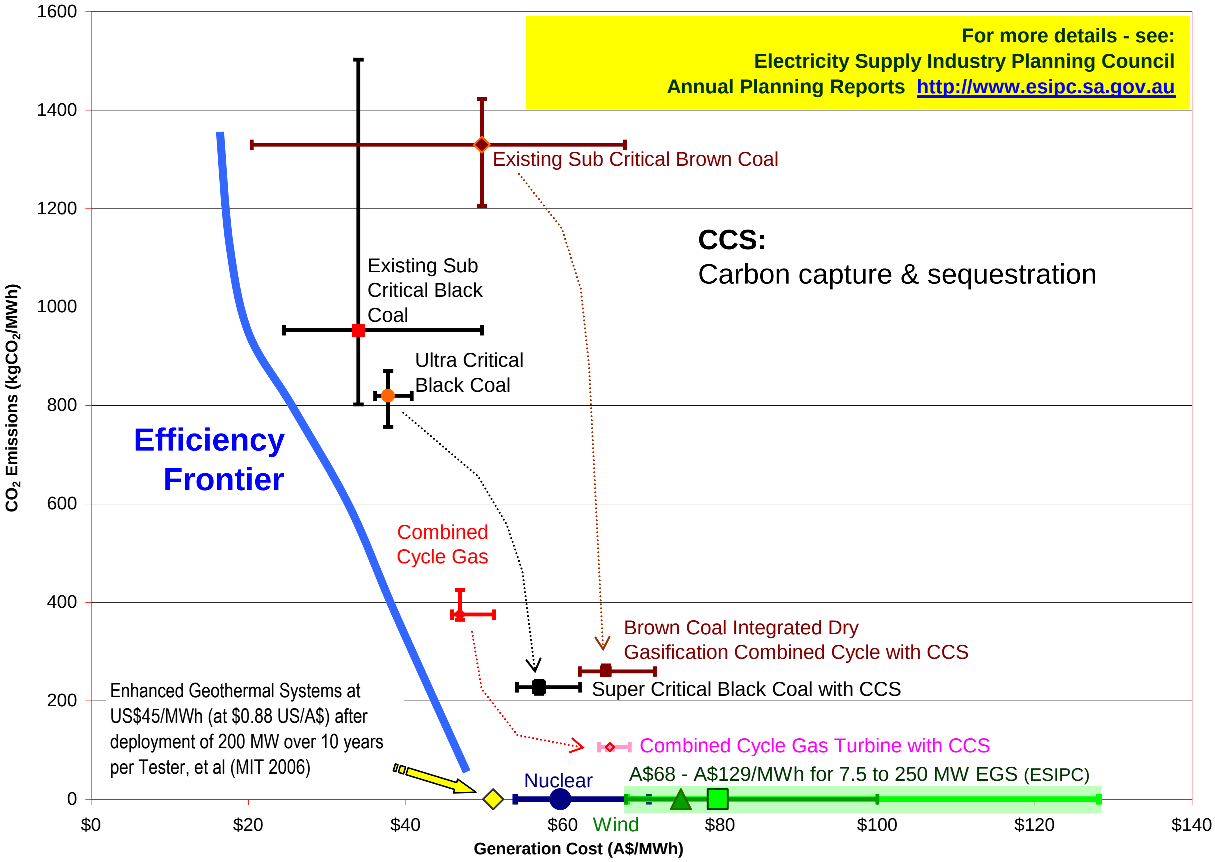

Figure 7.4 CO_2 emissions (kg/MWh) on the vertical axis versus AUS$ costs to generate electricity power in Australia on the horizontal axis to indicate relative costs and CO_2 emissions from various fuels, with and without carbon capture and storage (geosequestration). Source: Electricity Supply Industry Planning Council 2007 Annual Planning Report. See: *http://www.esipc.sa.gov.au/webdata/resources/files/APR_Final_for_Website.pdf*

7.7 Economics

7.7.1 Trends in Geothermal Investment

Assuming success in demonstration and proof of concept projects, the Electricity Supply Association of Australia concluded that 6.8 % of all Australia's power could come from geothermal by 2030 under a scenario that emissions are reduced to 70 % of 2000 levels by 2030. The forecast 6.8 % represents 5.5 GW in generating capacity from EGS. At roughly 2 % growth, Australia's power demand will grow from approximately 50 GW current generation capacity to approximately 80 GW in 2030.

Figure 7.4 illustrates the current costs of power generation from alternative fuels, including geothermal, coal, wind, gas and nuclear energy. At this point in time, coal and gas are the most competitively priced fuels for electricity generation.

In a global market with carbon pricing, geothermal energy is likely to be a significant growth industry. The anticipated cost of EGS electricity generation in Australia has been estimated at $68-$128 per MWh (ESIPC, 2007). Without carbon pricing, many forms of conventional energy generation such as coal and natural gas are more cost effective.
Investors have continued to support capital requirements for geothermal projects, and funding has continued to increase in 2007, with ten companies now listed on the Australian Stock Exchange.

In mid December 2007, the market capitalisation of these ten companies amounted to more than AUS$700 million.

7.7.2 Trends in Cost of Energy

Estimated costs to generate electricity from various fuels and plant-types are indicated on Figure 7.4. Australia's vast coal and gas reserves and resources are an important factor behind our very competitively priced domestic power supplies. Public opinion polls suggest that a majority of Australians would be willing to pay some price to help reduce greenhouse gas emissions. Certainly, the cost of energy is likely to rise in excess of the underlying rate of inflation (CPI) if the cost of reducing emissions is factored into the price of power supplies. The precise timing and level of price increase is, however, uncertain.

Table 7.4 EGS research priorities.

• Share knowledge & drive complementary research	
• Standard geothermal resource & reserve definitions	• Improved HTHP hard rock drilling equipment
• Predictive production modelling	• Improved HTHP zonal isolation
• Predictive reservoir and stress field characterisation	• Reliable HTHP pumps for modest hole diameter
• Mitigate induced seismicity / other HAZOPS	• Enable well longevity (20-30 years)
• Condensers for high ambient-surface temperatures	• Optimum HTHP fracture stimulation methods
• Use of CO2 as a working fluid for heat exchange	• HTHP temperature logging tools and sensors
• Improve power systems	• HTHP flow survey tools
• Education / training	• HTHP fluid flow tracers
• Economic modelling tools	• Mitigation of formation damage, scale and corrosion
• Technologies & methods to minimise water use	
	Overlaps with R&D priorities for the petroleum industry

7.8 Research Activities

7.8.1 Focus Topics

The principal focus topics of Australian research relate to:

- High grading of locations with high potential for the development of Enhanced Geothermal Systems
- Assessment of technologies (including numerical simulation techniques) with high potential to minimise costs and maximise efficiencies in the development of Enhanced Geothermal Systems
- Environmental impacts of developing Enhanced Geothermal Systems, including potential induced seismicity that can be associated with the fracture stimulation of geothermal reservoirs

These research directions are aligned with GIA Annexes I and III.

Considerable alignment exists between experts' research priorities for EGS exploitation. Summaries of priorities for HR EGS research established by the AGEG, the USA's Department of Energy

(2008) and the ENhanced Geothermal Innovative Network for Europe (ENGINE, 2008) also reveal considerable overlap with R&D priorities for the petroleum industry, as listed in Table 7.4.

7.8.2 Government Funded Research

7.8.2.1 Geoscience Australia

Key activities of Geoscience Australia's geothermal energy project under the auspices of the Federal Government's five year (2006-2011) Onshore Energy Security Program during 2007 including calculating the total thermal heat in place within the upper 5 km of the entire continent, compiling granite geochemistry and sediment basin depth as a first-pass geothermal play map, producing two factsheets, preliminary design work on a heat flow database, refining the geological datasets used in the Austherm05 dataset of Chopra and Holgate (2005), and ordering equipment to establish a heat flow measurement capability. Acquisition of seismic, MT, gravity, magnetics and geochemistry data continued in areas with energy potential.

7.8.2.2 South Australia

As detailed in Table 7.3, in the term April 2005 to the mid-March 2008, the South Australian Government has provided $1,350,000 in grants for Australian geothermal projects and research, and additional support is expected. In 2005, the Primary Industries and Resources South Australia (PIRSA) commissioned research by the Australian School of Petroleum at University of Adelaide to undertake a research study of potential induced seismicity associated with the fracture stimulation of ESG wells in the Cooper Basin. This research was undertaken to underpin PIRSA's approach to the regulation of fracture stimulating Hot Rocks. The results of this study are detailed in Hunt, *et al.* (2006; which can be found at: http://www.iea-gia.org/publications.asp). Key conclusions are:

- The Cooper Basin in South Australia is ideally suited to Hot Rock EGS activities in terms of natural background seismicity levels

- Reactivation of any basement faults in the region is unlikely in the vicinity of the Habanero Site

- Seismic events induced by reservoir stimulation at the Habanero well site in the Cooper Basin were of low magnitude (intensity) and fell below the background level that the government's current building design standards allow for. The petroleum industry operating in the same area have been using similar reservoir fracture stimulation methods safely for decades

- The static stress damage zone would not be expected to have any impact on identified local structural features. This is due to the nearby faults being beyond the reach of the induced seismicity associated with reservoir stimulation activity

Also in 2005, the Department of Primary Industries & Resources- South Australia (PIRSA) agreed to be the Contracting Party to the OECD's International Energy Agency's geothermal research cluster under the auspices of the Geothermal Implementing Agreement (GIA).

In early 2006, to foster the commercialization of Australia's hot rock resources at minimum cost and maximum pace, PIRSA reached out to Australian companies, researchers and government agencies with an interest in the development of Australia's geothermal resources; and in mid-2006, the Australian Geothermal Energy Group (AGEG) formed to provide a sector wide alliance to benefit from, and provides intellectual input into the IEA-GIA.

Table 7.5 AGEG endorsed research projects supported with joint PIRSA and geothermal sector support

Theme	Project Name	Summary of key project objectives	Research Partners
AGEG TIG 4 Engineering EGS	Geochemistry, Corrosion and Scaling in HDR Energy Extraction Systems	Determine the effect of variations in geochemical composition of circulating water on clogging of fracture networks in reservoir rock. **Budget:** $110,000 (50% from sector participants)	♦ U Adel (Ngothai & O'Neil) ♦ S.A Museum (Brugger) ♦ Ian Warke Inst. U of SA (Pring) ♦ Geodynamics (Wyborn) ♦ Petratherm (Reid) ♦ Eden Energy (Jeffress) ♦ Greenrock (Larking) ♦ PIRSA (Malavazos)
AGEG TIG 4 Engineering EGS	Full life-cycle water requirements for deep geothermal energy developments in South Australia	Water requirements for each step of geothermal through production will be quantified. An atlas of available water resources; processes for accessing these resources; and (possibly) software for calculating water requirements for specific projects will be developed. The aims are to allow individual project managers to manage water availability, and the industry to counter potential community concerns over water use for geothermal projects. **Budget**: $33,000 ($12,375 from PIRSA Tied Grant; balance from sponsor participants)	♦ Hot Dry Rocks Pty Ltd (HDRPL: Beardsmore, Baria, Cordon, Walsh, Waining & Cooper) ♦ PIRSA (Hill) ♦ Panax (de Graaf)
AGEG TIG 6 Engineering Power Generation	Preliminary assessment of the impact of geo-fluid properties on power cycle design	Study the relationship between the effect of non-condensable gas, fouling and corrosion caused by geofluid properties on surface heat exchangers and the heat transfer efficiency of the exchangers. **Budget:** $85,729 ($6,784 from PIRSA Tied Grant; balance from sponsor participants)	♦ U Adel. (Ashman, Gamboa & Nathan) ♦ Petratherm (Reid) ♦ Pac Hydro (Teoh) ♦ Eden Energy (Jefress) ♦ Greenrock (Larking) ♦ PIRSA (Malavazos)
AGEG TIG 6 Engineering Power Generation	Preliminary assessment of the potential for underground cooling on power cycle design	Test the cost-saving potential of using the thermally cool and stable soil layer to cool surface geothermal exchangers, pipework and plant. Compare different underground cooling systems with air cooling systems in Australian conditions. **Budget:** $44,550 ($22,275 375 from PIRSA Tied Grant; balance from sponsor participants)	♦ U Adel. (Dally, Nathan & Ashman) ♦ Pac Hydro (Teoh) ♦ Petratherm (Reid) ♦ Eden Energy (Jeffress) ♦ Greenrock (Larking) ♦ PIRSA (Malavazos)
AGEG TIG 6 Engineering Power Generation	State of the Art in Power Cycles for geothermal applications and bottoming cycles	Make a detailed comparison of the performance and operating conditions of selected existing geothermal power plants with the range of conditions expected to apply in South Australia. Develop a detailed model of the Kalina cycle using HYSYS and compare with existing models - ORC and SC. **Budget**: $83,710 ($41,855 from PIRSA Tied Grant; balance from sponsor participants)	♦ U of Newcastle (Doroodchi) ♦ U Adel (Nathan & Ashman) ♦ Pac Hydro (Teoh) ♦ Petratherm (Reid) ♦ Eden Energy (Jeffress) ♦ Greenrock (Larking) ♦ PIRSA (Malavazos)
AGEG TIG 6 Engineering Power Generation	Development of a geothermal power plant cost estimator - Stage 1: basic estimates	Develop a model to estimate costs of geothermal power generation (South Australian conditions). The model will provide input options for key variables such as well depth, ambient conditions, geofluid temperature *etc*. **Budget:** $40,979 ($8,610 from PIRSA Tied Grant; balance from sponsor participants)	♦ U Adel.(Nathan) ♦ Petratherm (Reid) ♦ Eden Energy (Jeffress) ♦ Greenrock (Larking) ♦ PIRSA (Malavazos)
AGEG TIG 4 Geology EGS	Adelaidean reservoir characterisation	Characterise Adelaidean rocks for their potential to serve as heat exchange reservoirs within geothermal insulators and potential for geosequestration reservoirs in the vicinity of coal-fired electricity plants in the Port Augusta region **Budget:** $55,000 ($27,500 from PIRSA Tied Grant; balance from sponsor participants)	♦ U Adel. (Ainsworth) ♦ Petratherm (Reid) ♦ Eden Energy(Jeffress) ♦ Torrens (Matthews) ♦ PIRSA (Hill)
AGEG TIG 9 Geology Data Management	Forward prediction of spatial temperature variation from 3D geology models	Develop model for rapid calculation of spatial variations of temperature from 3D geology. Compare model-derived temperatures with observed to refine model. Demonstrate methodology via a case study of Petratherm's Paralana Project. **Budget:** $110,000 ($27,500 from PIRSA Tied Grant; balance from sponsor participants)	♦ Intrepid (Gibson) ♦ Calcagno (BRGM), ♦ GA (Budd) ♦ Petratherm (Reid) ♦ Eden Energy (Jeffress) ♦ PIRSA (Hill)
AGEG TIG 4 Geology EGS	3D reconstruction of the Adelaide Geosyncline	Produce a geologically and geophysically sound 3D model of the Adelaide Geosyncline from studies of outcrop geology (existing geological maps, satellite images analysis, field work) and potential field data (gravity and magnetic data) interpretation and forward modelling. **Budget**: $248,324 ($27,858 via PIRSA Tied Grant; balance from sponsor participants)	♦ U Adel. (Backe & Giles) ♦ U of Pau (France); ♦ U of Toulouse (France) ♦ HDRPL (Beardsmore) ♦ Torrens (Matthews)
AGEG TIG 2 Geol. / Engin../ Finance Reserve Definitions	Geothermal Reserve and Resource Estimates and Definitions	Establish a trustworthy code and guidelines for estimates of the in-place and extractable geothermal heat energy in hot rock resources. Sustain the draft to international peer review, including comments from the ASX, the JORC Committee, the IEA's GIA, AGEG members, and others. **Budget:** $27,500 (50% from sector participants)	♦ SKM (Lawless) ♦ Geodynamics (Williams); ♦ GA (Holgate); ♦ Petratherm (Reid) ♦ Torrens (Matthews) ♦ Greenrock (Larking); ♦ HDRPL (Beardsmore) ♦ Eden (Graham Jeffress) ♦ Intrepid (Gibson) ♦ PIRSA (Goldstein)

In May-July 2007, PIRSA made two tied grants to the University of Adelaide to foster the emergence of South Australian universities to become the world's hub for excellence in innovative Hot Rock geothermal energy research, demonstration and development projects. These include:

- A $50,000 tied grant to extend the findings from Hunt, *et al.* (2006) to the Adelaide Geosyncline. This will enable an analysis of induced seismicity risks associated with geothermal reservoir stimulation operations. This will result in the establishment of peer-reviewed protocols for assessing and managing potential induced seismicity risks arising from these activities. The resulting protocols will also have relevance to induced seismicity risk management for geo-sequestration operations. The protocols will have direct application to regions identified to be of high Hot Rock potential in Australia. Operators of geothermal energy projects in Australia will then have a credible foundation to develop or their own hazard management strategies to avoid negative impacts from induced seismicity. PIRSA's regulatory aim is two-fold: (1) foster robust risk-management frameworks and (2) sustain widespread, multiple-use land access for geothermal energy projects by attaining stakeholders' confidence that regulated activities undertaken by companies will deliver safe and sustainable operations

- A $250,000 tied-grant to initiate Hot Rock geothermal research in the South Australian context. The tied grant requires project plans to be agreed by the geothermal sector- through the Australian Geothermal Energy Group (AGEG). The framework specified in the relevant Deed between the University of Adelaide and South Australia's Minister for Mineral Resources Development is designed to:

  - Enable and stimulate national and international collaboration in geothermal energy research

  - Attract in-kind and financial inputs from non-SA Government sources that are a multiple of the SA Government inputs. The Australian geothermal industry, the Federal Government (through Geoscience Australia and the CSIRO) and capable universities both in and outside South Australia (in addition to the University of Adelaide) are expected to welcome and participate strongly in this initiative, and/or complementary initiatives to follow

  - Ensure that funded projects are focused on what industry considers to be high priority research, findings undergo high quality peer review, and final reports of findings are prepared and made freely and openly available

  The criteria for tied grants are designed to:

  - Underpin practical, high priority research aligned with the geothermal industry's emerging requirements and endorsed by the AGEG and an AGEG Technical Interest Group Leader

  - Entice at least matching funds from project participants, thus creating leverage for practical, high priority research aligned with the geothermal industry's emerging requirements

  - Foster collaboration between industry and university researchers from across Australia by allowing up to 80 % of the funds for any single project (and up to 80 % of the $250,000 tied grant) to be used to bring in expertise from outside the University of Adelaide, thus enabling other capable institutions (in South Australia and elsewhere) to participate in studies relevant to the advancement of geothermal energy development with generic and/or specific application to South Australian geothermal projects

Table 7.5 summarizes the nature of the AGEG endorsed research projects underway under the South Australian Grant to the University of Adelaide. The aggregate budget for these AGEG endorsed research projects is $737,538 (including $250,000 from PIRSA). The quality and impact of reports on findings and scope of inputs from non-SA Government sources are key performance indicators for this initiative. The findings of these research projects will be made freely available, and the experience gained will inevitably be leveraged into further valuable research and the development of a service sector for the geothermal industry. This initiative will be complementary to any/all other proposals from the Federal Government and other jurisdictions to support geothermal research.

7.8.2.3 Queensland

In September 2007, the Queensland State Government committed $15 million to the Queensland Geothermal Energy Centre of Excellence (QGCoE) at the University of Queensland for research towards exploitation of the deep geothermal reserves of South Australia and Queensland through: (1) resource management and optimization; (2) optimum power conversion; (3) power plant cooling systems; and (4) long-distance electricity transmission. The Centre will work with other national and international research groups to address all challenges that need to be overcome before deep geothermal energy becomes a proven commercial reality. The specific research plans for the Queensland Geothermal Energy Centre will be finalised by September 2008. It is expected that a major thrust of the Centre will be the supercritical CO_2 geothermosiphon directed towards a field demo project in 2013 as shown in Figure 7.5. The Centre will also pursue novel power conversion systems for more conventional binary geothermal power plants, air-cooled heat exchangers and long-distance power transmission and electricity market and network modelling.

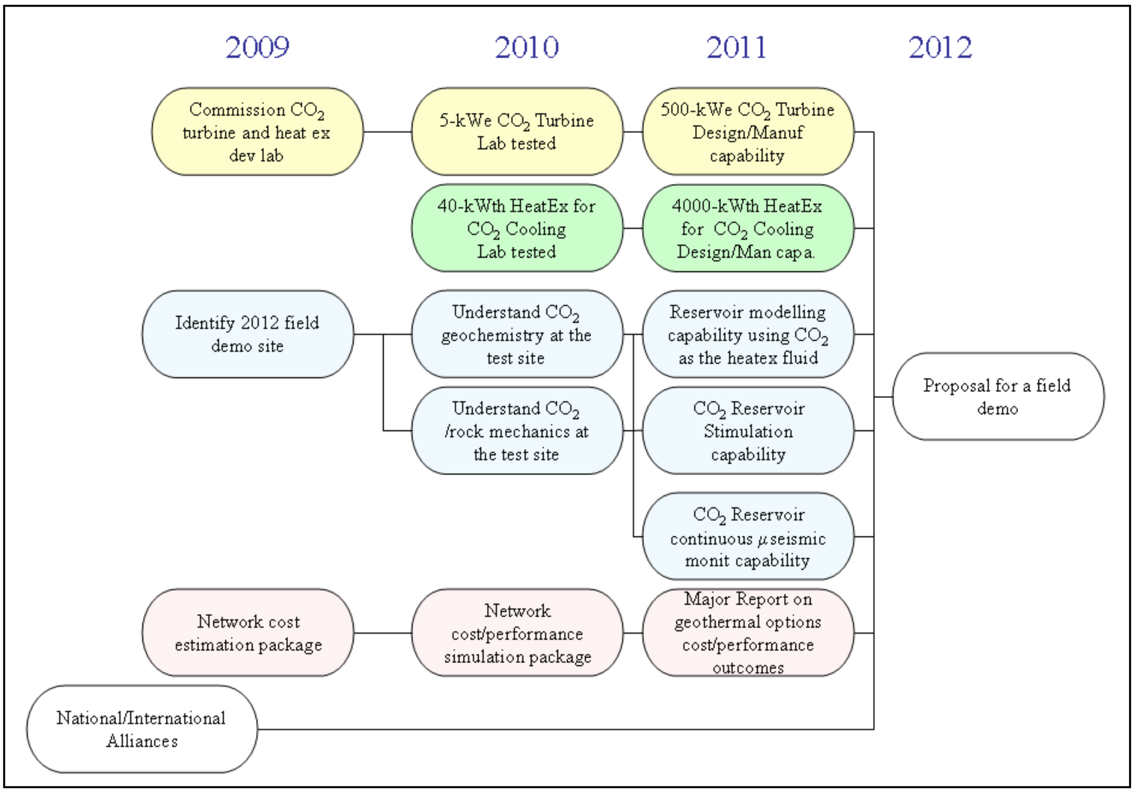

Figure 7.5 Road map to a field demo project using a supercritical CO_2 geothermosiphon.

The centre will also work with other Australian universities to introduce undergraduate and post-graduate programs to develop a skill base, and train postgraduate students. Hal Gurgenci is the inaugural Director of the QGCoC, which is expected to make a submission to the Garnaut Review to elaborate the prospectivity of circulating stored supercritical CO_2 in a closed loop through a hot dry rock reservoir both to yield geothermal power and sequester CO_2 as a by-product.

7.8.2.4 Western Australia

On 29 February 2008, the Western Australian State Government announced a new $2.3 million WA Geothermal Centre of Excellence. The Centre comprises three participants: CSIRO, The University of Western Australia, and Curtin University of Technology. Because of Perth's geological setting, the Centre focuses on direct heat use technologies (e.g. geothermally powered air conditioning and desalination) for use in population centres where there is shallow groundwater of moderate temperature. Geothermal groundwater convection in settings such as the Perth basin provides a natural underground heat exchanger. Owing to the high natural permeability there is no need for artificial hydraulic fracturing. For 3-D modelling of these geothermal systems the Centre will harness the supercomputers now being set up in Perth, and will make it possible to drive geothermal research into computationally intensive directions that had previously been out of reach in Australia. The Centre will also offer geothermal training to students and industry. The research is organised in three interlinked Programs: 1) Assessment of Perth Basin Geothermal Opportunities using presently available data; 2) Optimal use of geothermal resources; 3) Identification of Future Potential by going deeper.

7.8.2.5 Northern Territory

On the basis of geology, existing physiography and hot rock potential, an area in the vicinity of Katherine and within the zone covered by the existing major NT power transmission grid looks quite exciting. Hot Springs in the Daly region 100km north west Katherine and at Mataranka 120km SE of Katherine coincide with an interpreted presence of a major crustal heat source in the region.

NT government geologists have had little opportunity to further develop the interpretation of the heat source geology but the NT has good regional magnetic, gravity and particularly radiometric coverage which could be utilised by explorers to focus their research.

To assist in identifying geothermal opportunities in the Territory a review of the geothermal potential of the Territory is being prepared by one of Australia's leading geothermal experts, Dr Graeme Beardsmore. The results of this study were presented at Annual Geoscience Exploration Seminar (AGES) at Alice Springs in March 2007. It was also released as a CD containing a summary report and GIS. The GIS is intended to be a toolkit for use by geothermal explorers, containing multiple layers of information relevant to the assessment of geothermal potential.

7.8.2.6 Victoria

Geological Survey Victoria (GSV) initiated geothermal exploration activities in Victoria by integrating and adding value to assorted petroleum, mineral and water datasets and by commissioning new temperature sampling in boreholes. In addition, GSV is supporting heat flow research work at Melbourne University and is collaborating with Geoscience Australia to acquire thermal conductivity and downhole temperature data.

GSV has commenced a series of major studies that will better characterise the potential of Victoria's sedimentary basins and bedrock for geothermal potential.

The core of these studies will be the construction, as part of GSV's four-year Rediscover Victoria in 3-D initiative, of a fully attributed 3-D geological model of Victoria's sedimentary basins and basement terrains. The model will include the key sedimentary horizons and surfaces in basins across the entire state. Basin and crustal architecture, as well as basin thermal structure and subsurface fluid flow, are key science themes of the initiative. The major sedimentary basins, the Gippsland, Otway and Murray basins will be evaluated sequentially. Detailed investigations will be undertaken into factors such as top seal integrity, reservoir and source rock quality and distribution and fault geometries. Integration of these data will allow the development of high-resolution, 3-D fluid flow models.

7.9 Geothermal Education & Conferences

Geoscience Australia produced two factsheets, Electricity Generation from Geothermal Energy in Australia and Direct-use of Geothermal Energy: Opportunities for Australia available at: http://www.ga.gov.au/minerals/research/national/geothermal/index.jsp.

The South Australian Department of Primary Industries and Resources (PIRSA), as Contracting Party to the GIA and the secretariat for the Australian Geothermal Energy Group has developed a geothermal web page that currently serves as a public portal to salient information pertaining to geothermal energy in Australia, including Australia's GIA membership. Members are detailed at the following webpage: http://www.pir.sa.gov.au/geothermal/ageg/membership.

The Northern Territory proposes to develop web pages (as part of the Departmental web site) for geothermal education and information and will be seeking assistance from other State Governments and companies as the site develops.

There is a growing awareness of geothermal energy in Australia and this is reflected in the inclusion of geothermal energy within mainstream energy, petroleum and mineral conferences. On 1-2 August 2007, the 3rd Hot Rock Energy Conference in Adelaide, South Australia was attended by 120 professionals from the geothermal sector, business and government. Eighteen papers were presented over the 2-day conference.

7.10 International Cooperative Activities

Australia is a Member of the IEA Geothermal Implementing Agreement. Geodynamics and Green Rock Energy are Sponsor Members of the IEA Geothermal Implementing Agreement.

Petratherm has entered into an exclusive cooperative agreement with four Chinese government institutions to identify high prospect geothermal energy projects in China. The Asia Pacific Partnership (APP) which is supported by the Chinese and Australian governments will identify the potential for conventional geothermal, EGS, hot water and electricity plays in a number of provinces in China.

Geodynamics Limited and the Australian National University have formal agreements with Japanese researchers in geothermal energy.

AGEG representatives held discuss research directions with the USA's Department of Energy (Renewable Energy Group) and Lawrence Berkeley National Labs in 2007.

The French Bureau de Recherches Geologiques et Minieres (BRGM) has linkages with Intrepid Geophysics and Petratherm. BRGM have expertise in the integration of state of the art rapid 3-D geological modelling with geothermal temperature and thermal capacity latent in radiogenic granites.

7.11 Websites

- Petroleum & Geothermal Group, PIRSA: http://www.pir.sa.gov.au/geothermal and http://www.pir.sa.gov.au/geothermal/home

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Acknowledgements

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National Activities

Chapter 8

European Commission

The Soultz-sous-Forêts EGS power plant today (courtesy of Andreas Piontek).

8.0 European Union Policy

On 10 January 2007, the Commission presented an "energy and climate change package" including a Strategic Energy Review focusing on both external and internal aspects of EU energy policy. The package contained proposals for specific targets on:

- Renewable energy (20 % by 2020)
- Biofuels (10 % in transport by 2020)
- Greenhouse gas emissions reduction (20 % by 2020)

At the summit in March 2007, European heads of state agreed to move forward with ambitious objectives to slash greenhouse-gas emissions and boost renewable energies by 2020 in a bid to reduce the EU's dependency on imported fuels and set the pace for "a new global industrial revolution".

Central to the summit agreement is a recognition that energy and climate change policies should go hand in hand. It stressed the need for "decisive and immediate action" on climate change and underlined "the vital importance of achieving the strategic objective of limiting the global average temperature increase to not more than 2 °C above pre-industrial levels".

To achieve this aim, EU leaders agreed to:

- A binding target to slash the EU's greenhouse gas emissions by 20 % in 2020 compared with 1990 levels. EU leaders agreed that the objective should be pursued "unilaterally" even if there is no international agreement on reducing greenhouse-gas emissions after 2012 when the Kyoto targets expire

- A commitment to reduce emissions by 30 % provided that other industrialised nations, including the US, commit themselves to comparable emission reductions and that "advanced developing countries" (i.e. China and India) contribute as well in the framework of a post-2012 agreement

To achieve these objectives, the summit endorsed an action plan to be implemented between 2007 and 2009. The plan's main elements include:

- A binding target to raise the EU's share of renewables to 20% by 2020

- An obligation for each member state to have 10 % biofuels in their transport fuel mix by 2020

- Boosting energy efficiency with a target to save 20 % of the EU's total primary energy consumption by 2020. New initiatives here include proposals for an international agreement on energy-efficiency standards for consumer appliances

- Aiming towards "a low CO2 fossil fuel future" with support for clean coal technology, using carbon capture and storage deep underground

- Developing a European Strategic Energy Technology Plan to focus R&D efforts on low carbon technologies

- On nuclear, the Commission chose to take an "agnostic" stance, leaving it up to member states to decide

Continuing this policy, European Commission put forward ambitious targets on 23 January 2008, proposing a Directive on the promotion of the use of energy from renewable sources. This proposal sets the framework to achieve the target of a 20 % share of renewable energy sources in the final energy consumption by 2020. The attainment of this target will require the use of the diverse renewable non-fossil energy, sources, among which geothermal energy.

8.1 Current Status of Geothermal Energy Use in 2007

Few European countries have the natural resources necessary for electrical valorization of geothermal energy. At the end of 2006, the installed electrical capacity for the countries of European Union was 854.6 MW_e and the thermal capacity was 9564.6 MW_{th}, including 7,328.3 MW_{th} of geothermal heat pumps. The most active country has been Iceland, which more than double its installed capacity to reach 421.2 MW_e, with new power stations located in Nesjavellir, Hellisheidi and Reykjanes.

For the medium and low temperature geothermal energy, Hungary is the biggest user of medium and low temperature geothermal energy with installed capacity of 725 MW_{th} in 2006. Italy is the second ranked European Union country for low temperature applications with a capacity of 500 MW_{th}. France is the third larger user in the EU with an installed capacity of 307 MW_{th}.

The European Union is one of the main regions to have developed heat pump technology. The heat pump industry is currently the largest and the most dynamic sector of the geothermal energy industry. Sweden has the largest number of heat pumps with more than 270,000 units, i.e. a cumulated capacity of 2,431 MW_{th} (GEB, 2007).

8.2 Research Activities in the European Union in 2007

8.2.1 New Activities

On 1 January 2007, a new geothermal research project HITI (High Temperature Tools and Instruments) started. The project aims to provide geophysical and geochemical sensors and methods to evaluate deep geothermal wells up to supercritical conditions (T> 380 °C). Supercritical geothermal wells are presently non-conventional but may provide a very efficient way to produce electricity from a clean, renewable source.

A deep geothermal well will be drilled for this purpose into the Iceland volcanic zone, as part of the IDDP (Iceland Deep Drilling Project) and with joint funding from Icelandic industry and science. Aimed to explore supercritical wells and to enhance production from them, HITI is to develop, build and test in the field new surface and down-hole tools and approaches for deep high-temperature boreholes. A new set of tools and methods have been chosen to provide a basic set of data needed to describe either the supercritical reservoir structure and dynamics, or the evolution of the casing during production. The set of new instruments should tolerate high temperature and pressure in a highly corrosive environment. Slickline tools up to 500 °C and wireline tools up to 300 °C will be developed due to the present limitation in wireline cables (320 °C). For reservoir characterization, the measured quantities are temperature and pressure (for fluid characterization, thermodynamic modelling of the reservoir and thermo-mechanical modelling of borehole integrity), natural gamma radiation and electrical resistivity (for basement porosity and alteration), acoustic signal (with borehole wall images for reservoir fracturing and *in-situ* crustal stresses), reservoir storativity and equilibrium (from geothermometers and organic tracers) and fluid sampling. For casing and cement integrity, collar location, as well as thickness changes due to corrosion or plugging from mineral precipitation (from acoustic images again) will be measured. The new tools will be tested *in-situ* in existing Icelandic wells, including the IDDP hole.

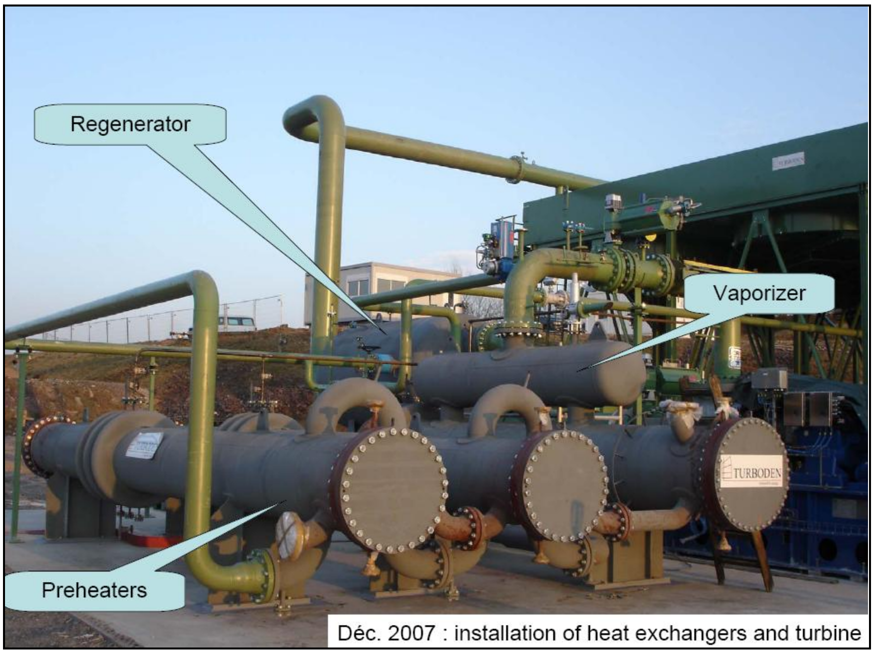

Figure 8.1 Soultz heat exchangers and turbine.

8.2.2 The Soultz EGS Pilot Plant

After the first stage of the Soultz pilot plant project was accomplished, which included the deepening of the GPK2 well to 5,000 m and then drilling of two more wells (GPK3 and GPK4) to the same depth, all from the same pad but with some 650 m bottom-hole separation between each one, the stimulation works started. The stimulation was necessarily to improve the connectivity to the natural system and the local permeability. Two kinds of experiments were tested at Soultz to enhance the hydraulic performance of the geothermal system. The classical treatment, hydraulic stimulation and also the chemical stimulation was tried out.

After all hydraulic and chemical stimulation tests, improvements were achieved in hydraulic performance of the boreholes. The initial productivity in well GPK2, before any stimulation, was estimated between 0.01 and 0.031 l/s/bar. After the stimulation, the productivity was estimated to around 0.8 l/s/bar and was close to the target of 1 l/s/bar. In well GPK3 the productivity increased to 0.39 l/s/bar and in well GPK4 to 0.5 l/s/bar.

Also, the first power production started. The first phase will be a long test of 1.5 MW_e plant, using fluid produced only from well GPK2 and reinjected into well GPK3. There will be a parallel test of production from well GPK4, as it needs further testing before it can be connected to the power plant.

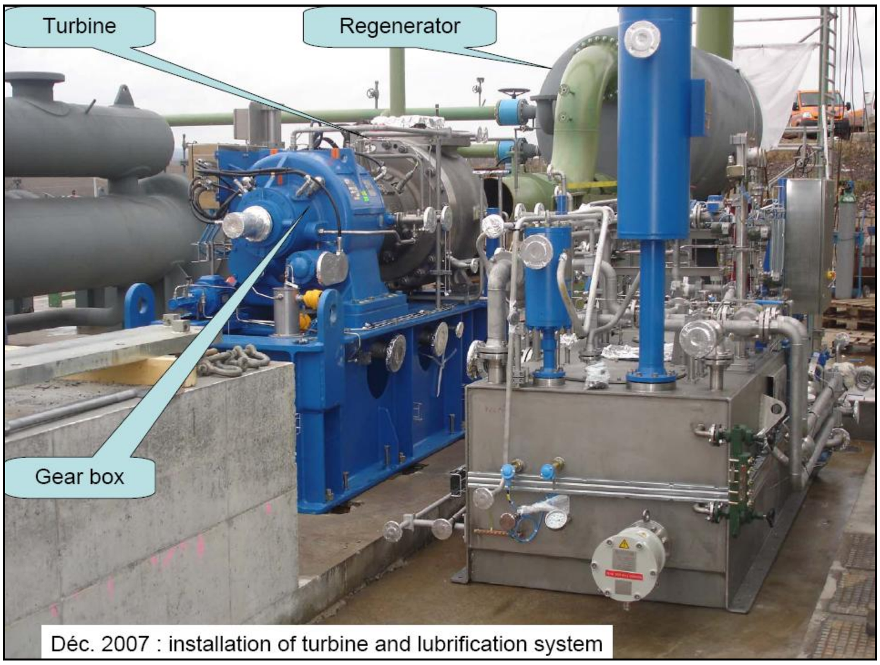

Figure 8.2 Soultz turbine and lubrication system.

In the long term, the goal is to bring the capacity to around 3 MW_e, and even increase the capacity, if the reservoir performs as expected.

8.3 References

GEB (2007) Geothermal Energy Barometer- September 2007.

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National Activities

Chapter 9

France

Overview of Soultz-sous-Forêts pilot power station July 2008 (courtesty of Albert Genter)

9.0 Introduction

France joined the IEA-GIA at the beginning of year 2007. Consequently, this is the first country annual report produced by France for IEA-GIA, and will thus include a brief overview of the geothermal potential in France.

There is a large diversity of geothermal resources in France, and as a result, all types of geothermal exploitation:

- Geothermal heat pumps can be installed almost everywhere, either ground source or groundwater. The entire French territory has a good supply of superficial water-bearing strata that can be exploited using heat pumps.

➢ Low-energy resources are mainly located in the two major existing sedimentary basins: the Paris Basin (for which Paris is the geographical centre) and the Aquitaine Basin (in southwest France). The resources are found at depths between 600 m and 2,000 m. Other French regions also have high potential for low-energy resources, but the geological structures are more complex and the fields much more localized (Hainault, Bresse, Limagne, *etc*.), and less known. Deeper in these basins can be found medium-energy resources which could be suitable for CHP exploitation.

➢ France also possesses high-energy resources that are potentially exploitable for electricity production. These are located essentially in its Overseas Departments (the volcanic islands of the French West Indies- Guadeloupe and Martinique, and the Indian Ocean- La Réunion).

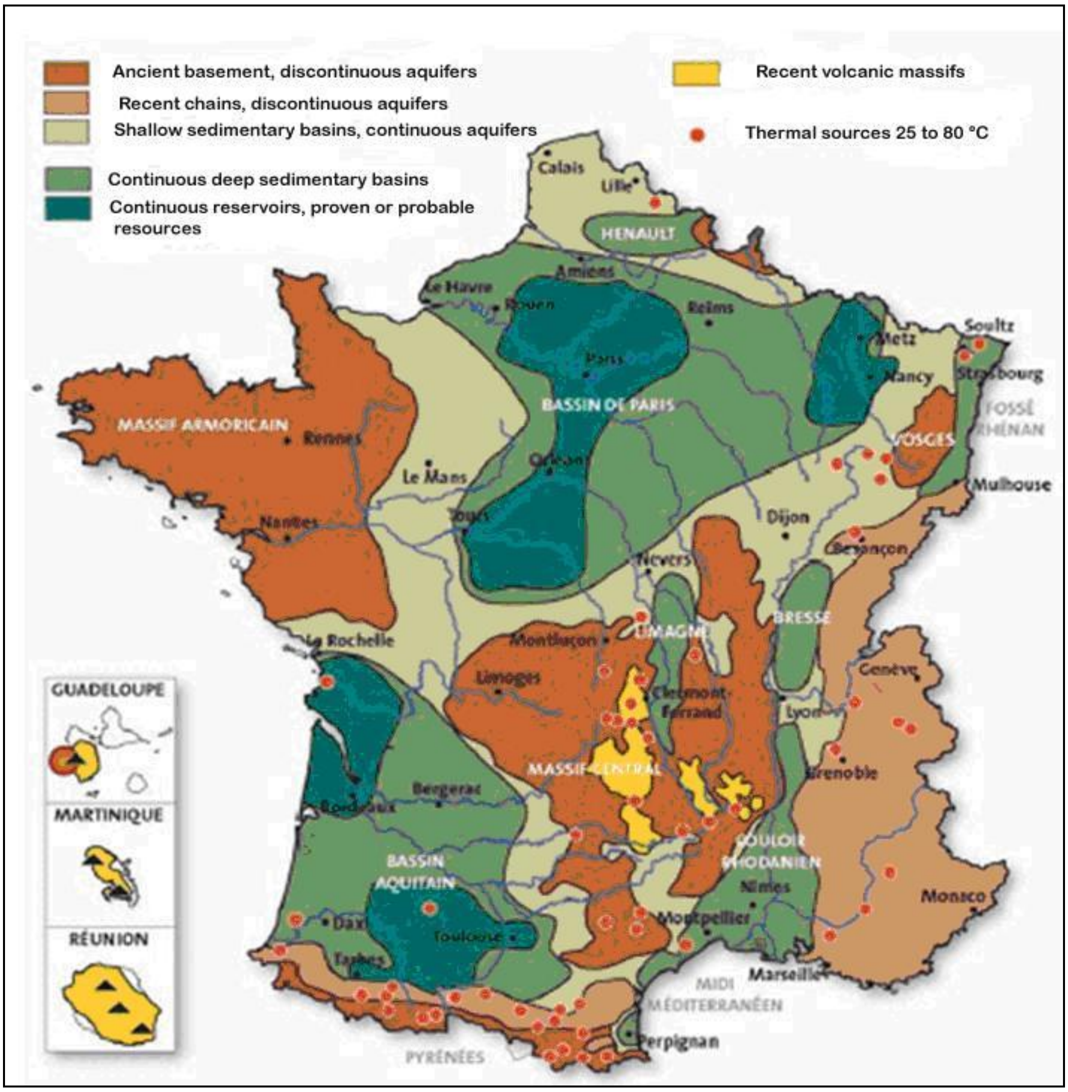

Figure 9.1 French geothermal resources.

The exploitation of geothermal resources in France has seen several phases:

➢ A major development phase based on low enthalpy resources from sedimentary basins at the beginning of the 1980s; with, in particular, more than 70 geothermal district heating systems operating in the Paris area

- A period of withdrawal during the 1990s marked by very little new activity. During this period, public support was geared essentially towards the Soultz-sous-Forêts Deep Geothermal Energy Programme

- A boost in activity since 1998 following the Kyoto Agreement, and the decision taken in France to resume an active policy for energy management and the development of renewable energies. Since 1998, geothermal energy activity in France has been concentrated on four main sectors:

  - Geothermal Heat Pumps (GHP)- The market has been undergoing regular and significant expansion for the past few years due essentially to the impetus from EDF (French Electricity Board), ADEME (French Environment and Energy Management Agency), BRGM (French Geological Survey), and a dynamic industrial influence

  - Geothermal district heating systems- The thirty or so systems still in operation persevered notably due to a public-support policy for the connection of new clients. The measures adopted enabled some 10,000 additional dwellings to be linked up to the systems, providing a total of approximately 170,000 connected dwellings. After some years of hesitations, new operations with drilling have been launched since 2007

  - Electricity production in the French Overseas Departments- A new 11 MW_e power plant has been in operation at Bouillante in Guadeloupe, since 2004, raising the site's total capacity to 15 MW_e. In Martinique and La Réunion Island, geothermal exploration programmes are planned to be launched in the near future in prospective potential areas identified during prospecting surveys on-going since 2000

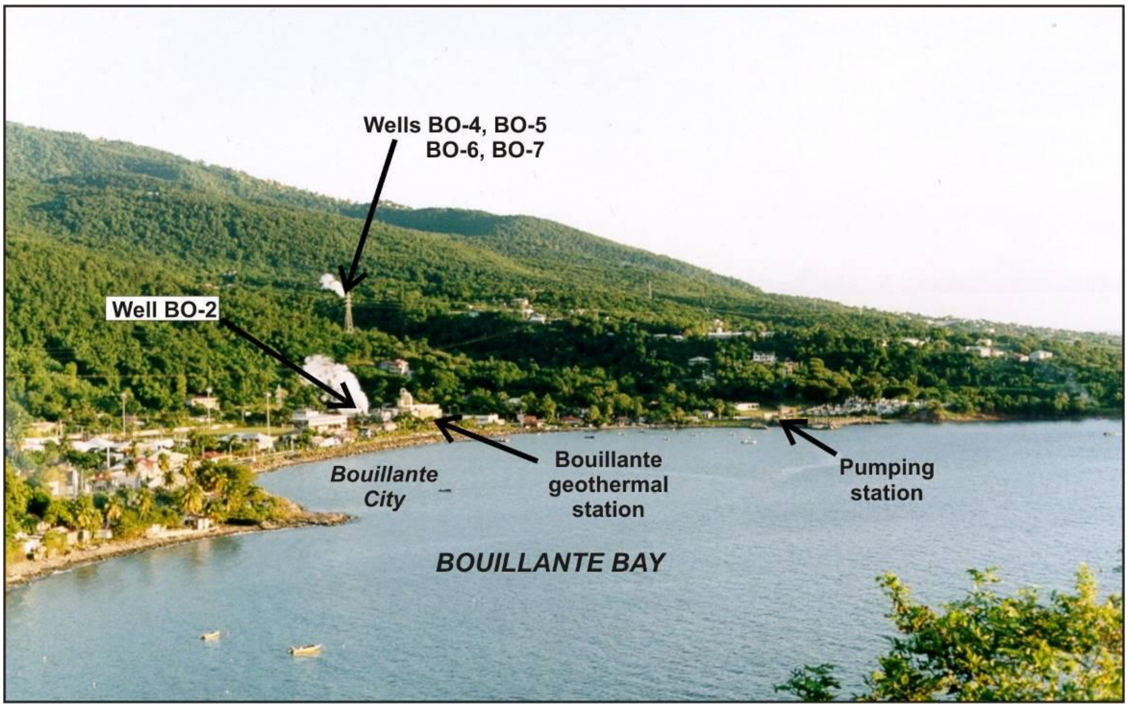

Figure 9.2 The geothermal plant in Bouillante Bay.

- Deep geothermal energy at Soultz-sous-Forêts- Construction of a scientific pilot plant module has been underway since 2002, following the R&D work conducted on the site since 1987. The pilot plant, comprising a three-well system drilled through granite to a depth of about 5,000 m, will become operational in 2008

Over the coming years, all these activities should continue in a sustainable manner, following the implementation of the French Energy Law in 2005 and the "Grenelle de l'environnement" process launched in 2007. These two elements, which establish the structure for the future French energy policy, assign renewable energies, including geothermal resources, an important role and, *a priori*, the necessary financial resources to allow their real development.

9.1 Highlights for 2007

The year 2007 was marked by some highlights illustrating this context:

- The national policy was deeply marked by the "Grenelle de l'environnement"- Nicolas Sarkozy launched just after his election a huge consultation process on all environmental issues of the French national policy. This "Environment Round Table" was named "Grenelle de l'environnement". Regarding the renewable energies, it was decided to set a target above 20% of renewable energy sources in energy consumption, a decision consistent with the decision of the European Council of 9 March 2007.

- In order to enhance its involvement in geothermal energy, BRGM created a department devoted to geothermal energy. This new department, with a staff of around twenty engineers, takes over the whole activity linked with geothermal energy previously realised by different units. Moreover, it shall promote geothermal energy and its different uses together with the ADEME, the French Environment and Energy Management Agency.

Concerning the different types of geothermal activity the main highlights are the following:

- Geothermal heat pumps: The market goes on with its fast growing pace (25% for the sales of GHPs for individual houses).

- Geothermal district heating: For the first time for more than 15 years, new wells have been drilled in Paris Basin- a doublet was drilled during the autumn 2007 for Orly city's district heating.

- Soultz-sous-Forêts: The project of a scientific pilot plant entered its final phase: a 1.5 MW_e turbine was delivered on site in November 2007, for a commissioning of the plant in 2008.

9.2 National Policy

9.2.1 Strategy

The French national policy towards renewable energies took a major turn with the "Grenelle de l'environnement", France's Environment Round Table. For the first time, the Round Table brought all the civilian and public service representatives together around the discussion table, thus forming 5 colleges: the State, unions, employers, NGOs and local authorities.

For three months, workgroups met to propose concrete action to be implemented at national, European and international level. In October, these proposals were opened up to debate by a range of public groups.

Following this debate stage, 4 round tables were organised. On 25 October 2007, the French President presented the conclusions of these discussions. Thus began a stage looking at the technical, legal and administrative aspects, which will serve to assess how best to implement all the measures decided upon. Around thirty operational committees met to define guidelines and objectives for operational programmes.

Regarding energy, the main conclusions were the following:

- Contributing in an ambitious and determined manner to the European objective of "3 x 20 in 2020" objective
- Setting France on the "factor 4" course- reducing our emissions 4-fold by 2050
- "+20 megatons of equivalent oil by 2020"- increasing our renewable energy production by 20 million equivalent oil tons by 2020 and exceeding 20% of renewable energies in overall final energy consumption nationwide
- Energy savings- opening up of sector-based projects: building- 38% over the next 12 years; transport/mobility- 20% over the next 12 years; setting up of immediate and/or structuring operational measures.

9.2.2 Legislation and Regulation

Geothermal activity is mainly covered by the mining code, which is constructed with a triple objective:

- Optimizing the exploitation of mining resources
- Minimizing the risks, pollution and inconvenience caused by this exploitation (same goals as the environmental code: risks, water, air, noise, *etc*.)
- Guaranteeing the health and safety of workers

Three distinct permits or authorisations are needed in order to exploit a geothermal deposit:

- Exploration permit, to be allowed to search for the geothermal deposit (art 98 of Mining Code)
- Exploitation permit that gives the owner an exclusive right on the resource in the perimeter of the permit. (Article 100 of Mining Code)
- Drilling authorisation and exploitation authorisation, before any mining work is started either in exploration or exploitation (Article 83 of Mining Code)

9.2.2.1 *Exploration and Exploitation Permits*

There are two different procedures for high temperature and low temperature resources (Table 9.1).

No exploration or exploitation permit is needed to conduct operation of *"very small importance*". The operation only needs to be declared to the local authority one month before it starts.

Contents of these permit applications:

- Financial and technical capacities of the applicant : the applicant must prove that he has the financial and technical ability to conduct the operation while respecting the goals of the mining code

- Permit perimeter and duration
- Work program and use of extracted heat
- Exploitation volume (if known)
- Environmental impact study- description of environmental risks and impacts caused by the project, and description of measures taken to reduce or suppress them

Table 9.1 Procedures for high and low temperature resources.

High temperature > 150°C	**Low temperature < 150°C**
• Application deposit to the Prefect services	• Application deposit to the Prefect services
• One month public enquiry	• 15 days public enquiry
• Competitors have one month after the end of the public enquiry to declare themselves	
• Consultation of relevant state services and town councils	• Consultation of relevant state services and town councils
• Permit granted by decree or ministerial act	• Permit granted by the Prefect after hearing by the departmental committee for environment and risks
• Duration of permits - 5 years max for exploration - 50 years max for exploitation	• Duration of permits - 3 years max for exploration - 30 years max for exploitation

9.2.2.2 *Drilling and Exploitation Authorization*

The procedure for drilling authorisation is the same for both high and low temperature resources:

- Application deposits to the Prefect services
- One month public enquiry
- Consultation of relevant state services and town councils
- Authorisation granted by the prefect after hearing by the departmental committee for environment and risks

The "very small importance" operations only need to be declared to the DRIRE one month before it starts. Strictly speaking , these operations are not exempted from drilling authorizations, but the procedure is much too complicated for individuals.

But in every case:

- Drilling deeper than 10 meters is subject to declaration (Article131 of the Mining Code)
- Information resulting from drilling is then placed at the disposal of the public by the BRGM (Article 132 of the Mining Code)

- Drillings and exploitation have to respect the general prescriptions (for a balanced management of the water resource and the protection of water with respect to pollution), as specified in the Water Law

Contents of drilling authorization applications:

- Detailed technical program of work

- Environmental study- description of environmental risks and impacts caused by the drilling, and description of measures taken to reduce or suppress them

- Health and safety document- evaluation of risks encountered by workers and description of measures taken to reduce or suppress them

- Description and evaluation of cost of end of exploitation operations. The applicant must define in advance how he will plug the wells and rehabilitate the site after the exploitation of the geothermal deposit is over. The cost involved must of course be compatible with the financial capacity of the applicant.

9.2.3 Progress Towards National Targets

The national targets for renewable energy to be taken in application of the conclusion of the "Grenelle de l'environnement" will be determined in 2008.

The national targets set after the law on energy in 2005 are presented in Table 9.2.

Table 9.2 National targets.

	2005	**2010**	**2015**
District heating – Paris Basin	105 ktoe	150 ktoe	300 ktoe
District heating – others	25 ktoe	35 ktoe	50 ktoe
Collective ground source and groundwater heat pumps	50 ktoe	75 ktoe	150 ktoe
Individual ground source or groundwater heat pumps	32 ktoe	140 ktoe	400 ktoe
TOTAL	**212 ktoe**	**400 ktoe**	**900 ktoe**

The fast growing rate of the market for geothermal heat pumps places France in a good position to achieve its targets for this sector. On the contrary, concerning district heating there were no new operations in 2005 and 2006, meaning that the renewal of this activity has been postponed for 2 years. Thus the 2010 target should be reached around 2012.

9.2.4 Government Expenditure on Geothermal Research and Development (R&D)

In 2007, the French Government spent 2.5 M €.

9.2.5 Industry Expenditure on Geothermal R&D

From 2001 up to 2007, 52 M € were allocated to the Soultz EGS research programme, mainly for logistic activities (construction of a scientific pilot with three deep wells and an ORC unit).

R&D activity in the field of geothermal heat pumps also exists, but it is very difficult to give a good estimate of the expenditures involved. The market in France in 2007 for domestic heat pumps reached 280 M €, only for the equipment production (air-air equipment excluded). Considering that the geothermal heat pumps market represented around 30% of this market and 5% of this part is devoted to R&D activities, the R&D expenditures in the field of geothermal heat pumps could be estimated in 2007 at 4-5 M €.

9.3 Current Status of Geothermal Energy Use in 2007

9.3.1 Electricity Generation

9.3.1.1 Installed Capacity

The geothermal plant of Geothermie Bouillante in Guadeloupe was the only plant producing electricity in France in 2007. The installed capacity (and operating capacity) is 15 MW_e.

9.3.1.2 Total Electricity Generated

The electricity production in 2007 was 94.9 GWh.

9.3.1.3 New Developments During 2007

There were no new developments in overseas departments in 2007.
On the mainland, at Soultz-sous-Forêts, a 1.5 MW_e turbine was delivered on site in November 2007, for a commissioning of the plant in 2008.

9.3.1.4 Rates and Trends in Development

The growth is flat for 2007. The commissioning of Soultz-sous-Forêts could represent a small increase in 2008. Apart that one, no new projects are planned at this date, but there are some prospects for several tens of MW_e in overseas departments in the next years.

There were no new wells drilled in 2007.

9.3.1.5 Contribution to the National Demand

Geothermal energy's contribution to both the installed capacity and the energy generation were negligible.

9.3.2 Direct Use

9.3.2.1 Installed Thermal Power

In 2006, the installed capacity was about 307 MW_{th} for direct use; and 922 MW_{th} for geothermal heat pumps.

9.3.2.2 Thermal Energy Used

In 2006, the thermal energy produced was 130,000 toe for direct use and about 180,000 toe for geothermal heat pumps (including the portion contributed by electricity).

9.3.2.3 Category of Use

Table 9.3 shows the various direct use operations in France.

Table 9.3 Direct use in France.

	Paris Basin	Aquitaine Basin	Other regions	Total
District heating	29	5	-	**34**
Fish farming, greenhouses, *etc*.	-	4	6	**10**
Bathing, …	-	9	3	**12**
Space heating without urban network	2	-	2	**4**
				60

9.3.2.4 New Developments During 2007

For the first time for more than 15 years, new wells have been drilled in Paris Basin- a doublet was drilled during the autumn of 2007 for Orly city's district heating.

This operation was conducted to replace an old doublet, following a scheme presented in Figure 9.3 below. The target aquifer was the Dogger aquifer, at a depth of 1,700 m, for a temperature of 75 °C. The obtained productivity is 300 m^3/h. Both wells are deviated (~40 °C).

The operation represented an investment amount of 10 M €, including the closing of the old doublet.

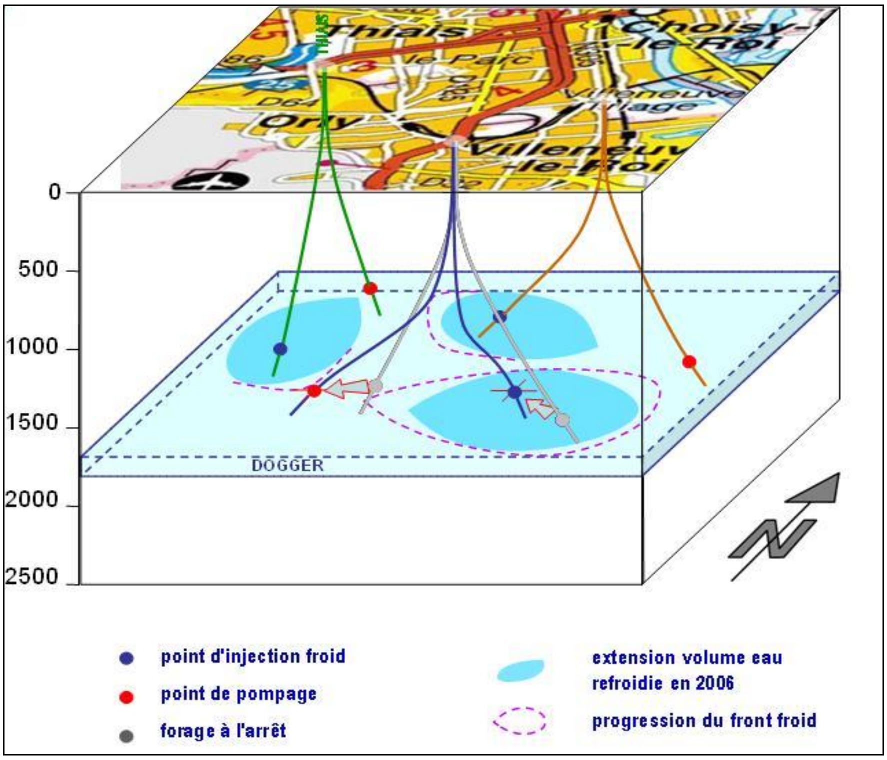

Figure 9.3 New doublet drilled in Orly in 2007.

9.3.2.5 Rates and Trends in Development

Direct Use- The operation of Orly was the refurbishment of an existing operation. So the impact on the development of activity is rather low.

The progress made in the past few years concerned mainly the extension of heating networks, at a pace evaluated around 5,000 toe substituted per year, which means a growth rate of 3.7 % per year. New projects are planned for 2008 and the following years, so that growth rate should increase.

Geothermal Heat Pumps- The boom of the market for geothermal heat pumps is illustrated in Figure 9.4.

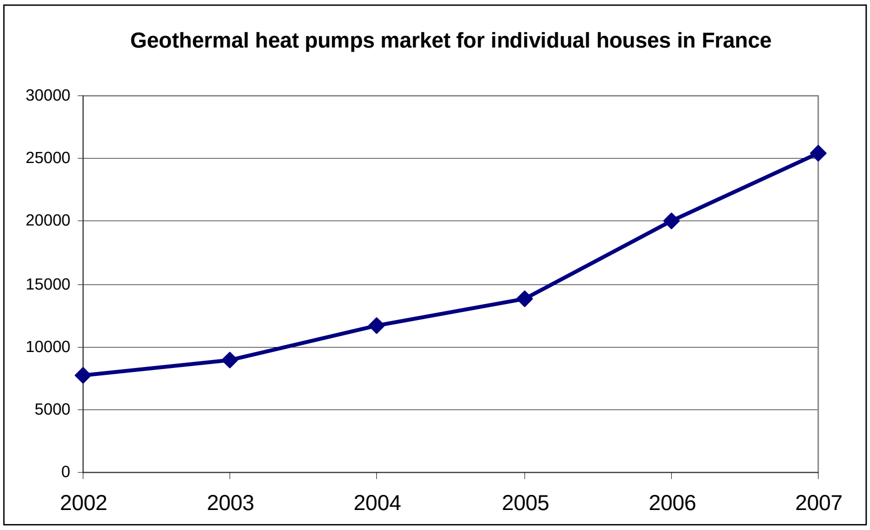

Figure 9.4 Geothermal heat pump growth in France from 2002 to 2007.

In 2007, one well was drilled for production and one for reinjection in Orly.

9.3.3 Energy Savings

9.3.3.1 Fossil Fuel Savings

The equivalent fossil fuel savings for electricity production was 27,000 toe; for direct use was: 130,000 toe and for geothermal heat pumps was about: 120,000 toe (renewable part of thermal energy produced).

9.3.3.2 Reduced/Avoided CO_2 Emissions

The avoided CO_2 emissions from geothermal electricity production in Guadeloupe was about 76,000 tonnes of CO_2 (in Guadeloupe, geothermal electricity is substituted for fossil fuel electricity with CO_2 content around 0.8 tonnes of CO_2/MWh); while direct use avoided the emission of about 400,000 tonnes of CO_2. Emissions savings/avoidance associated with GHP use was not calculated since there was no methodology available for determining the type of power GHPs substituted for.

9.4 Market Development and Stimulation

9.4.1 Support Initiatives and Market Stimulation Incentives

9.4.1.1 Electricity Generation

New feed-in tariffs were established in July 2006. These tariffs are based on the net output production of the geothermal plant. On mainland France, the feed-in tariff is 120 €/MWh, while in overseas departments, it is 100€/MWh. Both tariffs are subjected to an actualisation rate.

9.4.1.2 Geothermal Heat

Several initiatives were taken concerning district heating and geothermal heat-pumps.

Reduced VAT- Since the end of 2006, a reduced VAT is applied for renewable heating, including geothermal energy. The heat price paid by the final user consists of two parts:

- The connection (subscription) is a fixed amount (which includes the refund of the investment, the maintenance, *etc*.): VAT = 5.5% for all heating networks
- The energy used (MWh): VAT = 5.5 % if an average of more than 60% of the energy comes from renewable (biomass, geothermal energy, waste energy recovery)
- For other (non-renewable energies) VAT = 19.6 %

Program for revival of geothermal district heating- The present-day energy context and the imperative need to combat greenhouse gas effects, have led to a re-examination of the development of new geothermal operations stopped 20 years ago in the Paris Basin. ADEME, ARENE and BRGM organized meetings and discussed these matters with stakeholders in 2007. Following these exchanges it has been decided to elaborate a programme to boost geothermal development for the Paris Basin.

This programme should define the necessary ways and means for creating new geothermal operations in the Ile-de-France (Paris area) region. This covers technical and economic aspects, and the identification of suitable contractors and operators. The creation of a Technical Center inside BRGM to support geothermal stakeholders, for design, realization and exploitation was decided.

9.4.2 Financial Initiatives

Financial incentives concerned domestic heat pumps with an income tax cut from the government and public incentives through ADEME for the other geothermal fields of activity.

9.4.2.1 Geothermal Heat Pump Incentives

In 2005, the public authorities implemented a strong subsidy scheme for domestic heat pumps foreseen to last until the end of 2009. This subsidy is an income tax cut that takes the form of a reimbursement of 50% of the price of only the machine (meaning excluding the heat source collection system, the heating emission system and the labour costs for installation). The money is given as a reduction of the income tax of the family, or directly through a bank transfer in case the family is not submitted to an income tax. In 2007, the subsidy for geothermal heat pumps following this scheme was estimated to 90 M€.

9.4.2.2 Other Geothermal Fields of Activity

A new ADEME subsidy scheme for the development of renewable energies was set up in 2007 for the 2008-2013 period, including more subsidies for geothermal energy than the previous scheme. In this new system:

Feasibility studies for geothermal projects can be supported up to 50% of the cost of the study.

Investments can be supported up to 40%, for demonstrating operations, *i.e.*, operations with new concepts or with technologies not well-known, as for example operations with energy piles or underground thermal energy storage operations coupling solar heat and geothermal borehole heat exchangers. Support of up to 30 % for operations not disseminated widely enough but which can be easily replicated, *i.e.* exemplary operations like greenhouse heating or swimming pool heating with geothermal energy, plants with deep aquifers not often exploited. Support of up to 20% is available for the dissemination, e.g. geothermal district heating plant exploiting well-known deep aquifers like in Paris Basin, or shallow aquifers exploited with heat pumps for large buildings heating and cooling.

9.4.3 Risk Insurances

The development of geothermal energy in France was encouraged by the implementation of a global scheme involving financial guarantees designed to cover project investors against the geological uncertainties specific to this activity (which was then new). The guarantees covered the following risks:

- The risk, during the drilling phase, of not obtaining geothermal resource matching the flow rate and temperature requirements enabling to assure the profitability of the planned operation (risk called "**Short Term risk**"), and

- The risk of seeing this resource, when it exists and is exploited, lessen or disappear before the amortization of the equipment as well as the risk of damage affecting the wells, the material and the equipment of the geothermal loop during the exploitation period ("**Long Term risk"**).

9.4.3.1 Short Term Guarantee

To cover the "Short Term" type of risk, a guarantee fund called "Short Term Guarantee Fund" was implemented by the Authorities in 1982. It guarantees that a project manager that will have undertaken drilling for geothermal energy production can be reimbursed for all or part of the investments made in the event of total or partial failure of the drilling operation.

The "Short Term Guarantee Fund" was initially funded with 3.8 M€, an amount to which were added the contributions paid by the project managers that have subscribed to the Fund (1.5% of the drilling amount) and the interests coming from cash available and invested.

9.4.3.2 Long Term Guarantee

The role of this Long" Term risk insurance was also very important since, at the beginning, several barriers, psychological as well as technical and financial, were hindering the launch of the projects. As regards the banks, the existence of a coverage for geological risks not insured by the traditional insurance companies, has also allowed their reluctance to be overcome and has contributed to facilitate funding of projects by making them more secure.

This scheme, created by Authorities in 1981, has also allowed project managers to be covered during the entire exploitation phase against the risk of having the geothermal resource decrease or disappear, and against damages that may occur to their installations.

The guarantee system relies on a mutualisation fund called: "Equalization fund for long term geothermal risks".

To launch the guarantee system, this fund received an allocation from the State, to which were added several subscription renewals from ADEME.

To date, the funds provided by Authorities have reached 8 M€.

The balance of the fund is also assured by the means of contributions made by project managers benefiting from guarantees, an amount totally 7 M€, matching the some forty operations that have joined the system to which are added the interests of cash invested.

The guarantees offered initially covered only a 15-year period. In 1999, this period was extended another 10 years following a general request from project managers of the plants guaranteed. This facility was made possible through the payment by ADEME of a complementary amount associated on equal basis to the supplementary contributions from project managers.

The guarantees cover: wells; materials and equipment of the geothermal loop, provided that the damage occurs within a time frame smaller than the normal lifetime of these materials; and flow rate and temperature of the geothermal fluid.

The other causes of damage, such as for the lack of maintenance and the electrical breakdowns; manufacturing or assembly defaults; the poor optimisation of the exploitation, sabotage or fire, are excluded from coverage.

In 2006 a new fund was created by ADEME for the development of new plants. The guarantees are the same that those of the existing system, but the duration of the guarantee is different, 20 years *versus* 25 years.

9.5 Economics

9.5.1 Trends in Geothermal Investment

The only significant investment in 2007 was the drilling in Orly, which amounted to 10 M€.

9.5.2 Development and O&M Costs

9.5.2.1 Direct Use

The cost data obtained for the Orly operation are presented in Table 9.4.

Table 9.4 Costs for Orly development in 2007.

Activity	€
Coordination of the work	350,00
Drilling of a doublet and closing of the old one	8,000,000
Casing and pumps	1,400,000

9.5.2.2 Enhanced Geothermal Systems- Soultz-sous-Forêts

The company in charge of the Soultz project made an evaluation of the cost for a “standard” 3 MW_e EGS power plant in Alsace, with production from 3 km depth, based on the cost recently observed for the materials (D Fritsch, 2008). The results are presented in Table 9.5.

Table 9.5 Estimate of costs for a 3 MWe power plant in Alsace.

	Investment Costs	
2 wells	12 M€	6 M€ each
ORC plant (3 MWe)	4.5 M€	1500 €/kWi

Pumping system	0.8 M€	LSP, injection pump
BOP (CW, Mech., Elec.)	1.2 M€	Outdoor plant
Reservoir investigation	0.5 M€	MT, VSP, stimulation
Contingencies	1 M€	
TOTAL	**20 M€**	

Operating costs were estimated as 3.5 % of the CAPEX (700 k€/yr), consumption of auxiliaries of about 33 % of the gross power produced and investment during operation of 0.5 M€/5-years.

9.5.3 Trends in the Cost of Energy

The cost of the heat produced by a conventional geothermal district heating plant serving 5,000 equivalent-dwellings (as in Paris area) can be estimated at 35 € per MW_h (~ 22 US$/$MW_h$) vs 43 €/$MW_h$ (~ 27 US$/$MW_h$) for the heat produced with natural gas.

For electricity generation, available data which concern only the two existing units in Bouillante in Guadeloupe are not significant (island context, only 2 units, *etc*.).

9.5.4 Employment in Geothermal Sector

The number of people employed in the geothermal sector is estimated at 600 for conventional activities (such as geothermal district heating plants or geothermal power plants) and approximately 2,000 people for the geothermal heat pump sector.

9.6 Research Activities

9.6.1 Focus Areas

The creation of a department dedicated to geothermal energy inside the BRGM at the beginning of the year allowed the enhancement of the R&D activity coordinated mainly by ADEME and BRGM. Many types of geothermal energy topics are being investigated. Two strategic issues are emphasized:

- The integration of geothermal energy in construction design (heat pumps, heating networks, *etc*.): Participating in the geothermal energy boom involves facilitating the decisions of the contracting authorities, contractors and various professionals who are involved when geothermal heat is selected as the energy solution for heating purposes, whether this be for housing or for industrial, agricultural, leisure activities, *etc*. In this area, research is conducted for incorporating geothermal energy into the energy solutions for buildings.

- The development of knowledge relating to geothermal resources: Research concerns the deep resources of sedimentary basins, such as the Paris Basin, in addition to the high enthalpy fields in volcanic contexts, such as in France's overseas Departments, and experimental new generation systems, in particular at Soultz-sous-Forêts. BRGM's position as France's reference institution for the Earth Sciences makes it the natural player for working on these issues.

9.6.2 Government Funded Research

Publically funded geothermal energy R&D activities in France come principally through:

- Projects funded by the ANR (national agency for research)

- Projects funded by ADEME
- Projects funded by regional authorities
- Contribution of public research institutions, mainly BRGM and CNRS

The main R&D projects running in 2007 were:

9.6.2.1 Concerning Integration of Geothermal Energy in Construction Design

COFOGE: COnception des FOndations GEothermiques- The design of geothermal pile heat exchangers (2006-2007). This project aims to facilitate the introduction in France of installations with geothermal pile heat exchangers, using a global approach aimed at identifying the pros and cons of their development. It is mainly a question of developing a "state of the art" that includes a market study for France, professional habits and current regulations, and a review of the tools and techniques developed in Europe for studying the subsurface and the thermal system in foundations, and then combining them.

Partners in this study were: CSTB (coordinator), ALTO Ingénierie, BRGM, INES/LOCIE, SOLETANCHE.

GEOBAT- Geothermal storage for optimizing energy consumption in buildings (2007-2008). The project aims to facilitate the introduction in France of the geological storage of heat and cold at the scale of a building.

The partners in the investigation were: CSTB (coordinator), BRGM, LOCIE-University of Savoie, CEP-ENSMP.

Creation of an experimental platform for geothermal heat pumps and their underground heat exchangers in Orléans- In the context of the State-Région Centre Contract (2007-2013), BRGM and the Centre Regional Council have joined forces to create an experimental platform for geothermal heat pumps and their underground heat exchangers aimed at a global assessment of the performances of heating systems functioning with geothermal heat pumps based on the three constitutive elements: *i.e.* the ground, the geothermal heat pump and the building.

In 2007, the design of the platform was conducted. The activities will include three dimensions:

- Research-development- development of new products, performance qualification of the underground heat exchangers, assessment of their impact on the ground, *etc.*)
- Evaluation or certification of the systems
- Installation of a network of demonstrators in order to validate the developed new technologies or new concepts.

Moreover, this project associates ADEME, CSTB and some private companies, and will integrate the virtual platform on energy in building developed by CSTB, CNRS and CEA. The amount of funding is: 3.4 M€ for the period 2007-2013.

Reversible Greenhouse Air Conditioning- (2006-2007): CTIFL (Centre Technique Interprofessionnel des Fruits et Légumes: Interprofessional [Fruit and Vegetable Technical Centre]) wishes to develop the "sustainable greenhouse" concept by promoting greenhouse air conditioning using very low enthalpy geothermal energy (shallow groundwater). The prefeasibility study made by BRGM considered the technical aspects (capacity of the groundwater, heat balance in the shallow aquifer, impact), as well as the regulations and economics relative to the hydro-geological aspects.

The partners were: ADEME, CTIFL and the amount of funding was 100 k€ for the period 2006-2007.

9.6.2.2 Concerning Development of Knowledge Relating to Geothermal Resources

CLASTIQ- CLAyed SandsTone In Question. This project (2006-2008) aims to estimate the geothermal potential of the clayey-sandstone reservoirs of the Paris Basin and of a few key sectors in mainland France. It will review the configurations of geothermal operations carried out on the same type of reservoirs in Europe and also consider the reinjection problems.

Partners are: ADEME/BRGM; and the amount of funding is 700 k€ for the period 2006-2008.

GHEDOM 2- The second phase of the GHEDOM (2005-2008) project is to develop methods for estimating the geothermal potential of a high-enthalpy field in a volcanic island environment, like that of France's Overseas Départements , and to continue optimizing the surveillance, exploitation and management methods of the Bouillante geothermal field in order to improve and secure the production of electricity.

Partners are: ADEME, BRGM, and the funding for the 2006-2008 period is 700 k€.

GEFRAC 2- This study (2006-2008) has two objectives. The first objective is to improve the computing path aimed at describing the hydro-thermo-mechanical behaviour of the geothermal exchangers in a fractured medium. The computing path takes into account conceptual models according to stacked scales ranging from that of the well environment to that of the exchanger dimensions. The aim is to model the access to the exchanger taking into consideration different thermo-hydro-mechanical (THM) couplings based on a realistic geometry of the fracturing. The second objective is to obtain the experimental capability for undertaking fracture percolation tests with the injection of a chemically reactive fluid and to acquire data on the water-rock interactions in the geothermal systems in order to estimate the consequences on the permeability of the fractured medium.

Partners are: ADEME/BRGM/Itasca/Mines Paris, with funding of 700 k€ for the period 2006-2008.

9.6.3 Industry Funded Research

From 2001 up to 2007, 52 M€ were allocated to the Soultz EGS research programme, mainly for logistic activities (construction of a scientific pilot with three deep wells and an ORC unit).
R&D activity in the field of geothermal heat pumps exists too, but it is really difficult to give a good estimation of the expenditures involved.

The market in France in 2007 for domestic heat pumps reached 280 M€, only for the equipment production (air-air equipment excluded). Considering that the geothermal heat pumps market represented around 30 % of this market and 5 % of this part is devoted to R&D activities, the R&D expenditures in the field of geothermal heat pumps could be estimated in 2007 at 4-5 M€.

9.7 Geothermal Education

There are currently no education courses dedicated to geothermal energy in France.

An initiative was taken by ADEME and BRGM who, in 2007, created a 3-day training course for non-technical people on the subject "management of a GHP project for building". A test session took place in 2007. This training course will be deployed in 2008.

9.8 International Cooperative Activities

In 2007, BRGM was the coordinator of the ENGINE project. The ENGINE Coordination Action (ENhanced Geothermal Innovative Network for Europe), supported by the European Commission within its 6th R&D Framework Program, started in November 2005 and will end in April 2008. Its main objective was to coordinate present R&D initiatives for Enhanced Geothermal Systems (EGS), ranging from the resource investigation and assessment stage to exploitation monitoring.

Thirty four partners were involved in ENGINE, representing 16 European Countries plus Mexico, El Salvador and Philippines. It was meant to complement other Framework Programme instruments in contributing toward integrating research in Europe through well-planned networking and coordination activities. International cooperation has also been developed through the Coordinator participation in the IEA Geothermal Implementing Agreement and links established with other initiatives to promote EGS in US and Australia.

ENGINE has organised 3 conferences and 7 specialised workshops. Material and newsletters collecting a review of all the activities are available on the website: http://engine.brgm.fr

Furthermore, French companies and research institutions were involved in several R&D projects funded by the EU (Groundreach, Groundhit, Low-bin, HitI, I-Get, Soultz project).

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National Activities

Chapter 10

Germany

Wellhead at Landau EGS power and district heating development (courtesy of Lothar Wissing).

10.0 Introduction

In 2007, about 14 % of Germany's gross electricity consumption was generated from renewable energy sources, which means that the 2010 target (12.5 %) has already been significantly exceeded. Overall, 2007 was a milestone year in our efforts towards greater climate protection. Ambitious climate protection targets and measures became anchored in Government policy, at the national, European and international level.

In March 2007, the Heads of State and Government of the European Union, under Germany's Presidency of the European Council, agreed ambitious climate protection targets. By the year 2020, the European Union is aiming to:

- Reduce its emissions of greenhouse gases by at least 20 % compared to 1990 levels, with a promise to increase this to 30 % if other industrialized countries are prepared to make a similar commitment
- Reduce its forecasted energy consumption by 20 %
- Increase the proportion of renewable energies to 20 % of total energy consumption

Against this background, at the Cabinet meeting in Meseberg, near Berlin, in August 2007, the German Government set out the cornerstones of an integrated climate and energy package containing a multitude of laws and measures. The package also includes national targets for increasing the use of renewable energies. Phase one of the integrated climate and energy package was adopted by the Cabinet on 5 December 2007, and includes the amendment to the Renewable Energy Sources Act (EEG), a Renewable Heat Energy Sources Act (EEWärmeG), plus provisions on the use of cogeneration, energy saving, transport and fuels.

The use of renewable energies in Germany gained additional impetus last year. Renewable energies contributed approximately 8.5 % (2006: 7.5 %) of total final energy consumption in Germany (electricity, heating, fuels) in 2007. Renewable energies' share in Germany's total primary energy consumption (13,878 PJ) increased from approx. 5.5 % in 2006 to approx. 6.7 % in 2007 (calculated using the physical energy content method) and has almost doubled within just five years (2003: 3.5 %).

As a consequence, renewable energies have become even more significant for climate protection. It has been calculated that the use of renewable energies reduced CO_2 emissions by a total of about 114 Mtonnes in 2007 as a result of their substitution for other forms of energy in the electricity, heating and fuel sectors; with about 57 Mtonnes attributable solely to the Renewable Energy Sources Act (EEG). This means that renewable energies saved approximately 15 Mtonnes more CO_2 than in 2006.

10.1 German National Policy

The aim of the Federal Government is a sustainable energy supply, *i.e.* an energy supply which ensures a reliable, economic and environmentally compatible provision and use of energy at all times as described in the 5th Energy Research Programme of the Federal Government "Innovation and New Energy Technologies" set into force at July 2005.

Therefore, the Federal Government's policy aims at:

- A balanced energy mix of fossil and renewable energies for ensuring Germany's energy supply
- Further increasing overall industrial energy efficiency and thus at the same time making a contribution to the good economic performance and competitiveness of German industry and also to climate protection
- Further raising the contribution of renewable energies to covering the primary energy demand and making them competitive as rapidly as possible
- Facilitating the phasing out of nuclear power step by step and without any adverse effect on a reliable and economic electricity supply

- Reducing the output of energy-related CO_2 emissions and the other greenhouse-relevant trace gases into the atmosphere as part of present and future international commitments in the most cost-effective manner possible

10.1.1 Geothermal Energy

2007 was a successful year for the use of geothermal energy in Germany. The first ever industrial plant for the generation of electricity and utilization of heat with year-round availability, the geothermal power station in Landau, Pfalz, began operation in November 2007.

In early 2008, another geothermal cogeneration plant in Unterhaching near Munich will be connected to the national grid. Unterhaching and Landau are two pilot projects with wide-ranging impacts. There are currently some 150 geothermal projects in total underway in Germany. Germany has huge geothermal resources, only very few of which have been tapped. Geothermal energy is virtually inexhaustible, and is continuously available all year round. This makes it attractive as an alternative base load supply. In Germany, the use of geothermal energy could potentially be a cost-effective solution for meeting part of our base load energy demand. To this end, Germany needs to acquire further experience in other projects, and permanently reduce the cost of exploiting and using geothermal energy. In the past, geothermal energy was only used for heating purposes in Germany. Since the amendment to the Renewable Energy Sources Act (EEG) in summer 2004, interest in geothermal electricity generation has also seen a significant increase.

Regions with hydrothermal resources, *i.e.* sites where hot water is found in underground water-permeable layers (aquifers) or in the permeable rock zones (fault zones), currently offer financially attractive potential for the use of geothermal energy. Particularly promising geological regions for this form of geothermal energy use are found in Upper Bavaria (Molassebecken), Oberrheingraben and Norddeutsches Becken. However, in Germany only 5 % of the geothermal resources are located in hot water aquifers and permeable fault zones, while the remaining 95 % are in crystalline, generally highly impermeable, deep rock, which necessitates special engineering techniques, such as EGS techniques, where heat is primarily drawn directly from the rock, and where the permeability of the rock must be artificially improved via the injection of water (so-called “frac” technique).

The water temperature in German geothermal projects ranges between 100-150 °C. However, this temperature level is only achieved at drilling depths of around 3,000 m, leading to relatively high drilling costs. Furthermore, the operating temperatures are very low compared with the generation of electricity from coal or gas. Consequently, special power stations are needed for geothermal electricity production. ORC plants (ORC = Organic Rankine Cycle) and Kalina plants achieve a gross electrical efficiency of 10-11 % at water temperatures of 120-150 °C. Taking into account electricity consumption by the power plants themselves, particularly the pumps, this produces a net efficiency of 5-7 %. For this reason, geothermal projects should always aim for a combination of electricity generation and heat use. As well as heating buildings, the heat can also be used in the industrial and commercial sectors.

10.2 Current Status of Geothermal Energy Use

10.2.1 Electricity Generation

In November 2003, the organic Rankine cycle was installed in Neustadt-Glewe for electricity production (230 kW_e). In November 2007, Germany’s first industrial year round geothermal plant for the simultaneous supply of electricity and heat began operation in Landau (Rhineland-Palatinate). With an electrical output of 3 MW_e, it will supply around 6,000 households with electricity. The geothermal plant in Unterhaching, near Munich, will be connected to the public grid at the beginning of 2008. It is anticipated that up to 3.3 MW_e of electrical power can be fed into the electricity grid.

Therefore, in 2007, and just at the beginning of Germany's geothermal power generation history, the supply of geothermal electricity was only in 0.4 GWh.

10.2.1.1 Rates and Trends in Developments

Materials used in geothermal systems must satisfy exacting requirements. They must be corrosion-resistant when used in hot and often very salty water, yet inexpensively available. For this reason, one of the key tasks in the construction and operation of geothermal systems is to overcome the problem of corrosion in all system components. The GeoForschungszentrum Potsdam (GFZ/National Research Centre for Geosciences), the Bundesanstalt für Materialforschung und -prüfung (BAM/Federal Institute for Materials Research and Materials Testing) and the companies Schmidt & Clemens and Bayer Technologies have conducted extensive experiments into the qualification of materials. They have applied and evaluated preventive, active and passive corrosion protection techniques on simple, high-strength carbon steels, nickel-based alloys and titanium alloys under geothermal requirements, proving that oxide layers form on non-rusting steels even at 5 to 20 ppm oxygen. In order to be able to provide operationally reliable system components for geothermal plants in future, more in-depth work is needed on materials qualification in various thermal water cycles with laboratory-assisted corrosion experiments and operational field trials.

In order to be able to use geothermal energy, powerful pumps are needed to transport the thermal water from the reservoir. These pumps are exposed to high temperatures and the aggressive properties of thermal water, and are therefore subject to frequent failures. With this in mind, the company Flowserve, in Hamburg, is developing a pump which has been adapted to the specific requirements of geothermal energy. It is designed to be far more reliable than other pumps currently on the market, in order to minimize the financial risk of a pump failure (total funding amount: 4.3 M€). Apart from the feed pump, reinjection pumps also play a key role. So-called plunger pumps, which are capable of covering a wide range of pressures and flow rates with a consistently high level of efficiency, are particularly well-suited to this purpose. However, the pumps previously available on the market were not efficient enough for use in geothermal plants, and were also very expensive to purchase. The companies: geox GmbH, Bestec and Uraca have developed a special geothermal plunger pump which is now undergoing long-term testing in Landau.

Siemens AG is developing a special diagnostic system to analyze the operating and maintenance costs of Kalina geothermal power plants and minimize the technology-specific risks to the operator. To this end, operational data from Kalina power plants currently in operation is being logged and evaluated. The diagnosis system provides a database for the financial assessment of operating risks. It is hoped that an improved maintenance concept will further reduce operating costs. The idea is that these experiences will help to optimize the entire plant concept and enhance the overall cost-effectiveness of geothermal power plants based on the Kalina principle.

Siemens is also developing a new working fluid for Kalina plants, which it hopes will boast superior thermal transmission properties compared with the ammonia/water mixture currently used. It also hopes to achieve cost savings with machine parts, particularly the turbine. Parallel to this, the circuit will be optimized in terms of process and design, while exploring the application opportunities of a two-phase turbine for geothermal power plants. It is hoped that the improved working fluid and optimized turbine will lead to increased electricity production, coupled with reduced investment and maintenance costs. In this way, the generation of electricity from low-temperature sources should become more competitive, and geothermal power plants should become more cost-effective.

10.2.1.2 Energy Savings and Reduced/Avoided CO_2 Emissions

Due to the small amount of geothermal electricity generation there are no figures for equivalent fossil fuel energy savings available.

Through the use of geothermal energy, about 0.5 Mtonnes of CO_2 were avoided.

10.2.2 Direct Use

10.2.2.1 Installed Thermal Power

In 2007, the total direct use of geothermal energy was for near-surface geothermal energy 7,700 TJ/yr (2,139 GWh final energy) and for deep geothermal energy 600 TJ/yr (160 GWh final energy). Consequently, 2.6 % of the renewables heat supply is based on geothermal energy, mainly on heat pumps (Figure 10.1).

With geothermal heat supply 0.532 Mt of CO_2 were avoided in 2007.

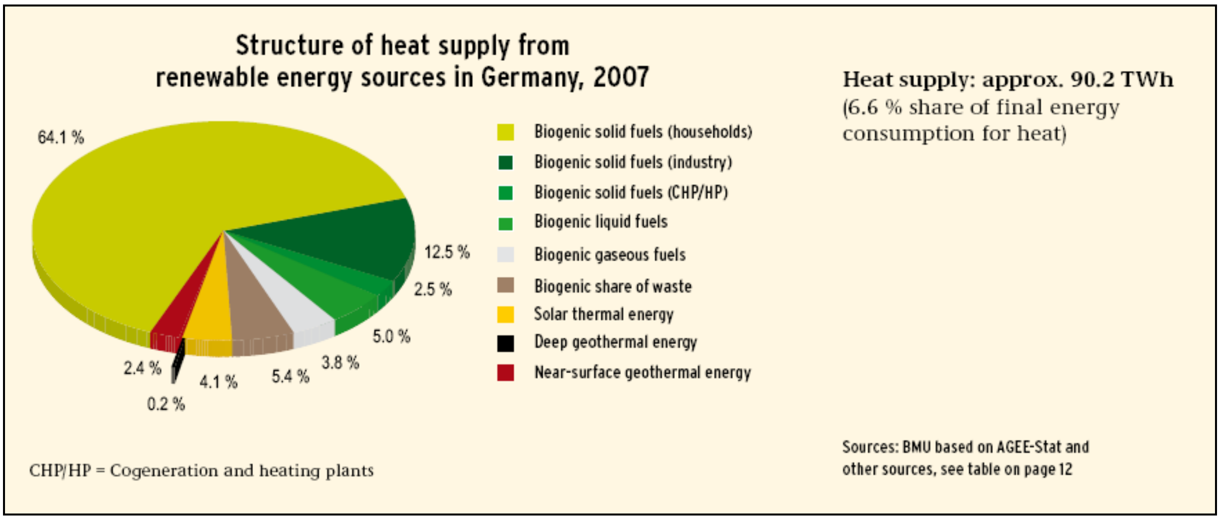

Figure 10.1 Structure of renewable energy heat supply in Germany in 2007.

10.3 Market Development and Stimulation

The use of geothermal energy on the heating market rose slightly once again in 2007. Suppliers of heat pumps sold 45,300 systems (2006: 44,980). In consequence, approximately 300,000 heat pump systems were installed in Germany at the end of 2007. About 15 % of the heating systems deployed in new buildings are now heat pumps. The German Federation's Market Incentive Programme primarily promotes investment in the use of renewable energies in the heating sector and is therefore contributing to the development of renewable energies in this field. About 164,000 systems were funded and investments worth some 1.7 B€ initiated under this programme in 2007. Due to the currently high demand, there is a significant price increase for the installation of heat pumps and a shortage in the availability of drilling equipment and skilled staff.

In the heating market, the various types of biomass make the biggest contribution to the generation of heat from renewable energies, supplying about 84 TWh of renewable heating (~ 93 %). The proportions of renewable heating derived from solar energy and geothermal energy are still relatively negligible at 4.1 % and 2.5 %, respectively.

The turnover in 2007 from the construction of plants for the use of geothermal energy is about 601 M€. Figures, which make a distinction between single technologies like heat pumps, district heating or deep geothermal energy technologies, are currently not available.

10.4 Development Constraints

The average geothermal gradient in Germany is 30 $^{o}C/km$, quiet low for deep geothermal applications. Only in certain regions like the upper Rhine rift valley and the German molasse basin do higher geothermal gradients occur. Therefore, deep drilling down to 3,000-4,000 m is necessary to reach temperatures above 100 ^{o}C needed for electricity generation. Associated with this fact are high drilling costs which influence the economic success. Further constraints are the finding risks for such depths and the complicated geological structures in some regions of interest. In the northern basin of Germany the geothermal resources have a high salinity.

Currently, the availability of drilling rigs is poor due to the huge demand from the oil industry. The prices are consequently high for drilling and some projects are being postponed.

10.5 Economics

The production price of conventionally generated electricity is about 4-7 €-cents/kWh and the consumer prices are 18-22 €-cents/kWh. Prices for energy- oil, gas, coal, electricity, are dependent upon the world market prices.

Electricity generation by geothermal techniques is not yet competitive without government funding. The combined use of the heat for district heating is essential for the economical success of an electricity generating project. For this reason the tendency can be recognized to design projects more for district heating than for electricity generation.

Geothermal electricity generation is being funded by 0.15 €/kWh for plants up to 5 MW_e installed capacity.

In 2007, 4,500 people were employed in the geothermal sector

10.6 Research Activities

10.6.1 Focus Areas

The aim of the BMU's research funding in the field of geothermal energy is to make the energy stored in the earth's crust available to generate electricity and heat in a cost-effective manner. As the use of geothermal energy in Germany is still in its infancy, there is a high demand for research and development work, as well as for demonstration projects.

The compensation payable under the Renewable Energy Sources Act (EEG) for electricity fed into the grid has created favourable economic framework conditions for geothermal power plants. The update of the EEG adopted by the Federal Cabinet on 5 December 2007 envisages further funding improvements. However, geothermal projects require high initial investments, and all geothermal drilling entails significant risks. For example, with hydrothermal projects there is always the risk that the conditions underground will fail to live up to expectations. Technical drilling-related problems can also lead to escalating costs. In the past, these risks have been the main obstacles to the accelerated exploitation of geothermal resources in Germany.

With this in mind, the new guidelines of the Marktanreizprogramm (market incentive programme) set out new funding components designed to control the risks. More funding will be made available for drilling costs, and loans will be exempt from liability up to a certain level, in order to hedge the discovery risk. The BMU's research funding also focuses on minimizing risks. The priority areas of geothermal research funding are set out in the BMU's funding announcement of 21 September 2006:

- Development of methods and techniques to minimize the discovery risk for drillings within the context of exploration

- Development of measurement techniques and equipment capable of supplying reliable data, both while drilling under typical geothermal conditions (high temperatures, high pressures and corrosion), and for storage management purposes, and which can also be used for forecasting and storage models

- Development and improvement of drilling techniques used specifically for tapping into geothermal reservoirs

- Development and improvement of methods and techniques to optimize reservoir management and influence productivity (such as simulation techniques, frac techniques, monitoring systems)

- Development of equipment, apparatus and machinery capable of reliable, low-maintenance operation under typical geothermal conditions (e.g. pumps)

- Investigation, optimization and development of methods and techniques for converting geothermal energy (hot water and steam) into usable heat and electricity (e.g. cogeneration of power/heat/cooling, ORC and Kalina processes or innovative techniques, also in combination with other renewable energies)

- Addressing fundamental technical issues relating to the incorporation of geothermal energy into local supply systems (heat/electricity), also in combination with other renewable energies, with a high multiplication potential

In 2007, the BMU approved a total of 17 new projects with a funding volume of 8.1 M€. In total, 14.4 M€ went to ongoing projects in 2007.

10.6.2 Government Funded R&D Projects

10.6.2.1 Landau

Figure 10.2 Landau geothermal power facility, Landau, Germany (courtesy of Bestec GmbH).

In November 2007, Germany's first industrial year round geothermal plant for the simultaneous supply of electricity and heat began operation in Landau (Rhineland-Palatinate) (Figure 10.2). With an electrical output of 3 MW_e, it will supply around 6,000 households with electricity. Electricity is generated via an ORC (Organic Rankine Cycle) plant. With this technique, the heat is transmitted to an organic solution, which circulates in a closed secondary circuit. Organic media have a higher steam pressure than water (the standard working fluid in power plants), and can be used in a steam turbine from temperatures as low as 90 °C. Initially, the surplus heat will be sufficient to heat 300 households, rising to 1,000 households when capacity is upgraded.

The two drill holes in Landau have a drilled depth of 3,400 m. They are spaced 6 m apart at the surface, and run directionally underground in opposite directions, so that they are around 1000 m apart at their final drilled depth. This is equivalent to the size of the thermal water reservoir, with a water temperature of approximately 155 °C. I n order to minimize the discovery risk and achieve financially viable delivery rates, a multi-horizon approach has been applied, which uses the thermal water from different underground horizons- shell limestone, mottled sandstone and crystalline (granite). In this way, a delivery rate of 70 l/s was achieved with a productivity index of 3 l/s/bar. Total investments for this project are around 20 M€ (BMU funding total: 2.5 M€).

10.6.2.2 Unterhaching

The geothermal plant in Unterhaching, near Munich, is to be connected to the public grid at the beginning of 2008. The local district heating network has been supplied with hot water since the start of the 2007 heating period. The thermal output is currently 27 MW_{th}. In summer, when district heating utilization levels are low, it is anticipated that up to 3.3 MW of electrical power will be fed into the electricity grid. Electricity is generated using a Siemens Kalina plant operating in the low temperature range below 200 °C, which converts existing energy in the thermal water into electricity more efficiently and cost-effectively than before.

Two boreholes have been drilled to depths of 3,446 m and 3,557 m. Pump tests produced results with water temperatures of up to 127 °C and a delivery rate of more than 150 l/s. The two boreholes are approximately 3.5 km apart. Approximately 2.4 M€ is being spent on accompanying research. Additionally, the programme has been awarded around 4.7 M€ from the BMU's environmental innovation programme. Parallel to this, the project has been granted a reduced-interest loan from the KfW and partial debt relief from the BMU under the Marktanreizprogramm (market incentive programme).

10.6.2.3 Groß Schönebeck

At the geothermal site in Groß Schönebeck, near Berlin, the second borehole was completed in 2007. The final drilled depth of 4,400 m was achieved in January 2007. Above ground, the boreholes are about 28 m apart, while at their final depth around 475 m apart. The temperature of the thermal water is around 150 °C. The research centre Geoforschungszentrum Potsdam (GFZ/National Research Centre for Geosciences) is continuing its research work in Groß Schönebeck.

A special non-reservoir-damaging drilling technique has been developed and trialled for tapping into the thermal water reservoir. The drilling process requires continuous rinsing with a water/oil mixture which cools the drill bit and conveys the abraded rock upwards out of the borehole. "Under-Balanced Drilling Technology" (UBD) made it possible to carry out the drilling work without damaging the underground heat reservoir. The reservoir and borehole are therefore perfectly prepared for a management period of 20-30 years.

The second stage of this project involved creating an underground heat exchanger. To this end, the underground rock was fractured using high water pressure to make it permeable. Fractures were stimulated in 3 horizons (multi-horizon approach). The flow rates required for electricity production were achieved during the initial circulation trials. Upon completion of the on-going research and development work in Groß Schönebeck, a geothermal power plant for electricity production will be built.

10.6.2.4 Neustadt-Glewe

Geothermal heat for a neighbouring residential area has been produced in Neustadt-Glewe since 1994. Since 2004, an Organic Rankine Cycle (ORC) plant has additionally produced 150 kW of electricity during the summer months. The Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources), Geothermie Neubrandenburg and the Verein für Kernverfahrenstechnik und Analytik Rossendorf (VKTA) are collaborating on a joint project focussing on issues relating to the use of geothermal facilities. In this project, the thermal water circuit of the Neustadt-Glewe plant includes a bypass, allowing materials to be selectively used and assessed. The bypass will also be used to examine deposits (scale formation) using mineralogical and chemical analysis techniques. Particular emphasis will be given to the transferability of the results to other geothermal plants in the North German Basin region.

10.6.2.5 Soultz-sous-Forêts

The project in Soultz-sous-Forêts (Alsace) is supported by the European Union, France and Germany has been intensively pursued since 1986 to develop the EGS technology. In 2007, a platform was completed for installation of the power plant facilities. The wellhead of borehole 2 has been refitted to accommodate a rod pump. The turbine housing of the ORC plant has been manufactured and is currently undergoing assembly while the cooling circuit of the plant is under development. Electricity production with a gross output of 1.5 MW_e is scheduled to begin during the first half of 2008. The project, which has been ongoing since the summer of 1987, has received total funding from Germany of around 31 M€, with similar amounts also contributed by France and the European Union.

10.7 Geothermal Education

Education with the focus on geothermal issues is offered by universities like University of Bochum, RWTH Aachen, the Technical University Berlin and the University of Potsdam.

Additionally, seminars and lectures are held by several institutions and associations involved in geothermal energy.

10.8 International Cooperative Activities

The Federal Ministry for Environment, Nature Conservation and Nuclear Safety Focus supports the project in Soultz-sous-Forêts and participation in the IEA as member of the Geothermal Implementing Agreement.

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National Activities

Chapter 11

Iceland

Well K-36 was flow tested for 5 days and appears to yield between 20-30 MW_e of superheated steam, though the steam proved corrosive. Information from this well will provide valuable information for the IDDP. (Photo taken 12 December 2007 by Ásgrímur Guðmundsson).

11.0 Introduction

During the 20th Century, Iceland has emerged from one of Europe's poorest countries, dependent upon imported oil and coal, to a country with one of the highest standards of living where practically all stationary energy, and 81 % of primary energy, is derived from indigenous renewable sources with near carbon-free electricity production. This is the result of an effective policy in making renewable energy a long-term priority in Iceland. Nowhere else does geothermal energy play a greater role in providing a nation's energy supply.

Geothermal primary energy consumption contributed 66 % in year 2007, equivalent to 135 PJ and has increased by 22 % from 2006 (Figure 11.1). The increase is a result of two new geothermal power plants, Hellisheidarvirkjun and Reykjanesvirkjun. However, the principal use of geothermal energy is for space heating with 88 % of houses heated with geothermal energy.

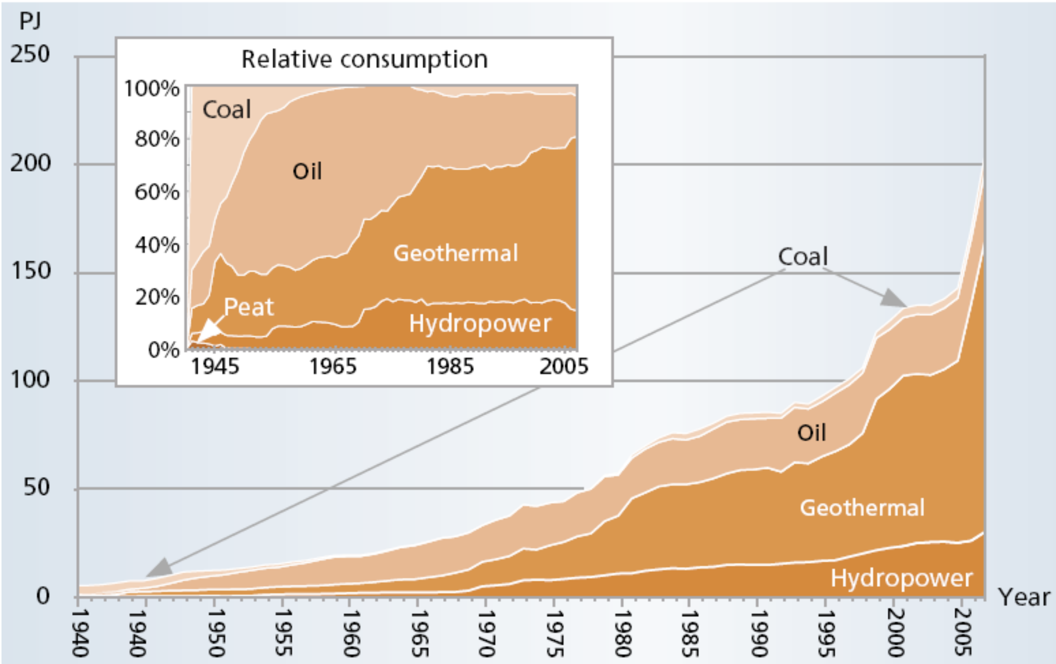


Figure 11.1 Primary energy consumption in Iceland 1940-2007 (Energy Statistics 2008, Orkustofnun)

11.1 Highlights for 2007

Reykjavik Energy installed a 33 MW_e low-pressure turbine in autumn 2007, increasing the total capacity to 123 MW_e of Hellisheidi geothermal power plant. Hitaveita Sudurnesja installed a 30 MW_e turbine, bringing the total capacity of Svartsengi geothermal power plant to 76 MW_e.

Currently, geothermal power plants having a total estimated 785 MW_e installed capacity on 7 geothermal fields are under formal consideration (Table 11.1), of which 90 MW_e will be installed in autumn 2008. Icelandic international cooperation to expand development of geothermal resources around the world has continued to increase.

Table 11.1 Installed and planned electric capacity in August 2008 (Orkustofnun).

Geothermal Field [MWe]	2005	2006	2007	Licensing	EIA completed	EIA started	Future	Total
Bjarnaflag	3	3	3	-	90	-	-	93
Krafla	60	60	60	-	-	150	30	240
Þeistareykir						150	90	240
Húsavík	2	2	2	-	-	-	-	2
Hengill area	120	210	243	90	225	-	90	648
Svartsengi	46	46	76		-	-	44	120
Reykjanes		100	100	-	-	80	20	200
Other fields	-	-	-	-	-	-	1720	1,720
TOTAL	**232**	**422**	**485**	**90**	**315**	**380**	**1994**	**3,263**

11.2 National Policy

It is the policy of the Government of Iceland to increase the utilization of the renewable energy resources even further for power intensive industry, direct use and the transport sector, keeping in harmony with the environment. A broad consensus on conservation of valuable natural areas has been influenced by social opposition, and increasing over the last decade against large hydropower and some geothermal projects. The Icelandic Government decided in 1997 to develop a Master Plan for potential power projects. All proposed projects are being evaluated and categorized on their energy efficiency and economics, as well as on the basis of the impact that the power developments would have on the environment (Figure 11.2). The Master Plan is to be presented to the Icelandic Parliament for formal consideration in 2010. In addition, there has been a governmental effort to search for geothermal resources in areas where geothermal energy has not yet been found. A map of Iceland with identified and anticipated geothermal resources is illustrated in Figure 11.3.

Figure 11.2 Steam rising at the geothermal field Brennisteinsfjöll on Reykjanes peninsula. The field is one of the proposed power project sites under consideration in the Master Plan. (courtesy of J. Ketilsson)

In Iceland, ownership of resources is associated with the ownership of land. However, exploration and utilization is subject to licensing. Three major amendments have recently been made to the energy legal framework in Iceland: (1) The ownership of resources can no longer be sold by the state or municipalities, although utilization rights can be leased to a developer for up to 65 years with a possibility of extension. Royalties for the utilization are determined by the Prime Minister. (2) Producers of electricity compete on an open market in Iceland. Therefore CHP power plants are obliged to keep separate accounts for heat and power production to prevent cross subsidization of electricity. (3) The National Energy Authority can grant licenses on behalf of the Minister of Industry.

11.3 Status of Geothermal Energy Use in 2007

11.3.1 Electricity Generation

As a result of a rapid expansion in the power intensive industry in Iceland, the demand for electricity has increased considerably. This has partly been met by increased geothermal electricity generation. Total installed electric capacity of geothermal power plants was 485 MW_e at the end of year 2007, and will most likely increase to 575 MW_e by the end of 2008, with a 90 MW_e expansion at Hellisheiði power plant. Electricity generation from geothermal power plants was 3.6 TWh in 2007, which is 18 % of the 20 TWh estimated electrical production capacity of harnessable geothermal resources in Iceland (see Figure 11.4).

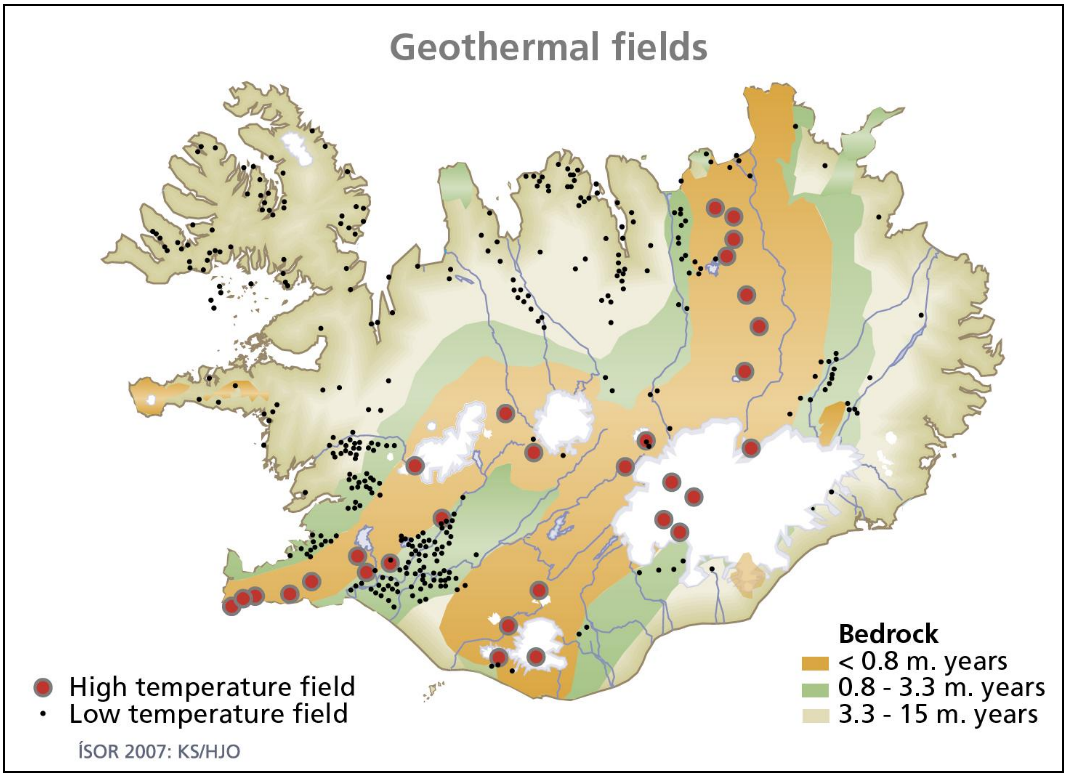


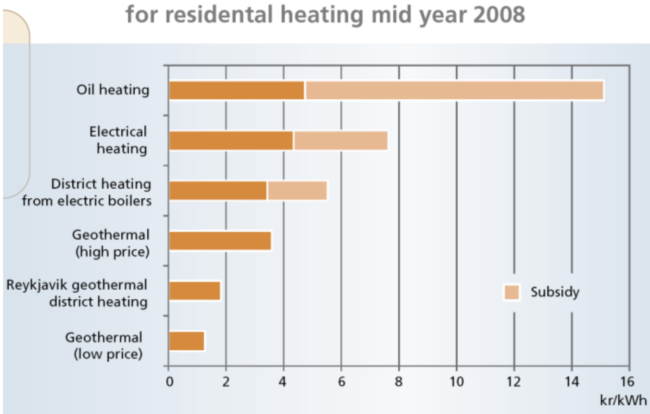
Figure 11.3 Location of high temperature geothermal fields in the volcanic zones of Iceland and clusters of low temperature springs on the flanks of the volcanic zones. Iceland is located onboth a hotsport and the Mid-Atlantic Ridge, which runs right through it. This combined location means that geologically the island is extremely active. (Energy Statistics 2008, Orkustofnun)

11.3.2 Direct Use

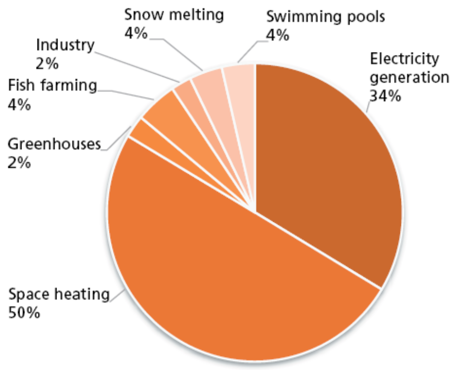
The total direct use of geothermal energy in 2007 was estimated to be 26 PJ, of which 19 PJ was for space heating. Currently, 88 % of houses are heated with geothermal energy. However, 9 % are still electrically heated and 3 % of houses receive heated water from electric or oil steam boilers. Heating of swimming pools is also one of the most important types of geothermal utilization in Iceland and the one with the longest tradition. Snow melting on pavements and parking lots has been common in Iceland for the past 15-20 years. There has been no considerable increase in direct industrial uses of geothermal energy in Iceland during the last years; and in 2004, the diatomite plant at Lake Myvatn, which consumed 444 TJ/yr, closed down. A seaweed processing plant at Reykhólar, W-Iceland, uses about 150 TJ/yr for drying. A plant for the commercial production of liquid CO_2 has been in operation at Haedarendi in SW-Iceland since

1986. Geothermal water is also used for space heating of greenhouses and for small scale timber and fish drying. Various energy statistics can be found in Figure 11.4.

Comparison of energy prices for residental heating mid year 2008



Utilisation of geothermal energy 2007



The main district heating companies in Iceland

	Number of wells 2007	Population 2007	Distribution 1000 m³ 2007
Orkuveita Reykjavikur *geothermal*	93	198,331	80,000
Hitaveita Sudurnesja hf.	13	23,782	14,608
geothermal		20,228	13,203
electricity / oil		3,554	1,405
Nordurorka hf. *geothermal*	18	18,885	7,077
Skagafjardarveitur *geothermal*	10	3,232	5,300
Selfossveitur *geothermal*	7	7,454	3,700
All heating services	328	284,100	135,000

Installed capacity in power station

	2007		2006	
	MW	%	MW	%
Hydro	1.758	74,4	1.162	68,4
Geothermal	485	20,5	422	24,9
Fuel	120	5,1	113	6,6
Total	**2.363**	**100,0**	**1.697**	**100,0**

Electricity production

	2007		2006	
	GWh	%	GWh	%
Hydro	8.394	70,1	7.289	73,4
Geothermal	3.579	29,9	2.631	26,5
Fuel	3	0,0	5	0,1
Total	**11.976**	**100,0**	**9.925**	**100,0**

Figure 11.4 Energy Statistics in Iceland (Energy Statistics 2008, Orkustofnun). The exchange rate was 81 ISK/US$ on August 25, 2008.

11.3.3 Energy Savings

In 2006, the total CO_2 emission from geothermal power plants was 156,323 tonnes, as can be seen in Table 11.2. Geothermal utilization was equivalent to 823,340 toe in year 2007 (IEA conversion factor: 41,868 GJ/toe for both heat and electricity).

11.4 Market Development and Stimulation

The high demand for electricity for power intensive industry resulting from the favourable prices of electricity has resulted in large-scale geothermal power development in Iceland. The power intensive industry consumed 73 % of the total consumption in 2007. Due to the success in Iceland, the geothermal industry has been increasingly exporting the know-how to other countries both as consultants and as investors at the feasibility stage. The government gives grants to various projects with emphasis on finding usable geothermal water for space heating in areas where resources have not yet been found.

Table 11.2 Emission of CO_2 in 2006 per electric and heat production (Orkustofnun).

Geothermal Field	Emission (tonnes/yr)	Emission per electricity production (g/kWh)	Emission per CHP production (g/kWh)
Reykjanes	21,528	42.3	
Svartsengi	46,491	124.8	47.1
Hellisheiði	9,220	53.9	
Nesjavellir	12,673	12.3	5.2
Námafjall	2,955	166.0	
Krafla	63,456	122.3	
TOTAL	**156,323**	**Weighted average: 59.7**	

11.5 Development Constraints

Development constraints are mostly due to environmental issues, though geothermal energy was looked upon more positively than hydropower in a recent national review. Local issues do place constraints on drilling sites and access to them. As well, the visual impact of geothermal power plants is becoming increasingly important. Another development constraint is the governmental subsidies, amounting to 950 M ISK in 2007, to communities where there is no access to geothermal water for space heating (see Figure 11.3). The subsidies, although effective for regional development, can decrease interest in search for geothermal resources.

Figure 11.5 Recently opened geothermal wells at Hellisheiði power plant which Reykjavik Energy operates (courtesy of J. Ketilsson).

11.6 Economics

Geothermal power is competitive with hydro in Iceland; providing reliable base load, green energy and favorable prices: 8 ISK/kWh + VAT for 3.5 MWh/yr consumption, but can get considerably lower for the power intensive industry due to very high load factor. For residential heating see Figure 11.4. The exchange rate was 81 ISK/US$ on 25 August 2008.

11.7 Research Activities

11.7.1 Focus Areas

The Iceland Deep Drilling Project (IDDP) could start a new era in geothermal development. The main purpose is to find out if it is economically feasible to extract energy and chemicals out of hydrothermal systems at supercritical conditions. The drilling of the first well IDDP-1 started at Krafla, NE-Iceland, in the spring of 2008 with 24 1/2" casing to 280 m and 18 5/8" casing to 800 m depth. The well will be drilled to 3.5-4.5 km depth in 2009. Research is also focusing on green initiatives in geothermal power plant design, e.g. hybrid cooling towers, underground pipelines and having only one separator on each platform with up to 5-7 deviated wells. For the Master Plan, research is ongoing on high temperature geothermal areas. In addition, geothermal areas are being searched for nearby districts that do not have geothermal space heating and Orkustofnun is involved in a few heat pump installments.

11.7.2 Government Funded Research

Orkustofnun represents the government in a steering committee of the IDDP. The total amount from Orkustofnun will be at maximum US$ 4.6 M. For a few years the Ministry of Industry has been running a program to encourage geothermal exploration for domestic heating in areas where geothermal resources have not been identified. For the years 2007-2009, 172 M ISK were granted to exploration in 29 places, for which the total cost is estimated to be 300 M ISK. The Icelandic International Development Agency (ICEIDA) is involved in stimulating geothermal utilization in developing countries, e.g. Nicaragua. The cost of just the Nicaragua-project as a whole is estimated to be just over US$ 4 M. ICEIDA has also participated in a joint project with six states in northwestern Africa. The project is in cooperation with the UN Environmental Programme, the KfW Bank in Germany and the Global Environment Fund, along with other donors relating to the research and use of geothermal energy in the northern reaches of the East African Rift (ARGeo).

11.7.3 Industry Funded Research

The three major power companies in Iceland each grant US$ 1.4 M for R&D of the IDDP. The power companies are as well responsible for drilling down to 3.5 km depth at their geothermal areas with an estimated cost of around US$ 13.9 M/well. In 2008, the energy fund of Reykjavik Energy granted 99 M IKR to 39 projects; and the energy fund of Landsvirkjun Power granted 40 M IKR to various energy projects.

11.8 Geothermal Education

The United Nations University-Geothermal Training Programme (UNU-GTP) has been operating in Iceland since 1979, with the aim to assist developing countries with significant geothermal potential to establish groups of specialists in geothermal exploration and development. An MSc programme was started in 2000 in cooperation with the University of Iceland. UNU-GTP receives its funding from the government of Iceland, US$ 5 M/yr.

The School for Renewable Energy Science (RES) in Akureyri and the Reykjavik Energy Graduate School of Sustainable Systems (REYST) both started their first academic year in 2008, offering education in the field of renewable energy with an emphasis on geothermal.

Figure 11.6 Fellows of the UNU Geothermal Training Programme in Iceland 1979-2007 (Orkustofnun).

11.9 International Cooperative Activities

Iceland is a member of IEA-GIA and leads the Annex VIII- Direct Use of Geothermal Energy and Task E- Sustainable Utilization Strategies of Annex I- Environmental Impacts of Geothermal Development. It is a member of the International Geothermal Association with two Board of Director Members; and now hosts the IGA Secretariat, having done so since September 2004. Iceland is also a Member of the World Energy Council and cooperates within the EU. It is also a partner of the Enhanced Geothermal Innovative Network for Europe (ENGINE) and HiTi-project, designing high temperature instruments for supercritical geothermal reservoirs, both of which are partly funded by the 6^{th} EU Framework Programme. Orkustofnun hosts the UNU-GTP and ICEIDA is involved in stimulating geothermal utilization in developing countries. The first Workshop on International Partnership on Geothermal Technology was held in Iceland 27-28 August 2008.

Iceland has a great deal of know-how and experience in the harnessing of geothermal sources, both for space heating and electricity generation. The Icelandic firms offer technical and investor know-how to maximize the profitability of investment in geothermal projects world-wide: Iceland GeoSurvey, Enex, Reykjavik Energy Invest, Geysir Green Energy, Glitnir Bank, Landsvirkjun Power, Mannvit, Exorka, Fjarhitun, Iceland Drilling Company and Linuhonnun take part in international cooperative activities.

11.10 References

Orkustofnun (2008) Energy Statistics 2008

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National Activities

Chapter 12

Italy

Figure 12.1 Travale 3 (20 MW_e) and Travale 4 (40 MW_e) power plants inserted in the beautiful Tuscan landscape (courtesy G. Cappetti).

12.0 Introduction

This chapter outlines the development of the geothermal activities in Italy in the year 2007.

Geothermal resources in Italy are used mainly for electricity production and Enel is the sole company operating in this sector of activities. From the beginning of the last century, when the first unit was installed in 1913 at Larderello, the geothermal installed capacity has been progressively increasing, reaching 810 MW_e at the end of the year 2005, where it currently stands at the end of 2007 since no new plants have been commissioned.

In 2007, the geothermal net generation reached 5,230 GWh. Though this represents only 1.8% of the total domestic generation, it meets about 25% of the electricity demand in Tuscany, the Italian region where all the geothermal plants are located.

In addition to electricity generation, geothermal fluids are used as heat sources, mainly for spas, space and district heating, greenhouses and fish farming. In 2007, the supply of thermal energy for direct uses totalled about 8,000 TJ.

12.1 The Electricity Market in Italy

In line with the European Directive (EC/96/92) relating to the creation of a single market for electric energy in Europe, on 19 February 1999 the Italian Government approved a Decree Law (n° 79/99) defining the basic rules for the new organization of the Italian electricity market. Accordingly to the new regulations, no individual operator was allowed to generate or import more than 50% of the domestic overall consumption of electric energy as from 1 January 2003.

In the period 2001-2003, in order to comply with this new legislation, Enel S.p.A. sold 15,057 MW_e of its generating capacity to other operators. As a consequence, several international competitors are now present in the Italian electricity market.

From 1 April 2004, the Italian Power Exchange has been operating and in the same year an independent private company, called TERNA, was established for the ownership and management of the national high voltage electric grid (transmission network).

The electricity needs in Italy reached 360,200 GWh in 2007, with a domestic contribution of 87.2 %, with the remaining 12.8 % imported.

As for the 314 TWh of domestic electricity generation, 84.3 % comes from fossil fuels, 12.2 % from hydro and 3.4 % from geothermal, biomass, wind and solar.

12.2 The Current Status of Geothermal Energy Use

12.2.1 Electricity Generation

All of Italy’s geothermal plants in operation are located in Tuscany, in the areas of Larderello/Travale-Radicondoli and Mt. Amiata.

As of 31 December 2007, 244 production wells were in operation with a steam network of about 180 km total length. In addition, 30 reinjection wells were in operation with a total water network of about 215 km.

Thirty-two units, with capacities in the range 10-60 MW_e, were in operation, with a total installed capacity of 810.5 MW_e and a maximum running capacity of 711 MW_e. No new power plants were commissioned in 2007.

The net electricity generation in 2007 was 5,233 GWh, the highest value so far produced.

12.2.1.1 Drilling Activities in 2007

- Drilling and completion of 1 production well and 1 reinjection well
- Workover/deepening activities in 5 wells

- Drilling and completion of 3 deep exploratory wells (maximum depth 4,097 m) in the frame of the "Deep Exploratory Program" launched in 2003 in the area of Larderello/Travale-Radicondoli.

In the year 2007 the total drilling activity in Italy has amounted to 15,363.20 m.

12.2.1.2 AMIS Plant Construction in 2007

The AMIS abatement plants were designed by Enel to remove H_2S and Hg from plant emissions. This technology makes it possible to substantially reduce the environmental impact of the generation park with a consequent acceptability improvement from the local population. It will eliminate the bad smell of H_2S present in the geothermal areas, and which represents a real nuisance for the people living near the plants. In addition, Hg removal will prevent possible effects of mercury build up in soils, water and food chain in the long-term operation of the plants.

In 2007, five additional AMIS plants were installed and operated in the Larderello area.

12.2.2 Direct Uses

In addition to the electricity generation, in Italy geothermal fluids are also used as thermal sources and in 2007 the total heat supply was equivalent to about 8,000 TJ/yr.

Most of the applications (60% of the supply) are devoted to bathing (temperatures less than 40 °C), which has a long tradition in Italy, dating back to Etruscan and Roman times. There are also several other uses including space and district heating, fish farming, greenhouses and industrial process heat.

Enel is engaged in geothermal direct use applications, supplying the equivalent of about 1,100 TJ/yr of geothermal heat and selling about 36,000 tonnes/yr of nearly pure CO_2, produced from a deep well located in the Torre Alfina field (Latium) that is used, after purification, in the food industry.

12.2.3 Avoided Emissions

The utilization of geothermal fluids for electricity generation and direct uses provides a saving of about 1.5 Mtoe (million tons of oil equivalent), avoiding, at the same time, emission to the atmosphere of about 3 Mt of CO_2.

It should be noted that the exploitation of steam-dominated fields reduces the amount of CO_2 naturally emitted from the soils in the geothermal areas, so that the total CO_2 emission (natural plus power plant emission) remains unchanged. For this reason, the CO_2 emission has not been included by ARPAT (the Italian Agency for the protection of the environment and the territory) in the greenhouse gas (GHG) inventory.

12.3 Market Development and Stimulation- Policies Supporting Renewable Resources

With the Decree Law (n° 79/99) specific policies for supporting the development of renewable resources have been adopted in Italy. This provision gave rise to the "Green Certificate" market.

Beginning in 2002, all operators (importers and producers of electricity from non-renewable sources) had to supply a quota of their production from renewable sources into the grid. The quota was initially, *i.e.* beginning in the year 2002, set at 2 % of the total energy, produced or imported, exceeding 100 GWh (excluding cogeneration, auxiliary consumption and exports).
Applied to the whole Italian market, the 2 % quota was at that time equivalent to about 5,000 GWh. This amount was large enough to effectively spur the market, considering that it had to be obtained

only from plants that began production or were re-powered (for the additional capacity only) after the law had come into effect.

The conceived mechanism provides a great deal of flexibility. Operators are allowed to meet their obligations either by generating directly; or by purchasing from others, some or all of the necessary "green" energy, or simply their rights (as in the spirit of the "Green Certificates").

According to a new Decree Law (n° 387/2003) issued on 31 January 2004, the initial quota of 2% was increased to 2.35% for the year 2005, to 2.7% for 2006 and to 3.05% for 2007 to keep up with international commitments for CO_2 emissions reduction.

As a consequence, the value of the kWh generated from renewables is the sum of the base price of the energy plus that of the market value of the Green Certificates (the latter is limited to the first eight years of plant operation). In the year 2007, this mechanism led to an average market price of 11.3 €-cent/kWh for the Green Certificates, to be added to the average price for the sale of electricity, which was around 7 €-cent/kWh.

The presence of the above mentioned Green Certificates makes it possible to proceed with the exploration, development and utilization of deep geothermal resources, which require the drilling of very expensive wells to depths up to 3,500-4,000 m.

State incentives for the use of heat from geothermal sources are also provided. They consist of:

- Incentive to the end users of 10.33 €/MWh_{th} on a permanent basis, plus 15.49 €/MWh_{th} to be confirmed every fiscal year

- Incentive to the developers for new supplies or for the increase of the existing ones, that is 20.66 €/kW_{th}

12.4 Environmental/Acceptability Aspects

The strong interaction occurring between geothermal activities and the territory, taking into account that we operate in Tuscany, has created serious obstacles to the development of new projects.

Aiming at the retrieval of constructive and mutually beneficial relations with the territory, Enel has initiated a number of initiatives with the aim of achieving a reduction of environmental drawbacks and an increase in acceptability.

New design solutions have been adopted to reduce the noise and visual impact of drilling pads, gathering systems and power plants. Moreover, an innovative plant for the abatement of mercury and hydrogen sulphide (AMIS) was designed and put into operation with very positive results, improving significantly the acceptability by local population.

In addition, it should be noted that, by law, Enel must pay a royalty for each kWh generated from geothermal resources to the municipalities and to the District where the plants are located. A District law has recently doubled the royalty to the municipalities of Tuscany. Starting from January 2003 Enel must pay:

- 0.1148 €-cent/kWh to the affected municipalities

- 0.0574 €-cent/kWh to the Tuscany District Authority

See Figures 12.1 (on the Chapter 12 introductory page), 12.2 and 12.3 for examples of environmentally compatible geothermal power station design and construction.

Figure 12.2 Reduced visual impact of the new gathering system in the Travale area (courtesy of G. Cappetti).

Figure 12.3 Production test in the Travale area (courtesy of G. Cappetti).

12.5 Economics

The geothermal projects developed in Italy during recent years have mainly pertained to deep resources, with relevant huge investments in drilling activities (wells up to 3,000-4,000 m deep). Therefore, the total capital cost for a new development project is around 3-4 M€/MW_e installed, depending on well depths, productivity and chemical composition of the fluids.

As discussed above, the development of new projects is still feasible because of the existence of Green Certificates.

12.6 Research Activities

Research activities have focused both on the implementation of advanced methodologies (3D seismic) aimed at reducing the mining risk for the deep wells and also on the methodologies aimed at the solution/mitigation of the corrosion problems in the wells, the gathering systems and power plants caused by the presence of chlorine in the steam produced from deep wells.

These activities have been carried out in collaboration with universities and research institutions both in Italy and in Europe.

12.7 International Activities

Enel has been engaged in several geothermal exploration and development programs in Central and South America, and in the USA.

In El Salvador, as partner of La Geo, Enel has completed the further development of the Berlin field with the drilling of wells and the construction of a 44 MW_e power plant that began the commercial operation in February 2007.

Exploration activities have been started in some areas of Chile, Nicaragua and Guatemala, while in USA, development programs for about 140 MW_e binary units have been initiated in four different areas of Nevada, Utah and California.

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National Activities

Chapter 13

Japan

Figure 13.9 Well N19-HA-1 in Hachimantai, Iwate Prefecture, Japan, on 28 May 2007 (courtesy of H. Muraoka).

13.0 Introduction

Japan's first geothermal power generation of 1.12 kW was experimentally performed in Beppu, Oita Prefecture, Kyushu in 1925. The practical use of geothermal power commenced in 1966, with the installation of the first plant, the Matsukawa Geothermal Power Plant of 9.5 MW_e (23.5 MW_e at present and sustainably working for 42 years), Iwate Prefecture, in northern Honshu.

Japan, as a volcanic country, is blessed with potential geothermal resources for development. However, the construction of geothermal power plants has been restricted due to factors such as the restrictions in National Parks and huge numbers of hot spring resort areas. At the end of the 1980s only nine plants were operating, with a total capacity of about 215 MW_e.

Since the two oil crises, the government rapidly promoted research and development in several areas of geothermal exploration and technology throughout the 1980s. As a result, geothermal development in several areas in the Tohoku and Kyushu Districts attained a construction rush in the early 1990s, more than doubling the total capacity to about 534 MW_e.

Immediately after the rush, Japan faced a deflation economy stage in the late 1990s, and the lines of incentive policies were withdrawn from geothermal energy, thus freezing the geothermal market. No new geothermal power plants have been constructed since the late 1990s, except for small-scale plants such as the Hachijojima geothermal power plant of 3.3 MW_e in 1999, the Kuju Kanko Hotel of 2 MW_e in 2000 and the Hatchobaru geothermal binary power plant of 2 MW_e in 2006. This pessimistic trend will soon be changed by the government decision in 2006 that geothermal energy should be revived into "New Energy".

13.1 Highlights for 2007

The year 2007 was marked by some highlights:

- Geothermal energy was included back into "New Energy" in Japan from April 2008, though it will virtually be restricted to only binary-cycle plants (Press release at January 29, 2008)

- The New Energy and Industrial Technology Development Organization (NEDO) adopted two new fields for the Geothermal Development Promotion Surveys: East Ikedako (Kagoshima) and Sado (Niigata)

- NEDO adopted the "Development of the Hot Spring Ecogene (ecology + co-generation) System" project in a R&D grant competition for new energy ventures

- The Japan International Cooperation Agency (JICA) completed the Master Plan Study for Geothermal Power Development in Indonesia

13.2 National Policy

13.2.1 Strategy

The Agency for Natural Resources and Energy (ANRE), the Ministry of Economy, Trade and Industry (METI), is in charge of Japan's energy policy. METI states that the promotion of the geothermal energy development is extremely important because geothermal energy is one of the oil alternative energies, and it is a clean, stable power supply of domestic production so answers a social request like reducing global environmental problems. Therefore, the inducement at the early stage of the geothermal power generation development such as private entrepreneurs is aimed at for a potential geothermal power.

To adjust environmental contribution statistics of the international standard "Renewable Energy", the New Energy Committee of ANRE under METI proposed that small-scale hydro and geothermal energy should be included back into the Japanese-specific category "New Energy", on 24 March 2006. This motion was positively discussed in the following two meetings of the Committee and adopted as an express statement on 26 May 2006. This will be legally enacted on "the Special Measures Law for the Promotion of Utilization of the New Energy" (so-called the New Energy Law) in April 2008.

13.2.2 Legislation and Regulation

The "Law Concerning Promotion of the Development and Introduction of Alternative Energy" was enacted in 1980 and the promotion strategy for geothermal energy was described. While the "Special Measures Law for the Promotion of Utilization of the New Energy (so-called New Energy Law)" was launched in 1997, geothermal energy was excluded from definition of New Energy which needs governmental support. Then the "Renewables Portfolio Standard Law" was enacted in 2003, where geothermal energy was included as renewable energy in this law but realistically restricted within binary-cycle plants.

There is no 'stand-alone geothermal legislation' that defines geothermal resources and governs their use and development in Japan. For example, an application of geothermal drilling is governed by the Hot Spring Law and its implementation is approved by hot spring deliberation committees in local governments.

13.2.3 Progress towards National Targets

The numerical target for geothermal electrical capacity remains 535 MW_e for the electricity power industries since FY2000. This means that the objective for the moment is only to maintain the current state. However, geothermal energy is expected to promote the developments, considering the mitigation of regional environmental impact by its clean nature, improvement of economy and reduction of the risks of energy security by its purely domestic origin. On the other hand, no target is placed on the direct use of geothermal energy, either qualitatively or quantitatively.

13.2.4 Government Expenditure on Geothermal R&D

A chronological change of government expenditure on geothermal development in Japan, including the geothermal R&D as well as the market stimulating subsidy, is shown in Figure 13.1.

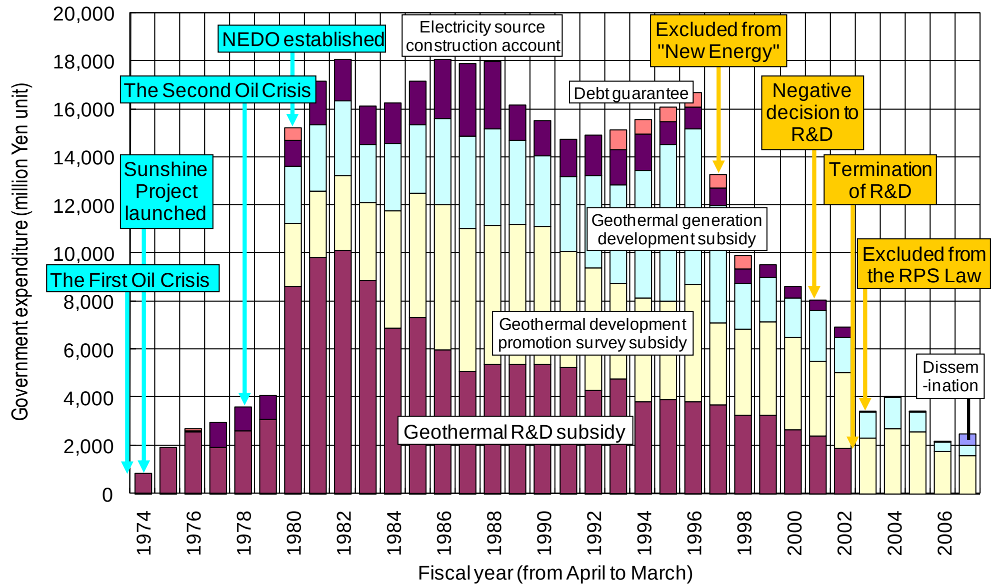


Figure 13.1 A chronological change of annual geothermal budgets in Japan.

The government expenditure has drastically been decreasing during the last decade, reflecting geothermal energy's exclusion from "New Energy" in 1997. Particularly, national geothermal R&D projects ceased in FY2002.

13.2.5 Industry Expenditure on Geothermal R&D

In the current, less incentive situation, the market for geothermal power generation developments in the private sector is inactive, except for overseas investment by trading companies and plant facility exports by turbine and generator makers.

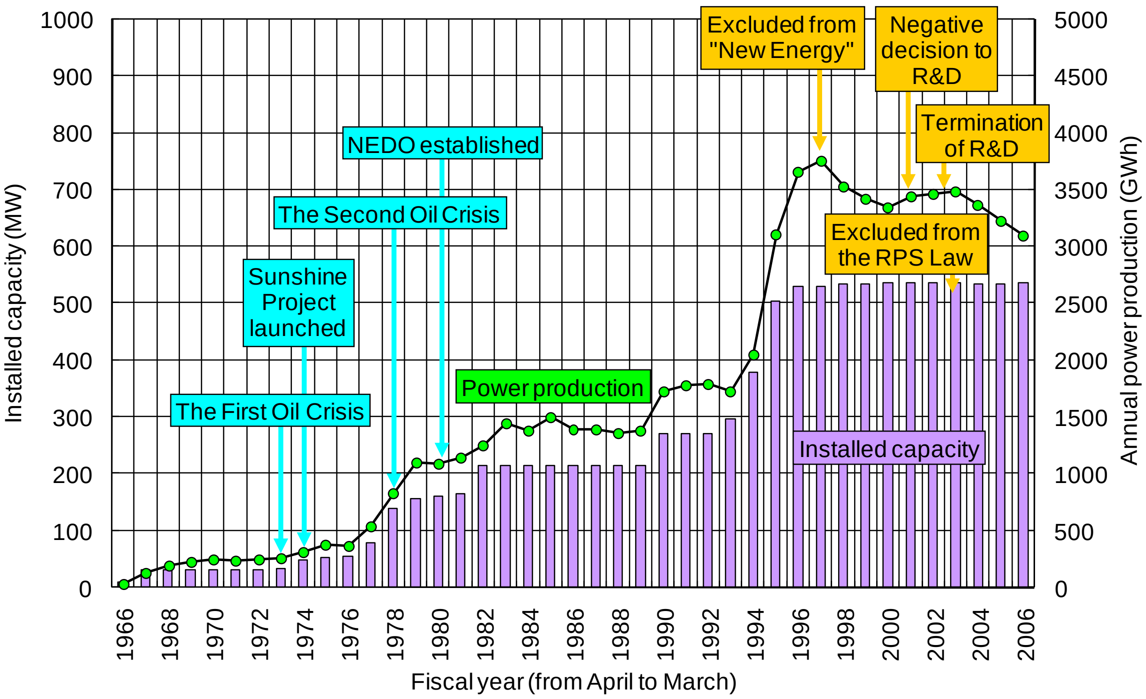
13.3 Current Status of Geothermal Energy Use in 2007

13.3.1 Electricity Generation

13.3.1.1 Installed Capacity and Electricity Generated

The total installed electricity generation capacity of geothermal energy at the end of March 2007 was 535.26 MW_e, including that of the companies' own private use power plants (the Thermal and Nuclear Power Engineering Society, TENPES hereinafter, 2008; Figures 13.2 and 13.3 and Table 13.1).

Figure 13.2 A chronological change of installed capacity and annual energy production of geothermal power plants in Japan.



The total electricity generation from geothermal energy in Japan during FY2006 (from April 2006 to March 2007) was 3,102 GWh (TENPES, 2008; Figure 13.2 and Table 13.1).

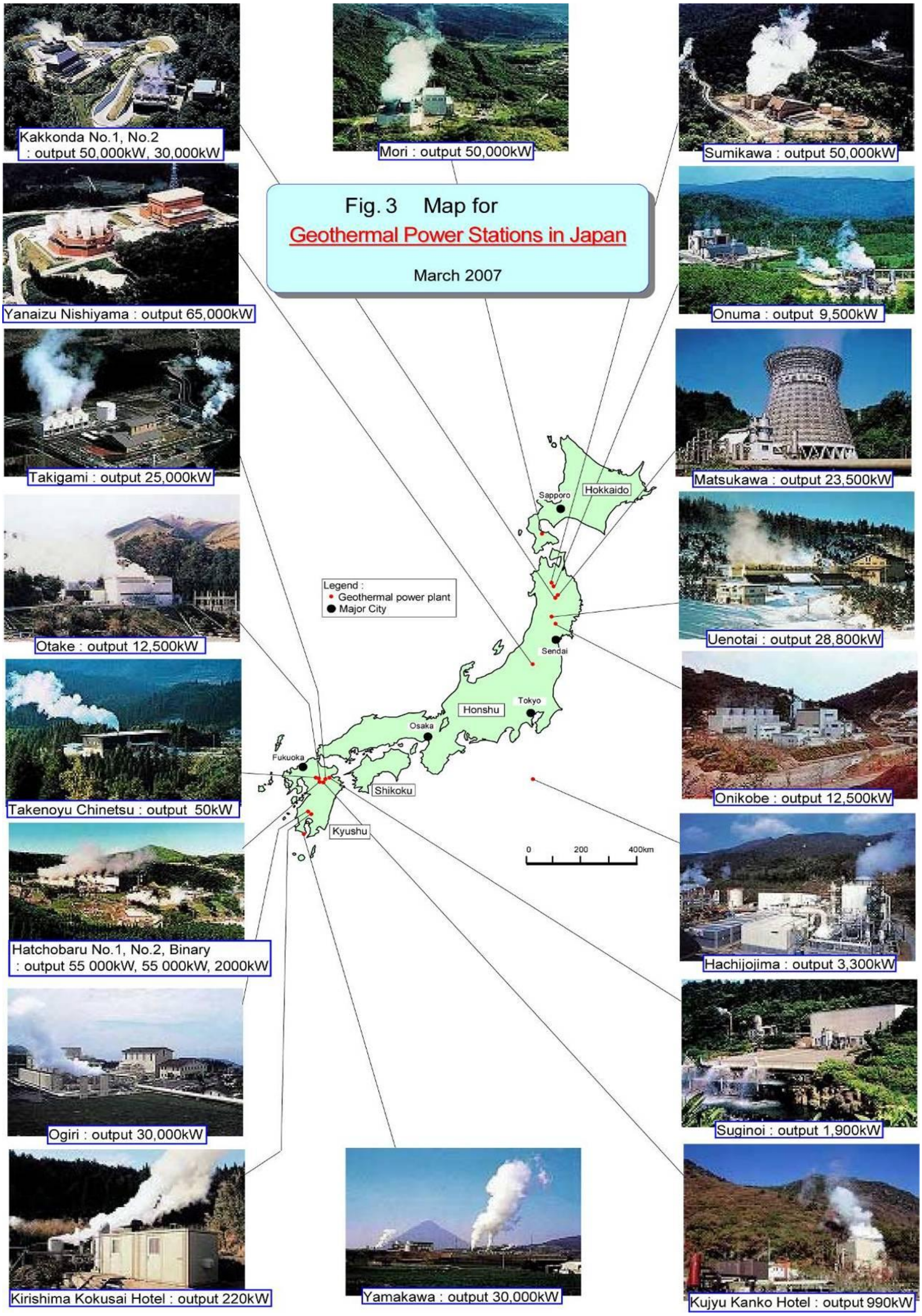


Figure 13.3 Map of geothermal power plants in Japan.

Table 13.1 Operating geothermal power plants in Japan from April 2006 to March 2007.

Name of power plant	Power plant operator		Authorized output (MW)	Annual energy production (MWh)	Start of operation
	Power generator	Steam supplier			
Mori	Hokkaido Electric Power Co., Inc.	Hokkaido Electric Power Co., Inc.	50.00	129,175	Nov. 1982
Sumikawa	Tohoku Electric Power Co., Inc.	Mitsubishi Materials Corporation	50.00	297,047	Mar. 1995
Onuma	Mitsubishi Materials Corporation	Mitsubishi Materials Corporation	9.50	60,435	Jun. 1974
Matsukawa	Tohoku Hydropower & Geothermal Energy Co., Inc.	Tohoku Hydropower & Geothermal Energy Co., Inc.	23.50	129,916	Oct. 1966
Kakkonda 1	Tohoku Electric Power Co., Inc.	Tohoku Hydropower & Geothermal Energy Co., Inc.	50.00	170,739	May 1978
Kakkonda 2			30.00	174,937	Mar. 1996
Uenotai	Tohoku Electric Power Co., Inc.	Akita Geothermal Energy Co., Ltd.	28.80	194,020	Mar. 1994
Onikobe	Electric Power Development Co.	Electric Power Development Co.	12.50	103,553	Mar. 1975
Yanaizu - Nishiyama	Tohoku Electric Power Co., Inc.	Okuaizu Geothermal Ltd. Co.,	65.00	389,678	May 1995
Hachijojima	Tokyo Electric Power Company	Tokyo Electric Power Company	3.30	15,005	Mar. 1999
Suginoi	Suginoi Hotel	Suginoi Hotel	1.90	12,780	Mar. 1981
Kuju	Kuju Kanko Hotel	Kuju Kanko Hotel	0.99	8,188	Dec. 2000
Takigami	Kyushu Electric Power Co., Inc.	Idemitsu Oita Geothermal Co., Ltd.	25.00	200,516	Nov. 1996
Otake	Kyushu Electric Power Co., Inc.	Kyushu Electric Power Co., Inc.	12.50	92,456	Aug. 1967
Hatchobaru 1	Kyushu Electric Power Co., Inc.	Kyushu Electric Power Co., Inc.	55.00	369,736	June 1977
Hatchobaru 2			55.00	430,743	June 1990
Hatchobaru Binary			2.00	12,849	Apr. 2006
Takenoyu	Hirose Trading Co., Ltd.	Hirose Trading Co., Ltd.	0.05	0	Oct. 1991
Ogiri	Kyushu Electric Power Co., Inc.	Nittetsu Kagoshima Geothermal Co., Ltd.	30.00	230,816	Mar. 1996
Kirishima Kokusai Hotel	Daiwabo Kanko Co., Ltd.	Daiwabo Kanko Co., Ltd.	0.22	482	Feb. 1984
Yamakawa	Kyushu Electric Power Co., Inc.	Kyushu Electric Power Co., Inc.	30.00	79,297	Mar. 1995
Total			**535.26**	**3,102,368**	

13.3.1.2 New Developments in 2007

The installed capacity of geothermal power generation in Japan slightly increased from 534.24 MW_e in March 2006 to 535.26 MW_e in March 2007, with a gain of 1.02 MW_e. This is ascribed to the following activity in the three plants (TENPES, 2008). Kyushu Electric Power Co., Inc. built a 2,000 kW_e binary power plant inside the Hatchobaru Geothermal Power Plant in February 2004 for the purpose to evaluate the cost and performance of the facility. After the two years' satisfactory demonstration, the plant was approved as a commercial plant and was put into operation since April 2006. Suginoi Hotel abandoned the former 3,000 kW_e plant in January 2006 and replaced it with a new 1,900 kW_e plant since April 2006. Kirishima Kokusai Hotel abandoned the former 100 kW_e plant in May 2006, and replaced it with a new 220 kW_e binary plant in August 2006.

13.3.1.3 Rates and Trends in Development

Japan's geothermal power market has lost the last decade since geothermal energy was excluded from "New Energy" in 1997. Although geothermal energy will be back to "New Energy" in 2008, the future trend is still obscure. Investment in large-scale power plant is too risky at present, circumstances that inevitably focus activities on the realistic option of developing small-scale power plants for the next few years.

13.3.1.4 Wells Drilled

During the year 2007, 6 production wells were drilled at 5 geothermal power stations (Sumikawa, Matsukawa, Uenotai, Ogiri and Hatchobaru). One reinjection well was drilled at the Hatchobaru Geothermal Power Plant.

Three exploratory wells were drilled in Hachimantai, 2 exploratory wells were drilled in Okushiri, and 1 exploratory well was drilled in Ikedako.

13.3.1.5 Contribution to National Demand

ANRE reported statistics on the details of national electricity generation capacity for FY 2006 (from April 2006 to March 2007) and the Energy White Paper 2008 (for FY 2006) on its Web site (ANRE, 2007; 2008). The former statistics give detailed numbers but their total is slightly lower than that of the latter, probably omitting minor categories of electricity sources. Therefore, we adopt the national electricity generation capacity from the Energy White Paper 2008, with the numbers are rounded off to nearest 10 MW_e. The total installed electricity generation capacity for the country at the end of March 2007 was 237,910 MW_e, where LNG power accounted for 25.2 %, nuclear power 20.8 %, hydro power 19.2 %, oil and other fire power 18.8 %, coal power 15.7 % and geothermal power 0.2 % (Figure 13.4).

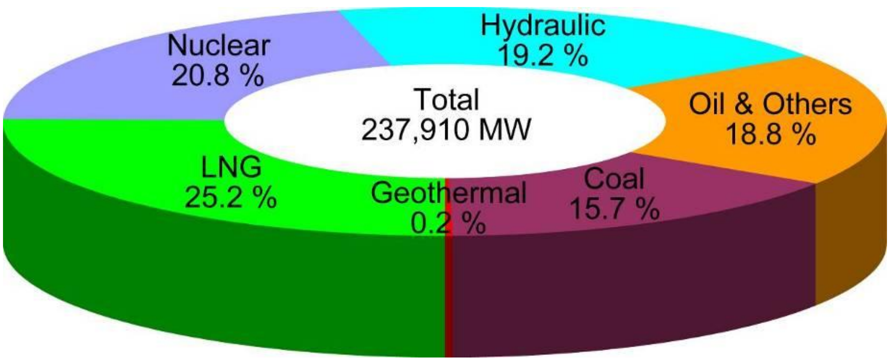


Figure 13.4 Share of installed capacities by individual generation sources in Japan from April 2006 to March 2007 (ANRE, 2008).

The national electricity generation is again adopted from the Energy White Paper 2008 (ANRE, 2008); with the numbers rounded off to nearest 100 GWh. The total annual electricity generation for the country at the end of March 2007 was 973,900 GWh, where nuclear power accounted for 31.2 %, LNG power 26.5 %, coal power 25.1 %, hydro power 9.3 %, oil and other fire power 8.0 % and geothermal power 0.3 % (Figure 13.5).

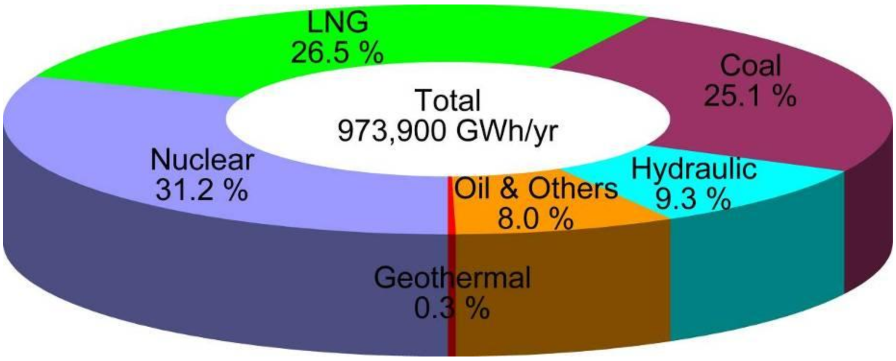


Figure 13.5 Share of electricity production by individual generation sources in Japan from April 2006 to March 2007 (ANRE, 2008).

13.3.2 Direct Use

To summarize geothermal direct use in Japan, special attention should be given to its huge number of hot springs for bath use. As often discussed, the energy saved by the hot springs for bath use in Japan is difficult to estimate because of the huge numbers of hot springs, but these hot springs are economically more important than any other geothermal resources for direct use in Japan.

Geothermal resources for direct use are classified here into three categories: hot water for thermal uses excluding bath use, geo-heat use including geo-heat pumps, and hot springs for bath use. Estimating the energy contribution by hot spring bath use is a long-pending project in Japan. Lund, *et al*. (2005) stated "...who do not keep accurate records of temperatures and flow rates of more than 25,000 hot spring sources in Japan". This is true; however, we present here statistical estimates of the energy contribution by hot springs for bath use. A preliminary result was described on the 2006 Japan Country Report (GIA, 2008), but the result is improved here.

13.3.2.1 Installed Thermal Power

Installed thermal power is described here for the three categories described above. The New Energy Foundation (NEF) in Japan periodically conducts a questionnaire survey on hot water for thermal uses to individual municipalities in Japan since 1990. The latest survey (the 8^{th}) was carried out in the year 2006 (NEF, 2007).

Questionnaires for hot water uses were sent to 267 municipalities in Japan and answers were returned from 116 of them. The number of facilities for the various hot water uses in Japan as of March 2006 was 697 (NEF, 2007). The facilities are generally dominant in northern and colder areas, but are also known in southern Kyushu. Installed capacity of hot water uses in Japan as of March 2006 is 400.3 MW_{th} in Japan (NEF, 2007). The largest application of hot water utilization is for road snow melting and it is followed by house heating and welfare facilities heating.

A questionnaire survey for geo-heat uses including geo-heat pumps was also conducted by NEF in 2006. The number of geo-heat use facilities in Japan as of March 2006 was 638, of which geo-heat pumps in a narrow sense are restricted into 116 and the others are more primitive types using soil air circulation. They are mostly used for house heating, followed by snow melting. Installed capacity of geo-heat uses in Japan, as of March 2006, is 13.3 MW_{th} (NEF, 2007).

Estimating the energy contribution from hot spring bath use is a long-pending project in Japan. The Ministry of the Environment (MOE) annually publishes statistics on the state of utilization of hot springs in Japan, but many data are given as total numbers without details of each hot spring (Figure 13.6; MOE, 2007). Then, a statistical approach is needed to estimate hot spring energy for bath use in terms of saving energy for these data. First of all, it should be noted that the Japanese commonly prefer thermal water at a temperature 42 ºC for bathing. In fact, the Japanese are heating water up to the temperature 42 ºC in most of their home baths using fuels or electricity. Therefore, this provides a baseline for saving energy by hot spring bath uses in Japan.

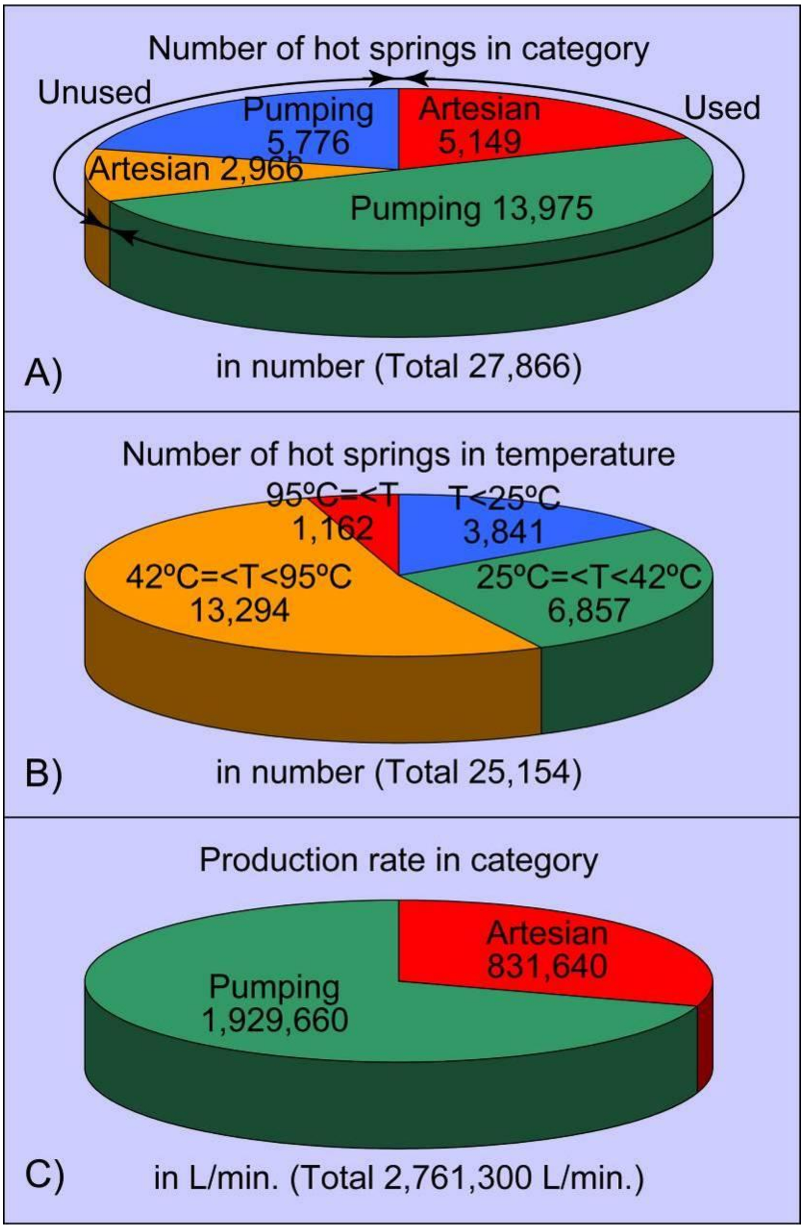


Figure 13.6 Available statistics on the hot springs in Japan as of March 2006 (MOE, 2007).

As of March 2006, there are 27,866 hot spring sources in Japan (Figure 13.6; MOE, 2007). Of these, 8,115 sources are natural hot springs and hot springs from artesian wells, and the remaining 19,751 sources are hot springs from pumping wells. To simplify, the former category is referred to as artesian springs and the latter as pumping springs hereinafter. Of these, 8,742 sources are unused, and the remaining 19,124 sources are used (Figure 13.6).

A total discharge rate of artesian springs is 831,640 l/min and that of pumping springs is 1,929,660 l/min as of March 2006 (Figure 13.6). Of the artesian springs, used and unused springs are 63.45 % and 36.55 %, respectively. If we assume that the discharge rate is proportional to the numbers of hot springs, the discharge rate of the used artesian springs is obtained as 527,676 l/min. However, the unused pumping springs should not contribute to the discharge rate described above because their pumps could have stopped since they were abandoned. Then, the discharge rate of hot springs by pumping wells is 1,929,660 l/min, *i.e.* 100 % of the total discharge.

To conservatively estimate, hot spring sources less than 42 ºC are neglected here, with those higher than 42 ºC only counted, because some of hot springs less than 42 ºC save a small amount of fuel energy but others rather consume fuel energy for heating to 42 ºC, almost compensating each other. As a percentage, the hot spring sources higher than 42 ºC are 57.47 %, and those lower than 42 ºC are 42.53 %. If the discharge rate is constant with the discharge temperature, each discharge rate higher than 42 ºC is simply estimated as 57.47 % of the entire discharge rate. This assumption is reasonable for the pumping springs, and then the 57.47 % of 1,929,660 l/min is obtained as 1,108,976 l/min. However, it is recently found that the discharge rate of the artesian springs clearly increases with the discharge temperature due to the effect of buoyancy of water (Figure 13.7; Muraoka, *et al.*, 2006). When we use the fitting curve at permeability 10^{-13} m^2 (Figure 13.7; Muraoka, *et al.*, 2006), the discharge rate of a hot spring source at the weighted mean temperature of 60.04 ºC (between 42 ºC and 100 ºC) is 546.74 l/min; and the rate at the weighted mean temperature of 28.24 ºC (between 0 ºC and 42 ºC) is 94.90 l/min. Therefore, when the numbers 57.47 % and 42.53 % are weighted by this ratio, it is estimated that the percentage of discharge rates of hot spring sources higher than 42 ºC is 88.61 %; and the rate of those lower than 42 ºC is 11.39 %. Then, 88.61 % of 527,676 l/min is 467,574 l/min (28,054 ton/hr) for the artesian springs, whereas 57.47 % of 1,929,660 l/min is 1,108,976 l/min (66,539 ton/hr) for the pumping springs.

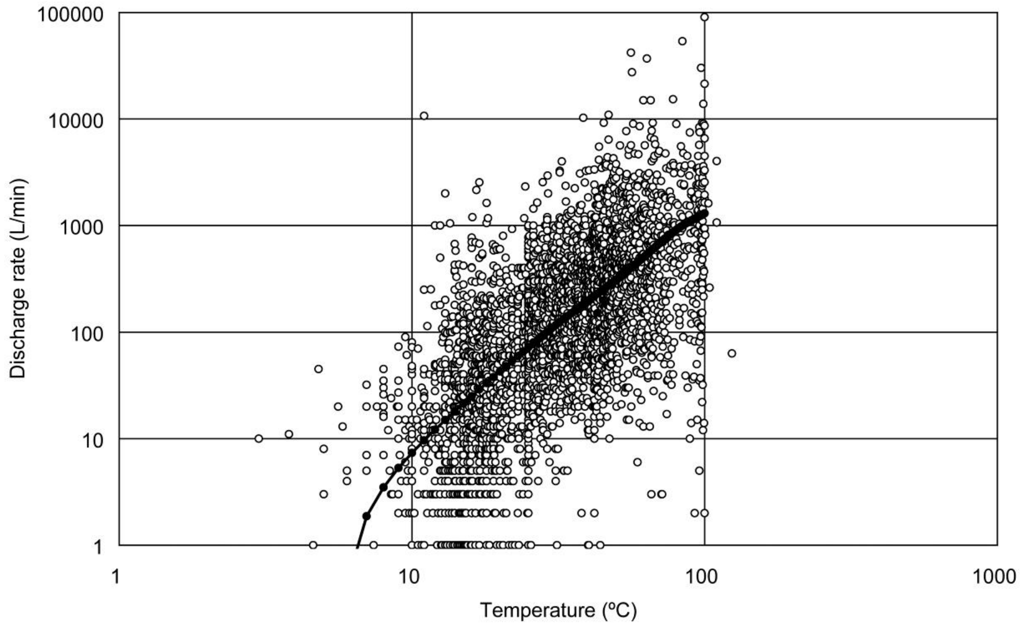


Figure 13.7 A bi-logarithmic plot of the discharge temperature and discharge rate of the 3,686 hot springs in Japan (Muraoka, *et al*., 2006). The fitting curve is given by one-dimensional advection flow equation under the assumptions of the reservoir depth is 1 km, discharge area is 10^4 m^2 and permeability is 10^{-13} m^2.

A mean reference temperature at ground surface in Japan is assumed to be 15 °C. For the artesian springs, the thermal capacity is 881.1 MW_{th}. For the pumping springs, the thermal capacity is 2,089.8 MW_{th}. The total thermal capacity of the hot spring bath uses is 2,970.9 MW_{th}.

Then, the thermal capacity is 400.3 MW_{th} for the hot water for thermal use without bath use, 13.3 MW_{th} for geo-heat use including geo-heat pumps and 2,970.9 MW_{th} for hot springs for bath use. The total thermal capacity of all direct use in Japan is, therefore, 3,384.5 MW_{th} (Table 13.2).

Table 13.2 Summary of geothermal direct use in Japan as of March 2006.

Category	Capacity (MW_{th})	Use (TJ/yr)	Use (GWh/yr)	Ratio (%)	Capacity Factor
Hot water use (without bath use)	400.3	4,887.9	1,357.8	11.77	0.39
Geo-heat use (including geo-heat pump)	13.3	67.9	18.9	0.16	0.16
Hot spring bath use	2,970.9	36,561.7	10,156.0	88.06	0.39
Total	3,384.5	41,517.5	11,532.7	100.0	0.39

13.3.2.2 Thermal Energy Used

As of March 2006, the total hot water thermal energy used for thermal use, excluding bath use, was 4,887.9 TJ/yr or 1357.8 GWh/yr (NEF, 2007). Snow melting is the largest type of hot water utilization, but the capacity factor is very low because it is only used in winter. On the other hand, the capacity factor for all-seasonal uses is relatively high. The “weighted” average capacity factor for hot water use is 0.39.

The total thermal energy used for geo-heat applications in Japan, as of March 2006, was 67.9 TJ/yr or 18.9 GWh/yr (NEF, 2007). The utilization capacity factor is again low in the snow melting and high in the house heating and/or cooling. The average capacity factor for geo-heat uses is 0.16.

For hot spring bath use, even if bath tubs are always filled with hot water, its utilization (capacity) factor depends on visitors’ soaking hours and is not known. According to the data from fiscal year 2005, the number of hot spring accommodations is 15,024, the accommodation guest capacity is 1,413,088, and the annual guest accommodation is 136,613,954 man-days. This means that the mean guest capacity of a hotel is 94.1 persons and an average hotel has 24.9 guests every day through the year. Even if there is some seasonal bias and popularity bias from one hotel to another, its utilization (capacity) factor is expected to be very high. However, to conservatively estimate, the annual day utilization factor related to the seasonal and popularity biases is assumed to be 0.75. In addition, most of bath tubs are cleaned every day so that the hourly utilization factor is assumed to be 0.52. Then, 0.75 multiplied by 0.52 makes 0.39, a very conservative assumption for the utilization (capacity) factor. Then, we obtain the annually used thermal energy 10,844.2 TJ/yr or 3,012.3 GWh/yr in terms of saving fuels by artesian springs.

For the pumping wells, we must subtract energy consumption for pumping from the thermal capacity. The thermal capacity is 2,089.8 MW_{th}. When we again assume the conservative utilization (capacity) factor to be 0.39, we find the annual thermal energy used is 25,719.9 TJ/yr from pumping wells. To conservatively estimate, the capacity of a down-hole motor pump is assumed to be 30 kW to lift 100 l/min of thermal water. This can pump up 6,000 l/hr by the energy consumption of 30 kWh. It is one of the worst efficiency assumptions for pumping. Then, to lift 1,108,976 l/min of thermal water, we need 332,693 kWh/yr of electricity consumption. It is equal to 1.20 TJ/yr. We must here consider of the difference in the energy quality in terms of the toe-basis (toe = tons of oil equivalent) that the produced electricity of 1 TJ is equivalent to 70.4 toe and the produced heat of 1 TJ is equivalent to 35.2 toe (Mongillo, 2005). Then, 1.2 TJ in the electricity basis is equivalent to 2.4 TJ in the heat basis. When we subtract 2.4 TJ/yr from

25,719.9 TJ/yr, the annually used thermal energy is estimated to be 25,717.5 TJ/yr or 7,143.7 GWh/yr in terms of saving fuels by pumping wells.

Summing up both hot spring bath uses, the annually used thermal energy of hot spring bath use is 36,561.7 TJ/yr or 10,156.0 GWh/yr (Table 13.2). The utilization (capacity) factor is here assumed to be 0.39 for a conservative estimate. Lund, *et al.* (2005) quoted the used thermal energy for bathing in Japan but the value was obviously too small due to the limited availability of the data.

The grand total of the three categories of the used thermal energy for direct use in Japan is 41,517.5 TJ/yr or 11,532.7 GWh/yr (Table 13.2).

13.3.2.3 Comment on Categories of Use

We here summarize the direct use in Japan (Table 13.2). We have conservatively estimated the used thermal energy of hot spring bath use in terms of saving energy for heating water up to 42 ºC. Nevertheless, as seen in Table 13.2, the hot spring bath use represents the largest contribution, 88.06 % of the direct use in Japan. Hot water use, excluding bath use, is 11.77 %, or one magnitude less than bath use; and geo-heat use including geo-heat pumps is 0.16 %, three magnitudes less than bath use. In other words, there is plenty of room for development in the other categories such as geo-heat pumps.

13.3.2.4 New Developments in 2007

As has been mentioned, NEF periodically conducts a questionnaire survey on two categories of direct use: hot water thermal use without bathing and geo-heat use including heat pumps. The two most recent surveys were carried out in 2002 and 2006 (NEF, 2003; 2007). Therefore, we can only compare four years' results between 2002 and 2006. The hot water thermal use without bathing decreased from 5,138.7 TJ/yr in 2002 to 4,887.9 TJ/yr in 2006. The main reason for this result is ascribed to the recoverability of the questionnaire surveys- they decreased from 147 replies/260 recipients in 2002 to 116 replies/267 recipients in 2006. The geo-heat use including geo-heat pumps increased from 22.3 TJ/yr in 2002 to 67.9 TJ/yr in 2006, more than a factor of three during the four years. Hot springs for bath use are constantly developed every year. The number of hot spring sources for bath use increased from 27,644 in March 2005 to 27,866 in March 2006, i.e. by 222, or 0.8 % annually. The discharge rate of hot springs for bath use increased from 2,712,140 l/min in March 2005 to 2,761,300 l/min in March 2006, an increase of 49,160 l/min, or 1.8 % annually.

13.3.2.5 Rates and Trends in Development

The hot water thermal use, excluding bathing, apparently decreased from 2002 to 2006 due to the recoverability of the questionnaire surveys, but this category may not have changed much. The geo-heat use, including geo-heat pumps, increased at factor of about three during the four years. This is equivalent to the rate of the 32.1 % every year. Although the present market for geo-heat use is still small, this rate is promising a rapid expansion in the near future. The numbers of hot springs for bathing were 13,079 in FY1962 and 27,866 in FY2005. If we simply apply a linear trend, the mean annual increment is 344. The discharge rate of hot springs for bathing was 930,110 l/min in FY1963 and 2,761,300 l/min in FY2005. If we simply apply a linear trend here, the mean annual increment is 43,600 l/min. This must be the largest and steadiest direct use market in Japan.

13.3.2.6 Number of Wells Drilled

The recent increase of hot spring sources for bathing is almost entirely performed by drilling. Therefore, the numbers of drilled wells are roughly the same as the increment number of hot spring sources 222 in FY2005. The numbers of drilled wells for the hot water uses and geo-heat uses are not given in the results of the questionnaire surveys (NEF, 2007). In some cases, development may be from drilling one well for hot water use; while for other cases, development may be by drilling several shallow wells, such as for geo-heat pump use. However, it seems clear that the number must be larger than the increment number of the facilities. The numbers of facilities of hot water uses increased from 692 in 2002 to 697 in 2006, and the increment was only 5 during the four years. The numbers of facilities of geo-heat uses increased from 276 in 2002 to 638 in 2006, and the increment was 362 during the four years.

13.4 Energy Savings

13.4.1 Fossil Fuel Savings/Replacement

The total geothermal electricity produced in Japan is saving 786,047 toe/yr (toe = tons of oil equivalent) in FY2007, based on the IEA-GIA conversion factor 1 GWh = 253.4 toe in produced electricity (Mongillo, 2005).

The total direct use energy produced in Japan is saving 1,461,416 toe/yr in FY2005, based on the IEA-GIA conversion factor 1 TJ = 35.2 toe in produced heat (*ibid.*).

The direct use energy produced in Japan must have increased from FY2005 to FY2007. Therefore, although the statistics of direct use is taken from FY2005, in the grand total of geothermal power and direct use, Japan is saving at least 2,247,463 toe/yr, in FY2007.

13.4.2 Reduced/Avoided CO_2 Emissions

When we assume the oil thermal power plants as a baseline, the total geothermal electricity produced in Japan results in avoidance of 2,534,334 tonnes of CO_2/yr in FY2007, based on the IEA-GIA CO_2 factor 817 kg/MWh in produced electricity (Mongillo, 2005).

When we assume the oil thermal power plants as a baseline, the total direct use energy produced in Japan avoids CO_2 emissions by 4,716,874 tonnes/yr in FY2005, based on the IEA-GIA CO_2 factor 409 kg/MWh in produced heat (*ibid.*).

The direct use energy produced in Japan must have increased from FY2005 to FY2007. Therefore, although the statistics of direct use are taken from FY2005, in the grand total of geothermal power and direct use, Japan avoided CO_2 emissions of at least 7,251,208 tons/yr, in FY2007.

13.5 Market Development and Stimulation

13.5.1 Support Initiatives and Market Stimulation Incentives

NEDO initiated "Geothermal Development Promotion Surveys" in prospective geothermal areas where investigation is hampered by survey risks, thereby expediting the development of geothermal power generation by private-sector companies. This program started in 1980. The survey program is composed of Surveys A, B and C, varying the scale and content depending upon regional potential and existing data. Surveys have been completed in 65 areas as at the end of FY2007. Since 1999, NEDO has carried out type C Surveys intensively, aiming at a further reduction of survey risks and development lead-time for private-sector companies to construct geothermal power plants based on those preliminary results. Therefore, geothermal reservoir evaluation using large-bore production wells for long-term production tests is included. The four areas selected for the surveys in FY2007 are considered to have potentials suitable for binary power plants smaller than 10 MW_e. Although the capacity is rather small, each area has particular characteristics that may promote further utilization of geothermal energy in the area. In Hachimantai, the area of the second year, two production wells and one reinjection well have been drilled (Figures 13.8 and 13.9 [see This Chapter title page]). One of them has succeeded in the temporary production of steam. In the west of Okushiri-cho, the area of the second year, one production well and one reinjection well have been drilled. One of them has succeeded in the temporary production of steam.

Figure 13.8 Two drilling rigs and alteration zones in Hachimantai, Iwate Prefecture, Japan, on 28 May 2007 (courtesy of H. Muraoka).

However, geothermal development was finished because it was judged that geothermal potential was not promising on the basis of results of geothermal reservoir evaluation and economy evaluation. In the east of Ikedako, a newly selected area, one production well has been drilled (Figure 13.10). As a result of well logging (Figure 13.11), it is expected that there is a promising area. In Sado, a newly selected area, previous survey results indicate a promising area.

The Japanese government has taken a leading role in the development of geothermal energy resources. The government has introduced a compensation system for geothermal developers that provide compensation for interest on bank credits to support developers undertaking well drilling, a process that requires a large investment at an early stage. There are two types of subsidies for companies developing power plants, one aimed at the drilling of exploration wells, with a subsidy ratio of 50 %; and the other for the construction of production and reinjection wells, and facilities above the ground, with a subsidy ratio of 20 %. These systems started in 1983. Beginning in 2002, binary facilities in geothermal power generation systems were awarded with a subsidy ratio of less than one-third.

Actual subsidy record for FY 2007:

- Production wells were drilled at: Matsukawa, 1 well; Ogiri, 1 well
- Reinjection well was drilled at: Sumikawa, 1 well; Hatchobaru, 2 wells
- Facilities : new pipe laying at Sumikawa, Takigami, and Ogiri

Figure 13.10 Well N19-IK-1 in East Ikedako, Kagoshima Prefecture, Japan, on 19 December 2007 (courtesy of H. Muraoka).

13.5.2 Development Cost Trends

The latest construction of the geothermal power plants was in 2000, except for the Hatchobaru binary power plant. There are no recent statistics on development costs. Therefore, it is difficult to comment on the development cost trends. In consideration of the problems such as power transmission lines, the trend of geothermal power plant design is shifting from a big scale to a relatively small scale. Therefore, the total cost of construction tends to decrease, but the unit construction cost is increasing.

13.6 Development Cost Trends

The recent reduction of political supports to geothermal development is a primary constraint to geothermal market promotion in Japan. Internationally, geothermal energy is categorized as a renewable energy together with solar, wind, hydro and biomass energy. However, in Japan, only solar and wind were classified as “New Energy” that enjoyed protection under the Special Measures Law for the Promotion of the Use of New Energy enacted in 1997. Geothermal energy was not included. Moreover, in 2001, biomass was added to the list of “New Energy” to be promoted by the New Energy Subcommittee of the Advisory Committee for ANRE, but geothermal energy was not. According to the Energy Supply and Demand Outlook presented by the government, future growth in geothermal energy is assumed to be zero. Consistent with this perspective, in 2001, the METI decided to cut the entire budget for geothermal energy research and development (Figure 13.1). This decision was purely political. However, the 2006 decision by ANRE, METI, to include geothermal energy in the category of "New Energy" should help reduce constraints on development.

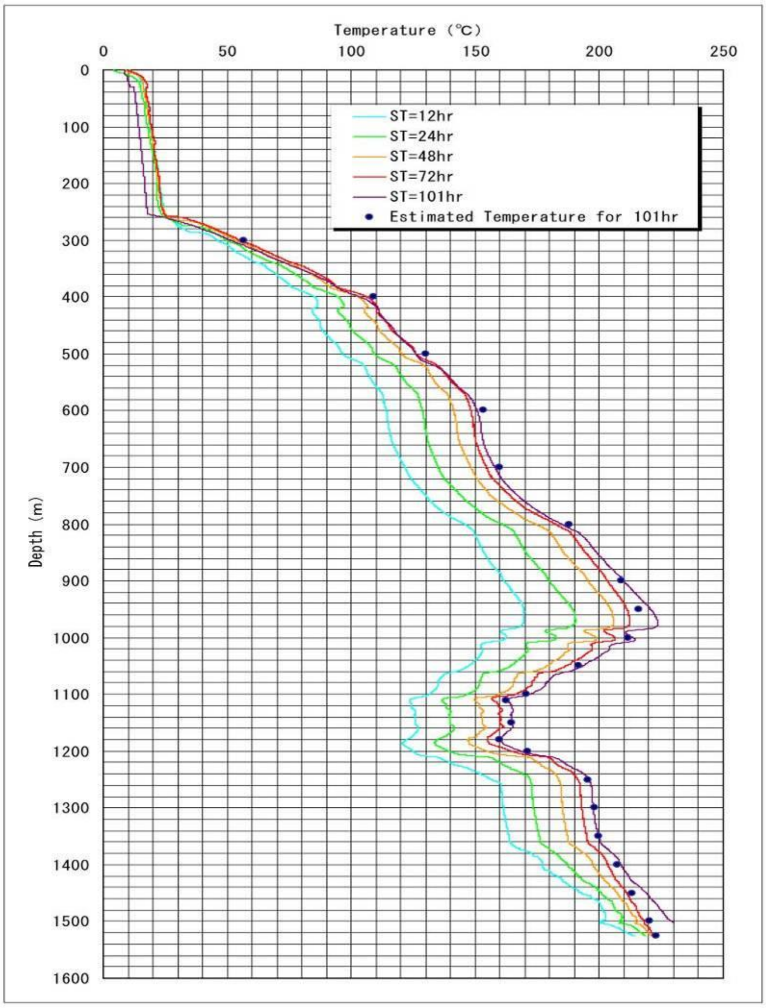


Figure 13.11 Temperature logging result of the well N19-IK-1in East Ikedako, Kagoshima Prefecture, Japan (courtesy of NEDO).

13.7 Economics

Japan's economy entered a serious deflation recession stage beginning 1991, after a long-lasting growing stage since 1955. Particularly, it has come to be more serious by sliding down to minus growth since the Asian currency crisis in 1997. This has dramatically made governmental tax revenues shrink and the government has withdrawn a variety of incentives from many fields, including geothermal R&D. Then, Japan's economy recovered gradually since 2002, but the policy to be a "small" government will still remain for the near future.

13.7.1 Trends in Geothermal Investment

Geothermal power generation is economically marginal in Japan, and therefore, investment in geothermal power developments is risky in the current situation where governmental incentives are not fully available. The investment in geothermal power development in the private sector is currently inactive except for that overseas investment by trading companies and that of product improvement investment by turbine and generator makers.

13.7.2 Turbine, Project, Well Drilling and O&M Costs

Reliable data for most of these items are not available, partly due to their confidential nature and partly due to too few references in the current inactive geothermal market. One of the reference data for the drilling cost is available from the cost estimation of conventional geothermal power developments in Japan (NEDO, 2002), where the drilling cost for a large-diameter production or reinjection well is assumed to be 230,000 Yen/m, equivalent to US$ 2,150/m; and US$ 4.3 M for drilling a 2,000 m depth well. This is still expensive- more than the world standard, but the recent drilling cost may have been further improved.

13.7.3 Trends in the Cost of Energy

Cost of energy is seldom published even by the government because of difficulty in the equal-base comparison under the different levels of political supports. It is old data, but ANRE (2001MS) estimated costs of a variety of energy sources, as of 1999, that show 7.3 Yen/kWh (US$ 0.068/kWh) for fire power averaged from oil, coal and LNG; 5.9 Yen/kWh (US$ 0.055 cents/kWh) for nuclear power; 66.0 Yen/kWh (US$ 0.617/kWh) for photovoltaic power; and 11.5 Yen/kWh (US$ 0.107 /kWh) for wind power. The cost of geothermal power at the nearest year can be referred to NEDO (2002). NEDO (2002) estimated costs of conventional geothermal power developments in 31 target geothermal areas without incentives from the Geothermal Development Promotion Surveys and drilling subsidy. The cost varies from 10.0 to 24.0 Yen/kWh, and most of them range from 10 to 14 Yen/kWh (from US$ 0.093/kWh to US$ 0.131/kWh). This range indicates a general cost of geothermal power in Japan. However, the traditional cost regime was drastically changed by the recent steep rise in the crude oil price.

As Japan is an oil-importing country, the recent steep rise in the crude oil price is changing the energy market regime. Geothermal power generation has been economically marginal in Japan, but, if the crude oil price will further rise, geothermal power generation will soon come to be competitive in cost to the hydrocarbon thermal power generation.

13.7.4 Geothermal Sector Employment

There is no reliable data on geothermal sector employment, but the Geothermal Research Society of Japan has about 550 members that give a reference number of people employed in the geothermal sector in Japan, because a number of non-geothermal employee members of the society may be roughly comparable with that of geothermal employees outside the society.

13.8 Research Activities

There have been no full-scale national projects for geothermal R&D in Japan since April 2003. However, the Geothermal Research Society of Japan still has about 550 members, preserving a high-level of motivation for geothermal R&D. Research activity is individually performed by national universities, national institutes and the private sector with their own budgets.

13.8.1 Focus Areas

Many researchers who are concerned with enhanced geothermal systems or engineered geothermal systems (EGS) are cooperatively participating in the Cooper Basin Project in Australia, including those from the Graduate School of Environmental Studies in Tohoku University, the Civil Engineering Research Laboratory (CERL) in the Central Research Institute of Electric Power Industry (CRIEPI) and the Institute for Geo-Resources and Environment (GREEN) in the National Institute of Advanced Industrial Science and Technology (AIST).

Geo-heat pump systems are currently one of the key research issues in Japan, mainly investigated by the Faculty and Graduate School of Engineering in Hokkaido University, Tohoku University, the Graduate School of Engineering in Kyushu University and AIST.

Geothermal reservoir engineering is mainly carried out by Kyushu University and AIST. Geothermal exploration techniques are mainly studied by Tohoku University, Kyushu University, Akita University and AIST. Nationwide geothermal resource assessments and databases are mainly conducted by AIST.

Numerous hot springs used to be one of the main obstacles for geothermal power development in Japan. However, Kalina-cycle, a current low-temperature power generation technique, enables us to generate electricity from waste thermal energy of high-temperature hot springs above the bath use temperature. The hot spring power generation also enables cooling of the high-temperature hot springs down to an adequate bath use temperature without dilution of balneological constituents. To open the new market for the hot spring power generation, the Geothermal Energy Research & Development Co., Ltd. (GERD) and GREEN, AIST, proposed the "Development of the Hot Spring Ecogene (ecology + co-generation) System" project to the competitive grant "Project to Support Innovative New Energy Technology Ventures" in NEDO. This proposal was adopted as the phase I (feasibility stage) in August 2007 (Figures 13.12 and 13.13). If this project will be further adopted as the phase II, a 50 kW_e class Kalina-cycle power generation system adequate to the hot spring power generation market will be completed in March 2010.

Figure 13.12 A carbonate scale evaluation test for the Hot Spring Ecogene System Project in Otari, Nagano Prefecture, Japan, on 19 January 2008 (courtesy of H. Muraoka).

Figure 13.13 Carbonate scale evaluation lines including heat exchangers for the Hot Spring Ecogene System Project in Otari, Nagano Prefecture, Japan, on 20 January 2008 (courtesy of H. Muraoka).

13.8.2 Government Funded

Geothermal research at national universities and AIST is supported by grants from the government. The amounts used in geothermal research in Kyushu University and Tohoku University are approximately 60 million Yen and 30 million Yen in FY2007, respectively. The amount used in geothermal researches at AIST is dispersed in several research groups and is approximately 20 million Yen in FY2007.

13.8.3 Industry Funded

Information about funding for geothermal R&D in the private sector is not necessarily open to public and is difficult to estimate. Japans' turbines and generators still have 75 % share in the world geothermal power plants and these makers may be investing in these R&D fields. For example, the new 220 kW_e binary plant at Kirishima Kokusai Hotel installed in August 2006 is a R&D demonstration facility owned by the Fuji Electric Systems Co., Ltd. The electric companies and their institute, CERL in CRIEPI, are funding geothermal R&D, but the amounts are unknown.

13.9 Geothermal Education

Geothermal education is mainly conducted by Kyushu University, Tohoku University and Akita University at both undergraduate and graduate levels. Recently, Kyoto University also began geothermal education at a graduate level. The Geothermal Research Society of Japan holds a forum on the geothermal energy for its enlightenment and dissemination to citizens once a year.

A new geothermal course was initiated at Kyushu University in October 2002 following the end of the JICA course. It is a doctoral program in the Graduate School of Engineering entitled: "International Special Course on Environmental Systems Engineering". Twenty students are admitted per year into the Graduate School of Engineering, ten of which are awarded with MEXT (Ministry of Education, Culture, Sports, Science and Technology) Scholarships. Participants in this course study under five advanced departments of the Graduate School of Engineering: Earth Resources Engineering, Civil and Structural Engineering, Urban and Environmental Engineering, Applied Quantum Physics and Nuclear Engineering and Maritime Engineering. Due to the international nature of this course, all the education is conducted in the English language.

13.10 International Cooperative Activities

JICA commenced the "Master Plan Study for Geothermal Power Development in the Republic of Indonesia" at the request of the Indonesian government in 2006. Geothermal potentials of shallow-level hydrothermal resources for power generation in Indonesia are estimated to be 27,357 MW_e, probably the largest geothermal resource country in the world. The current installed capacity was still 857 MW_e as of 2005, only 3 % of the total resource potential (Figure 13.14). In addition, Indonesia has slid down to an oil-importing country since 2002 and the diversification of the primary energy sources is a necessary issue. Particularly, geothermal energy is one of the potential candidates for oil-alternative energy sources.

Figure 13.14 Expanding Kamojang geothermal power plant in Jawa Barat Province, Indonesia, on 28 August 2007 (courtesy of H. Muraoka)

The Indonesian government drew up the National Energy Management Blueprint 2005-2025 where a challenging target of 9,500 MW_e in geothermal power capacity was planned for the year 2025. To attain this goal, the Indonesian government launched several new policies. The Geothermal Law was enacted in 2003. Re-organization of the geothermal sector in the government was made at the end of 2005. The Master Plan Study for Geothermal Power Development in the Republic of Indonesia aims at the systematic support for these efforts by the Indonesian government.

The output of the Master Plan Study for Geothermal Power Development in the Republic of Indonesia is a database for systematic assessment of representative geothermal fields in Indonesia and a scenario for systematic geothermal developments. The project is scheduled in a relatively short term from March 2006 to September 2007. After the 19 months' investigations, the draft final report was delivered to Indonesian counterparts in its final Workshop held in Jakarta, August 30, 2007 (Figures 13.15 and 13.16).

Figure 13.15 The final Workshop for the Master Plan Study held in Jakarta, Indonesia, on 30 August 2007 (courtesy of H. Muraoka).

Figure 13.16 The final Workshop for the Master Plan Study held in Jakarta, Indonesia, on 30 August 2007 (courtesy of H. Muraoka).

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National Activities

Chapter 14

Republic of Korea

Tripping in at the 2 km deep well, Pohang, Republic of Korea (courtesy of M. Mongillo).

14.0 Introduction

Although high-temperature resources for power generation do not exist in Korea, and even though Korea has only quite recently started utilizing low-temperature resources, there are increasing efforts for R&D and the fostering of geothermal utilization at government and industry level. It is well known that the geothermal resources in Korea are characterized by the absence of high-temperature resources for power generation and hot springs are associated with localized, deeply-connected fracture systems mainly in the granite areas. Recently we identified a geothermal anomaly in terms of high heat flow and geothermal gradient in the Tertiary sediment area in the south-eastern part of the Korean Peninsula, where the Pohang low-temperature geothermal development program is now being carried out.

Geothermal heat pump installations are now booming; the total produced energy approximately doubles every year. There is a strong subsidizing program for fostering renewable energy and the total estimated subsidy for geothermal heat pump installation in 2007 reached US$ 9.5 million.

14.1 Highlights for 2007

A total of 1,516 rock samples have been collected (2005-2007) throughout the whole territory and thermal properties such as thermal conductivity, thermal diffusivity and heat capacity of each sample have been measured and compiled into database along with other physical properties such as density and porosity.

The first geothermal assessment has been made using a volumetric method to give an estimate of geothermal potential of 100,000 EJ down to 5 km depth.

14.2 National Policy

14.2.1 Strategy

The Korean Government does not have an independent strategy for geothermal yet, but it has a “new and renewable energy policy”. In 2000, the government began to establish the foundation for certification research and performance analysis with an aim to promote the use of renewable energy. The development of Korean “new and renewable systems” began by focusing investment on the technology development in the three selected areas of photovoltaics, wind power and fuel cells with big market potential. The “Second Basic Plan for the Development, Use and Supply of New and Renewable Energy Technology (2003~2012)” was established in 2003 along with detailed promotional plans for the annual development and supply of new and renewable energy sources to achieve the goal of increasing the use of new and renewable energy to 3 % of the total primary energy consumption by 2006 and 5 % by 2011.

The Korean Government is to set up a new energy policy covering the period to 2030 and including an ambitious target of new and renewable energy’s share during the later half of 2008. R&D expenditure and a subsidizing program are expected to grow by significant amounts according to this new policy.

14.2.2 Legislation and Regulation

The “Alternative Energy Development Promotion Act” was enacted in 1987 and the “New and Renewable Energy Technology Development Project” was launched in 1988. In addition, the “Alternative Energy Development Promotion Act” was amended to the “Alternative Energy Development and Use Promotion Act” in 1997 to promote the use of new and renewable energy and to launch case supply projects (subsidizing program) as well as to offer long-term low-interest loans, tax benefits and government/public funds for those using new and renewable energy.

Also, the “Basic Plan for New and Renewable Energy Technology Development & Supply” was established in 1997 to promote the development and supply of new and renewable energy technology.

From 2004, the “Mandatory Public Renewable Energy Use Act” has come into effect and states that “in construction of all public buildings bigger than 3,000 m^2 in area, more than 5 % of total budget must be used to install renewable energy equipments." Geothermal heat pump installation is now being accelerated with this act.

14.2.3 Progress Towards National Targets

The total use of new and renewable energy at the end of 2007 reached 5.61 million tonnes of oil equivalent (toe), amounting to only 2.40 % of the total primary energy consumption (234.07 Mtoe). According to the "Second Basic Plan for the Development, Use and Supply of New and Renewable Energy Technology (2003~2012)", renewable energy's share should reach 3 % by 2006. However, as of 2007, this goal has not been reached, which is the main reason why the Korean Government is to set up a new policy in 2008.

The status and prospects of geothermal energy still do not seem significant because government program focuses on three major areas: photovoltaics, wind power and fuel cells. Fortunately, however, the importance of geothermal utilization is being acknowledged by the government and the public side, and geothermal's share of the market stimulating incentive has become significant. Therefore, we expect some remarkable progress can be made in the next five years.

Increases in geothermal heat pump installations and energy uses are illustrated in Table 14.1. The values are based on the officially reported installations and we expect the actual number of installations is much bigger than reported.

Table 14.1 Geothermal heat pump installation and energy uses* (2002-2007).

	2002	**2003**	**2004**	**2005**	**2006**	**2007**
Installed Capacity (MW)	0.73	2.35	6.19	8.16	35.1	20.5
Annual Energy Used (Toe) (GWh) (TJ)	122 1.44 5.2	393 4.64 16.7	1,355 16.0 57.7	2,558 30.2 109.0	6,208 73.3 264.5	11,114 131.53 473.5

* Values reported to New & Renewable Energy Center, Korea Energy Management Corporation (KEMCO)

14.2.4 Government Expenditure on Geothermal R&D

In 2007, total investments by government reached some US$ 7.8 M, including:

- Development of deep-seated, low-temperature geothermal resources: $ 2.4 million
- Information system of geothermal resources distribution and utilization: $ 0.8 million
- Various geothermal heat pump utilization and demonstration programs: $ 4.6 million (10 programs)

Government R&D expenditure is increasing with an annual rate of 10-20 %, depending on the applied subjects and Table 14.2 shows the statistics of the last four years:

Table 14.2 Geothermal R&D expenditure for the period 2004-2007.

	2004	**2005**	**2006**	**2007**
Government*	5,505	5,979	6,943	7,792
Industry*	758	881	1,148	1,800
Total*	6,263	6,860	8,091	9,592

* In thousands of US$ (US$ 1 = 1,000 Won)

14.2.5 Industry Expenditure on Geothermal R&D

Industry expenditure is still quite small and mainly a type of matching fund to government R&D funding which amounts to 15 % up to 50 % of total budget, depending on the size of business. In 2007, the total amount is estimated to be some US$ 1.8 M.

14.3 Status of Geothermal Energy use in 2007

14.3.1 Electricity Generation

There is no geothermal power generation in Korea at present.

14.3.2 Direct Use

14.3.2.1 Installed Thermal Power

By the end of 2007, the installed thermal power is 106.54 MW_{th}, including hot spa usage and heat pumps (Table 14.3).

Table 14.3 Geothermal direct heat uses, fossil fuel saving and avoided CO_2 emission in Korea as of December 2007.

Use	Installed Capacity (MW_{th})	Annual Energy Use ($TJ/yr=10^{12}$ J/yr)	Capacity Factor	Fossil fuel saving (toe/yr)	Avoided CO_2 emission (ton)
Individual Space Heating	1.73	33.86	0.62	1,618	3,847
Bathing and Swimming	31.50	485.73*	0.49	23,218	55,184
Geothermal Heat Pumps	73.31	473.46	0.20	22,631	53,790
Total	106.54	993.05		47,467	112,821

* Σ [(supplying water temp.: 42 – leaving water temp.: 27)×flow rate×operating time]

14.3.2.2 Thermal Energy Used

Direct use in Korea includes individual space heating with hot spring water, bathing (hot spa) and geothermal heat pumps (Table 3).

The thermal energy used in 2007 is estimated to be 993 TJ, and the capacity factors are 0.62, 0.49 and 0.20 for hot spa and heat pumps, respectively (Table 14.3).

14.3.2.3 New Developments in 2007

The new developments consisted of increasing geothermal heat pump installation.

14.3.3 Energy Savings

Fossil fuel savings and CO_2 emission reductions are included in Table 14.3, following IEA and GIA conversion factors.

14.4 Market Development and Stimulation

14.4.1 Support Initiatives and Market Stimulations Incentives

The Korean Government offers long-term, low-interest loans, tax benefits and government/public funds for those using renewable energy. Subsidies for geothermal installations through various renewable energy spreading programmes amounted to US$ 9.5 million in 2007. Also from 2004, the "Mandatory Public Renewable Energy Use Act" has come into effect and states that "in construction of all public buildings bigger than 3,000 m^2 in area, more than 5 % of total budget must be used to install renewable energy equipment." Geothermal heat pump installations are now being accelerated with this act.

Table 14.4 Subsidy# for geothermal installation for the period 2004-2007 (in Thousands of US dollars; US$ 1 = 1,000 Won)

	2004		**2005**		**2006**		**2007**	
	Capacity (MW)	Subsidy*	Capacity (MW)	Subsidy*	Capacity (MW)	Subsidy*	Capacity (MW)	Subsidy*
Deployment Program	2.83	1,886	5.92	3,642	16.94	9,541	15.37	8,351
Rural Deployment Program	1.44	1,505	1.82	1,770	2.57	2,252	0.76	1,191
Total	4.27	3,391	7.74	5,412	19.51	11,793	16.13	9,542

* The subsidy amounts are given in thousands US$.
# Note: Data correspond to year of subsidy support, so actual operations are to be one or two years later.

14.5 Development Constraints

14.5.1 Technical and Social Barriers

A barrier to the progress of geothermal heat pumps from the technical and scientific points of view may be explained by relative negligence of the importance of accurate information on the thermal properties of subsurface materials and the lack of scientific knowledge on hydrogeological conditions influencing the heat extraction/injection rate.

Also, the general perception that geothermal heat pump systems are of high initial cost while there does not exist any guaranteed example of performance since heat pumps are in the beginning stages of use. Therefore, people tend to consider that a natural gas or an oil boiler is cheaper in the initial stage and durable. The most serious problem is still the lower public awareness level than wind or photovoltaic, even some government officers and energy authorities think that geothermal is nothing but a heat pump.

14.5.2 Environmental Issues

The "Groundwater law" states that all boreholes must be reported on depth and purpose prior to drilling. Also, if somebody is to use groundwater, an environmental impact evaluation is required with results submitted. It is also effective for groundwater thermal utilization even though subject to re-injection. The heat pump business society claims that heat extraction from groundwater will not affect the quality of the water and thus thermal utilization should be free from such regulation. Some arguments are still continuing.

14.6 Economics

14.6.1 Trends in Geothermal Investment

Governmental investment in geothermal has steadily increased since 2003. Investment from industry has also increased as a matching fund to government R&D budget. Government investigation is being made though R&D expenditure and various subsidizing programs; statistics are available in Tables 14.2 and Table 14.4, respectively.

14.6.2 Trends in Cost of Energy

Because 97 % of fossil fuel is imported, energy cost in Korea reflects recent high oil prices. The price of electricity, however, does not change much, partly due to the high portion of nuclear power generation (~40 % of total generation) and partly due to government policy. The average electricity price is about US 7.8 cents/kWh. But it is highly possible that an increase in the electricity price by some amount will occur in 2008 because of the abnormally high oil price.

14.6.3 Number of People in the Geothermal Sector

The number of people in the geothermal sector is continuously increasing thanks to the active geothermal heat pump business. There are some 50 people in universities and research institutes including graduate students. In the industry sector, around 100 people are working on geothermal heat pump system design and installation, including drilling for borehole heat exchangers.

14.7 Research Activities

14.7.1 Focus Area

R&D activities in Korea are focused on 1) exploration and exploitation of low-temperature geothermal water for district heating, 2) characterization of geothermal resources, 3) sampling & measurement of subsurface thermal properties for borehole heat exchangers resulting in big database, 4) simulation of T-H-C coupled behavior with borehole heat exchanger with groundwater flow, and 5) utilizing groundwater thermal energy along with aquifer thermal energy storage (ATES). Almost all of the research activities are initiated by government funds. In this annual report, we describe items 2) and 3).

14.7.2 Government Funded R&D

R&D in geothermal investigation, exploration and exploitation is led by the Korea Institute of Geoscience and Mineral Resources (KIGAM), the only government funded research institute in the geoscience field in Korea. The Geothermal Resources Group of KIGAM is leading the two major government funded R&D programs: “Development of deep-seated, low-temperature geothermal resources” and “Information system of geothermal resources distribution and utilization”, those grants amount 33.6 % of the total R&D or RD&D funding.

RD&D programs on various geothermal heat pump applications are funded by the New & Renewable Energy Center, Korea Energy Management Corporation (KEMCO). In 2007, two new R&D projects were granted for groundwater thermal energy utilization: the single well groundwater-source heat pump system and the aquifer thermal energy storage system.

14.7.2.1 Sampling and Measurement of Thermal Properties

The rapid increase in geothermal heat pump installation is mainly due to a strong government subsidizing program. Although the installation of groundwater-source heat pumps is increasing its proportion, most of the heat pump systems so far are based on the borehole heat exchanger system.

Although geothermal heat pump installation in Korea is booming, quantitative information on the thermal properties of subsurface materials has not been provided yet. As a consequence, installed heat pump systems are likely to be over-designed, which makes the systems less competitive in terms of initial cost.

Since KIGAM started a five-year term government funded project titled “Information system of geothermal resources distribution and utilization” in 2005, a total of 2,163 rock samples were gathered based on 1:250,000 scaled geologic map by the end of 2007. Among them, thermal properties, including density, porosity, thermal conductivity, thermal diffusivity and heat capacity of 1,516 samples have been measured so far and compiled into database. The geothermal gradient distribution has also been updated to incorporate 715 well measurements for wells whose depths exceed 300 m. A heat flow distribution map resulted from the geothermal gradient map and some thermal conductivity measurements include 492 data. For heat production, we gathered 180 data from chemical analysis and gamma lay logging which will be discussed later. Figure 14.1 shows results of thermal conductivity, geothermal gradient, heat flow and heat production corresponding to their sampling locations in map.

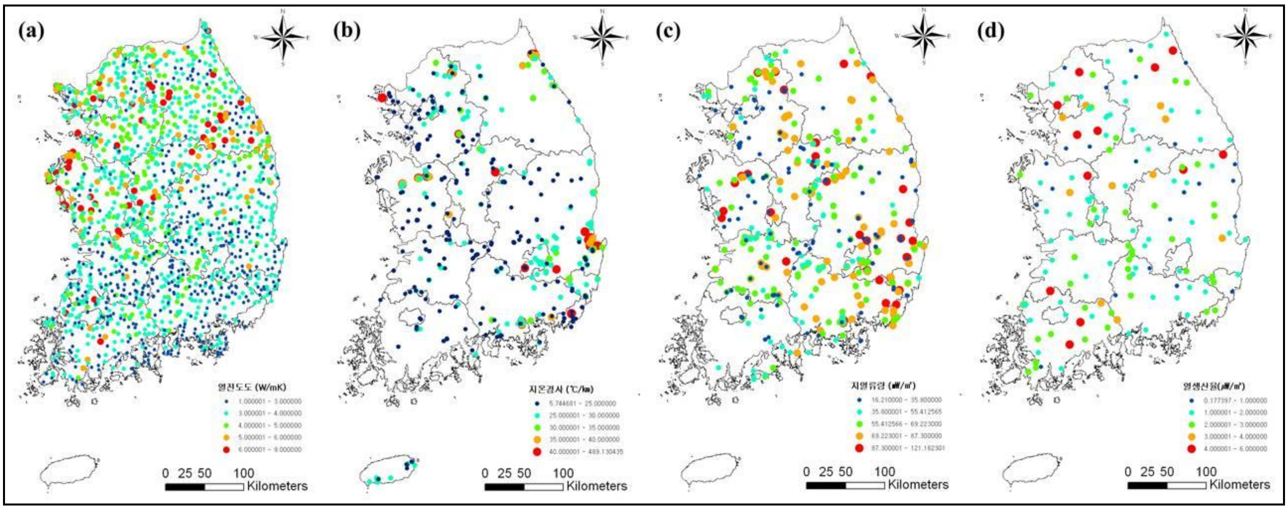

Figure 14.1 Thermal property distribution in Korea; a) thermal conductivity, b) geothermal gradient, c) heat flow, and d) heat production.

The study of heat production rates in Korea may be especially interesting, because the geology of Korea mainly consists of gneiss and granite. KIGAM compiled a heat production map using 180 samples throughout the territory: chemical analyses of 125 rock samples and interpretation of 55 gamma-ray logs in crystalline formation. The average heat production rates of granite (132 samples) and gneiss (48 samples) are 2.040±0.086 $\mu W/m^3$ and 2.041±0.162 $\mu W/m^3$, respectively. The heat production rate of the granite in Korea is lower than usual values (average of 3.0 $\mu W/m^3$). Figure 14.2 shows the heat production map and granite distribution map superimposed with locations of hot springs whose discharge temperatures are higher than 40 °C, except PCHS. Comparing those two maps we can find high heat production has little to do with hot spring occurrence, which is also true when we compare with heat flow distribution. So we can infer hot springs in Korea are mainly related with deeply extended fractures not with heat generation in granite.

14.7.2.2 First Geothermal Resources Assessment in Korea

Combining thermal properties shown in Figure 14.1 and surface temperature data has led to an update of the temperature distribution map at various depths (Figure 14.3). Finally, with measured density and heat capacity values, the first geothermal assessment in Korea can be provided by the following formulae:

Temperature at depth z: $$T(z) = \frac{A_0 b^2}{\lambda}(1 - e^{-z/b}) + \frac{Q_0 - A_0 b}{\lambda} z + T_0$$

Heat contents down to depth z: $$Q = \rho C_p V \{T(z) - T_0\},$$

Where T_0 is surface temperature, Q_0 the surface heat flow, A_0 the heat production, V the total volume in the depth interval, ρ the density, C_p the specific heat, λ the thermal conductivity and b the attenuation depth. Thus estimated, the heat content in Korean territory down to 5 km reaches some 10^5 EJ. That is approximately 10,000 times the primary energy consumption in 2006. This estimate is based on volumetric methods and practical geothermal reserves are far less considering small amount of available fluid contents and the viable technologies of today. However, the estimate is important as the first quantitative geothermal assessment in Korea.

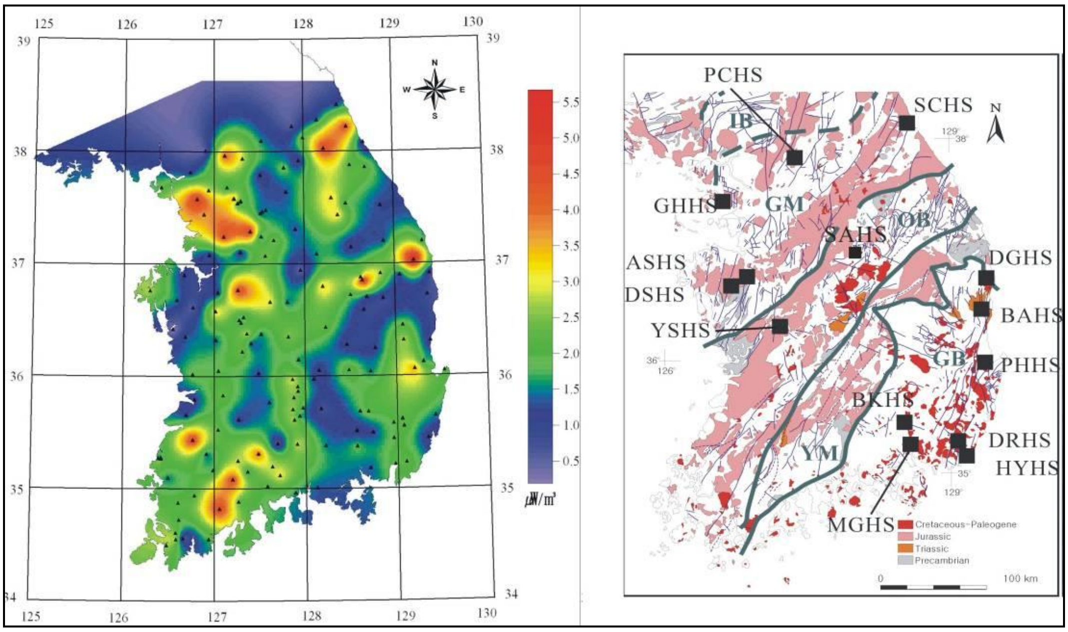

Figure 14.2 Heat production map (left) and granite distribution map superimposed with locations of major hot springs (right).

14.8 Geothermal Education

There does not exist regular curriculum for geothermal at university level yet. Public recognition, however, is increasing and there are special lecture courses for HVAC and architectural engineers to introduce general geothermal topics and state-of-the-art heat pump technologies once a year. Also, there are many small seminars about general geothermal topics reflecting increasing public recognition thanks to recent high oil price.

14.9 International Cooperative Activities

The major international cooperative activity of KIGAM includes participating on the IEA-GIA Executive Committee and in Annex VIII- Direct Use of Geothermal Energy. KIGAM also maintains research collaboration with the Institute for Geo-Resources and Environment (GREEN) of AIST, Japan, in geophysical exploration of geothermal resources and other geothermal related topics.

The Korean Technology Center for Geothermal Energy (KORGE) was established in 2006, aiming to foster geothermal utilization. KORGE opens the Accredited Installer Workshop in conjunction with International Ground Source Heat Pump Association (IGSHPA).

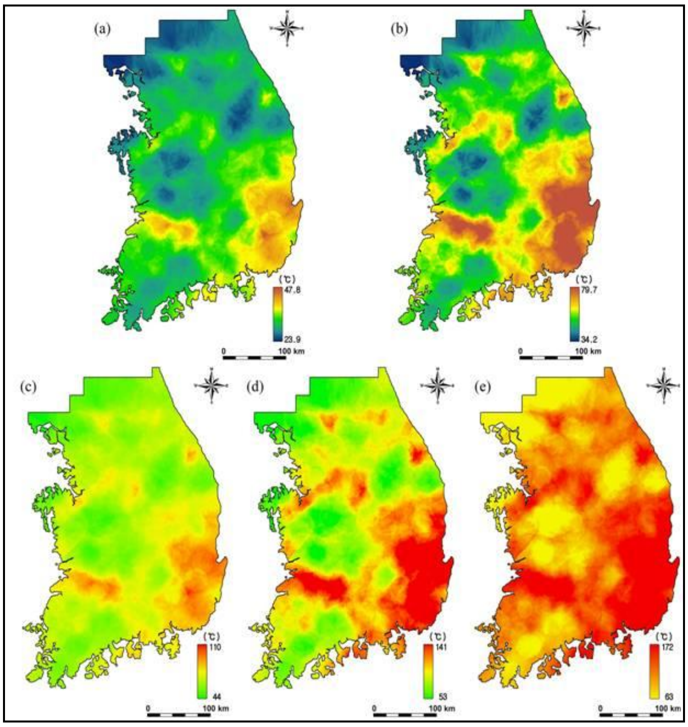

Figure 14.3 Temperature distribution with depth. a) 1 km, b) 2 km, c) 3 km, d) 4 km, and e) 5 km depth.

14.10 Websites

- Geothermal Resources Division, KIGAM: http://geothermal.kigam.re.kr
- Korean Technical Center for Geothermal Energy: http://www.korge.org

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National Activities

Chapter 15
Mexico

Los Azufres Geothermal Field, Mexico, showing production lines to separators, with dual silencers in background (courtesy of D. Nieva, IIE).

15.0 Introduction

Geothermal energy is, by far, the most important non-conventional renewable energy source utilized in Mexico. Although there is some tradition for direct uses of geothermal energy, mainly related to balneology, the most important use is for electricity generation.

Geothermal development for electricity generation started in Mexico in 1959, with the commissioning of the first commercial plant in the Pathé Geothermal Field, central Mexico (Figures 15.1 and 15.2). By December 2007, the geothermal-based installed capacity for electricity generation was 958 MW_e, placing Mexico in fourth place worldwide.

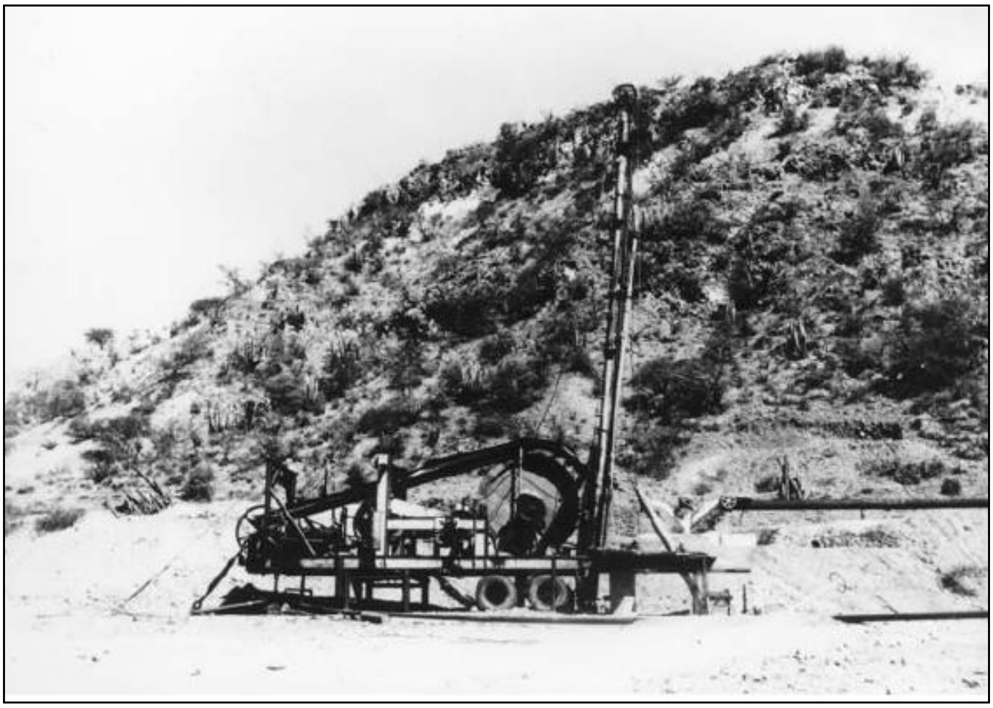

Figure 15.1 Production wells were drilled at Mexico's Pathé Geothermal Field in 1957 using early technology percussion drilling and steam powered machinery.The first geothermal power production in the Americas was generated at this field in 1959.
(Photo from GRC, 2003).

Figure 15.2 Steam flowing from the first geothermal production well drilled in 1956 at the Pathé Geothermal Field (Photo from GRC, 2003).

15.1 National Policy

About 78 % of the installed capacity for public-service electricity generation belongs to the two government-owned utilities, namely the Comisión Federal de Electricidad (CFE) and Luz y Fuerza del Centro (LyFC). The remaining 22 % belongs to private-owned companies. CFE is responsible for all electricity generated with geothermal steam. This primary energy source has been utilized for decades for power generation; the technology is considered mature, and it is set to compete under the same bases as fossil-fuel, conventional hydro and nuclear technologies.

CFE is currently doing feasibility studies to increase the installed capacity and replace some of the older power plants. The aim is to replace 75 MW_e with 100 MW_e in the Cerro Prieto Field, using the same amount of steam. CFE is also considering increasing by 46 MW_e the installed capacity in Los Humeros and taking steps to install 75 MW_e in the partially developed Cerritos Colorados field and undeveloped areas with geothermal potential (see below). Feasibility studies are also being conducted for the following projects: 50 MW_e in binary power plants in Cerro Prieto Field; replace seven five MW_e units in Los Azufres Field with two units, one of 50 MW_e and one of 25 MW_e, for a net increase of 40 MW_e using the same amount of steam; Research and Development of Hot Water (brine) Injection System in Cerro Prieto Field.

15.2 Current Status of Geothermal Energy Use

15.2.1 Electricity Generation

15.2.1.1 Installed Capacity, Electricity Generated and New Developments

The installed capacity in 2007 was 958 MW_e, distributed among the geothermal fields as follows: Cerro Prieto (720 MW_e), Los Azufres (188 MW_e), Los Humeros (40 MW_e) and Las Tres Vírgenes (10 MW_e).

The electricity generation with geothermal steam in 2007 was 7,393 GWh.

The eighth back-pressure unit of 5 MW_e was installed and commissioned at the Los Humeros field.

15.2.1.2 Number of Wells

During the year 2007, CFE drilled: 2 geothermal production wells in Cerro Prieto field, and 1 production well in Los Humeros field. For the year 2008, 9 production wells are scheduled for drilling at Cerro Prieto and no injection wells; 2 production wells are scheduled for Los Humeros, and 3 for Los Azufres field. One exploration is well is planned in Acoculco geothermal zone.

During the year 2007, CFE performed the following workover jobs: 14 in production wells in Cerro Prieto field and 2 in Las Tres Vírgenes field. For the year 2008, there are 11 scheduled in production wells in Cerro Prieto field.

15.2.1.3 Contribution to National Demand in 2007

Electricity generation from geothermal sources represents around 3.3 % of total generation in Mexico.

The geothermal contribution to electricity generation is more than 1.5 times higher than its contribution to the installed capacity (1.9 % of the total), reflecting the very high capacity factor.

15.2.2 Direct Use

The installed thermal power was 164 MW_{th} in 2007. Balneology was the main use at 160 sites distributed in 19 states.

15.2.3 Energy Savings

The electricity generated from geothermal steam in 2007 amounted to the avoided consumption of 36 PJ, 15.9 PJ and 8.9 PJ of primary energy from fuel oil, natural gas and coal, respectively, considering the typical mix of fossil fuels utilized in Mexico.

15.3 Market Development and Stimulation

At present there are no economic incentives for geothermal development in Mexico. CFE, the larger of two national utilities, increased its installed capacity for power generation with geothermal sources from 953 MW_e to 958 MW_e in 2007; and this is the only substantial increase expected throughout 2008, although studies for possible new developments and expansions in developed fields are underway (see below).

15.4 Development Constraints

As mentioned above, power generation with geothermal energy is considered conventional in Mexico, and thus it is set to compete under the same bases as fossil-fuel, conventional hydro and nuclear technologies. Therefore, it is fair to say that the main constraint for further geothermal development in this country is its economic disadvantage against modern fossil-fuel generation technologies. At least in one case, namely that of the Cerritos Colorados Geothermal Field, which is a fully proven resource, development has come to a full stop because of concerns from the local (State) government about possible environmental impact.

15.5 Economics

15.5.1 Trends in Geothermal Investment

As mentioned above, studies are underway in CFE for future developments in the order of 46 MW_e in Los Humeros; 100 MW_e in Cerro Prieto that will replace 2 of the older units (75 MW_e); 75 MW_e in Cerritos Colorados; 50 MW_e in binary power plants in Cerro Prieto; and for replacing seven old 5- MW_e units in Los Azufres Field with two units of 50 and 25 MW_e.

CFE is also exploring new fields in Acoculco and Tulecheck, and has plans to conduct exploratory studies in San Pedro, La Soledad and the Chichonal Volcano, among others.

15.5.2 Trends in Cost of Energy

The increase of the average price for electricity has accelerated in the last few years (*ca*. 5.4 % from 2000 to 2001, 14 % from 2001 to 2002, and higher increases after 2002), reflecting in good measure the trend of fossil fuel prices.

15.6 Research Activities

Most geothermal research activities in Mexico are focused on development and exploitation of resources for power generation. Specifically, they are aimed to improve the knowledge of the fields and thus the ability to predict their behaviour under continued exploitation. Some effort is spent in exploration of new areas with geothermal potential. Practically all geothermal research is funded by the federal government.

15.7 Geothermal Education

The University of the State of Baja California (UABC) use to offer a Geothermal Training Program (10 month program) which, in addition to the programs offered by Iceland (the United Nations University) and New Zealand (the Geothermal Institute of the University of Auckland), was utilized by CFE to train some of their young engineers. During the last years CFE has sent young engineers for training to Japan, under an agreement between JICA and the Mexican government, and CFE is planning to do the same in the next years. For the most part, mechanical, electrical, chemical and geological engineers are trained on the job, as part of their professional development in CFE and the Instituto de Investigaciones Eléctricas (IIE). Periodic professional meetings (congresses, seminars, *etc*.) provide a basis for continued education of geothermal personnel.

15.8 International Cooperative Activities

Mexico, through IIE and CFE, has participated in the activities of Annex I (Environmental Impacts of Geothermal Energy Development) and Annex IV (Deep Geothermal Resources), and is participating now in Annex VII (Advanced Geothermal Drilling Technologies) of the Geothermal Implementing Agreement.

In 2007, IIE continued a project for the evaluation of low and intermediate enthalpy geothermal resources in Mexico and Central America, with the aim of promoting direct uses of this energy source. This project is partially supported by the International Atomic Energy Agency.

15.9 References

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National Activities

Chapter 16

New Zealand

Figure 16.1 Poihipi 55 MWe geothermal power station, Taupo, New Zealand (courtesy of C. Bromley).

16.0 Introduction

The New Zealand geothermal scene continues to be very active. There has been recent installation of new generation, and commitments to new geothermal power plants and direct use applications. More than 600 MW_e of additional geothermal generation is looking feasible and commercially attractive over the next few years. Geothermal heat pumps have been slow to become established, but this looks like an area for considerable future growth. Regional and district councils have clarified the rules and policies related to takes and discharges of geothermal water. Central Government is dedicated to the greater use of renewable low-emission energy forms (including geothermal energy).

16.1 Major Highlights in 2007

Mokai, Rotokawa, Wairakei, Ngawha and Kawerau power plants have all been operating normally at full load. The other major highlights for 2007 include the commissioning of additional generation capacity at Mokai (+13 MW_e), the successful results of deep make-up drilling at Ohaaki (restoring about 40 MW_e worth of steam supply), the rapid construction of a new 100 MW_e power plant at Kawerau, and approvals granted for a significant new power plant at Rotokawa (130 MW_e). Additional steam supply from new wells in the Te Mihi sector of Wairakei has been used to fully load the nearby Poihipi power plant, increasing its average output by about 25 MW_e. This acceleration in development activity has been supported by intense drilling activity (about 20 new wells per year).

16.2 National Policy

16.2.1 Strategy

The New Zealand Government energy strategy (MED, 2007) shows that geothermal investment is currently competitive with a wide range of alternative generation sources and so presents an investment opportunity (even without renewable energy subsidies or carbon credits). Wholesale gas prices for thermal generation have more than doubled.

The equivalent of an additional 1000-1200 MW_e of competitive geothermal resources is readily available, even after disregarding environmentally protected fields from consideration and after de-rating fields that are close to population centres. Therefore, geothermal projects can meet more than a decade of electricity demand growth (660 GWh/yr). With a total capital cost of around NZ$ 4 M/ MW_e, such an expansion in geothermal generation equates to an expected $4 billion development programme over the next 10 years.

Figure 16.2 The Mokai 112 MW_e binary geothermal power plant nestled in a dairy farm.

16.2.2 Legislation and Regulation

In October 2007, an announcement was made by the NZ Government to ban all new fossil fuel (non-renewable) power plants for the next 10 years (except for emergency supply purposes). Geothermal was recognised as a resource vital to New Zealand's future energy mix and is economically competitive at the current average wholesale electricity cost of about 70 NZ$/MWh (US$50/MWh). Spot market prices vary with demand and hydro-lake capacity fluctuations.

16.2.3 Progress Towards National Targets

NZ geothermal growth potential could double or triple existing geothermal supply, provided access and regulatory barriers are overcome. The Government has streamlined consenting processes for critical renewable energy schemes, eg. Te Mihi and Wairakei developments, and plans to introduce a carbon emissions trading scheme is still being debated. In October 2007, the Government set targets for 2025 of 9.5 PJ/yr of additional direct use renewable energy (mostly geothermal or wood biomass), 90 % of all electricity from renewables and fast uptake of electric vehicles.

Figure 16.3 Production well at Ohaaki Geothermal Field.

16.2.4 Government and Industry Expenditure on Geothermal R&D

Government expenditure on geothermal research and development is presently about NZ$ 2 M/yr (US$1.4 M/yr), increasing to about NZ$ 3 M/yr over the next few years.

Mighty River Power and Contact Energy are the main geothermal operators and they expect to expend more than NZ$ 2 B in developing geothermal resources over the next 10 years. A small proportion of this is targeted at research to improve resource knowledge and reduce development costs. Specific applied research projects are linked with longer-term government-sponsored research programmes.

16.3 Status of Geothermal Energy Use in 2007

16.3.1 Electricity Generation

New Zealand's total installed capacity in 2007 was 452 MW_e.

In 2007, the total electricity generated was 3,272 GWh, with an average capacity factor of 83 %.

16.3.1.1 New Developments During 2007

The Mokai development was upgraded, with an additional 13 MW_e through upgrading Ormat units and steam turbine.

Additional deep drilling at Ohaaki Field has restored steam supply to enable about 75 MW_e of net generation. Resource potential output was de-rated in early 2007 to 50 MW_e (1 turbine) but was later re-rated to 75 MW_e out of 105 MW_e installed.

Figure 16.4 New well discharging vertically at Rotokawa Geothermal Field.

16.3.1.2 Rates and Trends in Development

Several new developments are under construction, including: 100 MW_e at Kawerau (steam turbine), 10 MW_e at well Ka24 (binary plant), and 15 MW_e at Ngawha (binary plant).

Many new projects have been committed, or consents granted and designs/equipment contracts well advanced: Rotokawa II (130 MW_e), Te Mihi (234 MW_e to replace Wairakei's 162 MW_e with more efficient plant), Tauhara (23 MW_e, binary).

Future projects at an early stage of planning include: Ngatamariki (80 MW_e?), Tauhara (220 MW_e?).

Consequently, there is a very real possibility of more than doubling NZ geothermal production within 5 years (Figure 16.5).

16.3.1.3 Number of Wells Drilled

In 2007, 20 wells were drilled: 15 for production and 5 for reinjection.

16.3.1.4 Contribution to National Demand

Geothermal comprises about 4.9 % of the national capacity. However, it generates 7.7 % of the total national electricity.

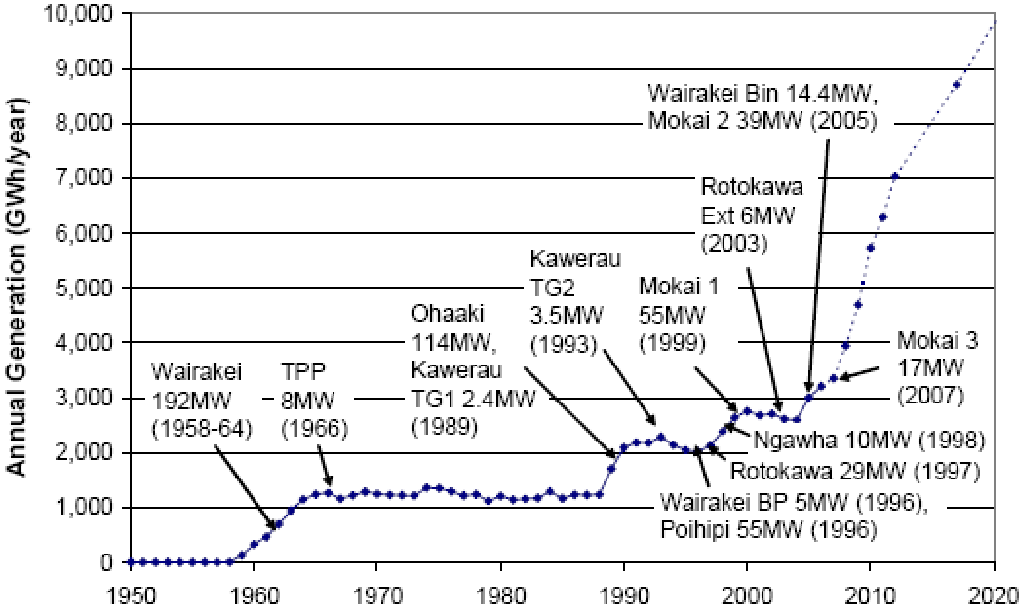

Figure 16.5 Historical and projected growth in NZ geothermal electricity – 2007 and beyond

Table 16.1 Table of New Zealand geothermal power projects, current, under construction and planned as of January 2008.

Geothermal System	Start Date	Capacity (MW_e)	Direct Use (MW_{th})	Constructing (MW_e)	Planned (MW_e)
Wairakei	1958-2005	176			234-162
Poihipi	1996	55			
Tauhara Centennial	2007		100		23
Tauhara Expansion					220
Kawerau	1958	14	200	100	
Ka 24				10	
Ohaaki (104 MW_e)	1989	50			
Rotokawa	1997	35			132
Mokai	1999-2007	112			
Ngawha	1998	10		15	
Ngatamariki					80
Total		**452**	**300**	**125**	**527**

16.3.2 Direct Use

16.3.2.1 Installed Capacity and Energy Used

The total primary energy discharged in 2007 was about 21 PJ/yr.

The thermal energy used in 2007 amounted to 9.8 PJ, with an average capacity factor of 47 %. About half of the direct use was for industrial process heating at the Kawerau Pulp and Paper Mill operated by Norske Skog, with the balance mostly used for space heating in Rotorua, Taurange and Taupo, with some wood drying and horticulture (e.g. tomato/capsicum glasshouses at Mokai, orchids at Wairakei) and aquaculture (e.g. Prawn Farm at Wairakei).

16.3.2.2 New Developments in 2007

the Tauhara Centennial Tenon Mill wood drying facility (100 MW_{th}) is now operational. A waste-wood pellet-drying facility (approximately 50 MW_{th}) at Tauhara (for domestic pellet burning heaters) is in the advanced stages of planning.

16.3.2.3 Rates and Trends in Development

Rates of growth have been relatively static over recent years but are predicted to accelerate in the next 10 years (Figure 16.6). Geothermal tourism is growing, and is also predicted to accelerate. This involves commercial visits by domestic and overseas tourists to natural geothermal parks and bathing at hot spring resorts (Figure 16.7).

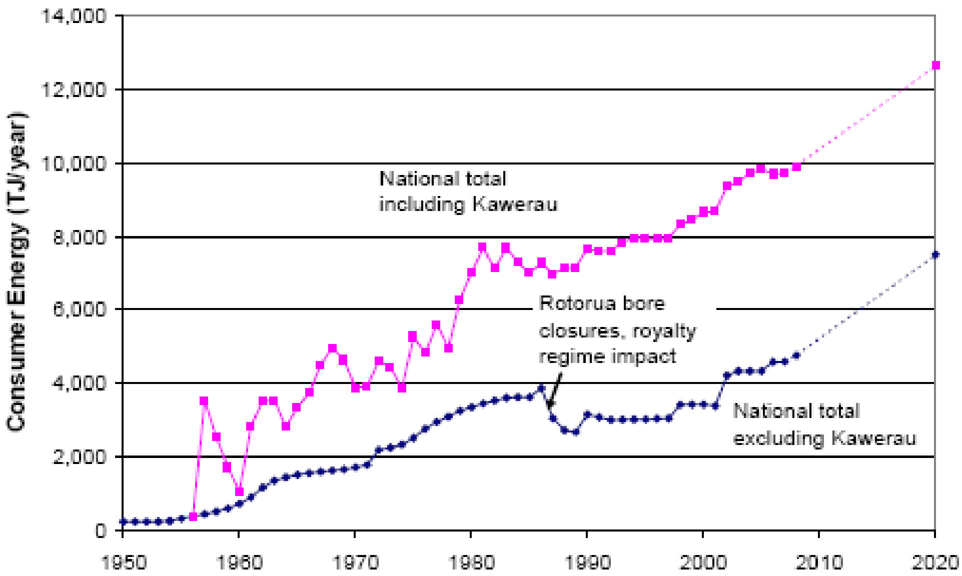

Figure 16.6 Historical and projected growth in direct use of geothermal in New Zealand.

16.3.3 Energy Savings

The fossil fuel savings/replacement for the 3,272 GWhr (11.78 PJ) of geothermal electricity generated in 2007 (at 70.4 toe/TJ) was about 0. 83 Mtoe/yr (assuming 70.4 toe/TJ).

The fossil fuel savings/replacement for 9.8 PJ of geothermal direct heating in 2007, assuming 35.2 toe/TJ) was 0.34 Mtoe.

The CO_2 emissions reduced/avoided for 3,272 GWh of electricity generation (using average of 817 t CO_2 /GWh) was 2.67 Mtonnes**.**

The reduced/avoided CO_2 emissions for 9.8 PJ of direct heating (using average of 114 tonnes CO_2/TJ) was 1.1 Mtonnes.

Using published data on gas content of discharged steam, the calculated actual CO_2 emissions from all NZ geothermal power plants producing 3,272 GWh in 2007 was 0.269 Mtonnes. This would have avoided CO_2 emissions from an equivalent (Huntly) coal-fired power station (3,272

GWh at 900 tonnes CO_2 /GWh) of 2.94 Mtonnes CO2**,** leaving a calculated net benefit from geothermal of 2.67 Mtonnes CO_2 (same as above). Such a calculation ignores the long-term effects of steam production on natural CO_2 emission rates through the ground.

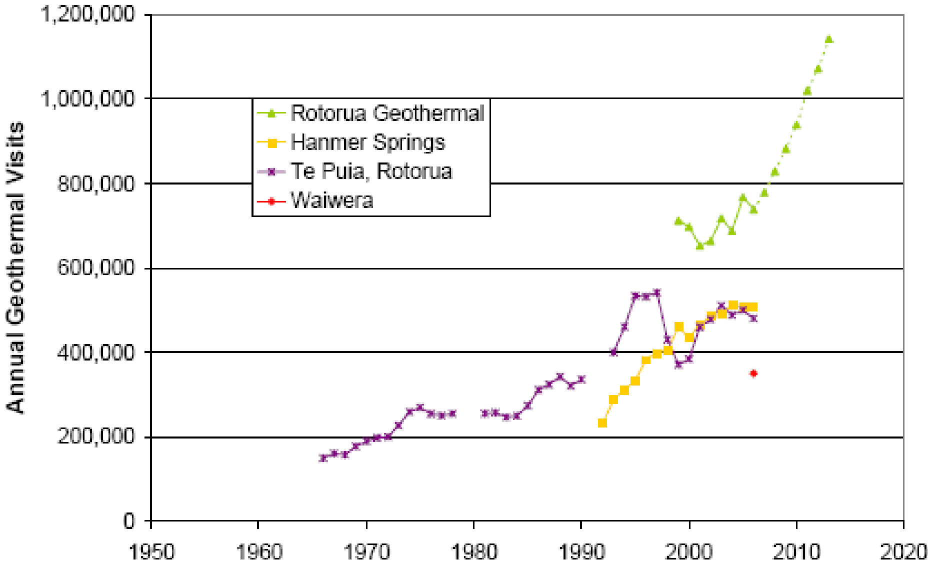

Figure 16.7 Recorded and projected tourist visits to geothermal attractions (bathing and geyser visits) in New Zealand.

16.4 Market Development and Stimulation

There is no direct government support in the form of renewable energy feed-in tariffs or subsidies in New Zealand. Normal market forces are sufficient to drive investment in geothermal. However, New Zealand participates in the Clean Development Mechanisms programme under the Kyoto Protocol.

Total capital costs of generation from new geothermal plants now average about NZ$ 3-4 M/MW_e installed. Drilling costs have increased significantly in recent years (~ 50 %) to about NZ$ 4 M/2km deep well, due to a shortage of rigs, shortage of skilled manpower and increasing consumable costs (steel and cement). This is anecdotal information, actual drilling costs and contract prices are usually commercially sensitive.

16.5 Development Constraints

Environmental issues and consideration for tourism and natural feature preservation significantly constrains the potential for future geothermal energy development in New Zealand. In the Waikato Region alone, about 50 % of the estimated economically accessible resources are categorised by the regional authority (Waikato Regional Council) for “protection” due to outstanding natural characteristics. Others are only available, at present, for small “research” takes or “limited” development as a precautionary measure. Resources that are located near cities (e.g. Rotorua and Taupo) are subject to stricter control of fluid take and injection rates (with more stringent conditions on resource users) in order to minimize the risk of possible adverse effects on urban environments (such as subsidence, hydrothermal eruptions or pressure interference between bore users).

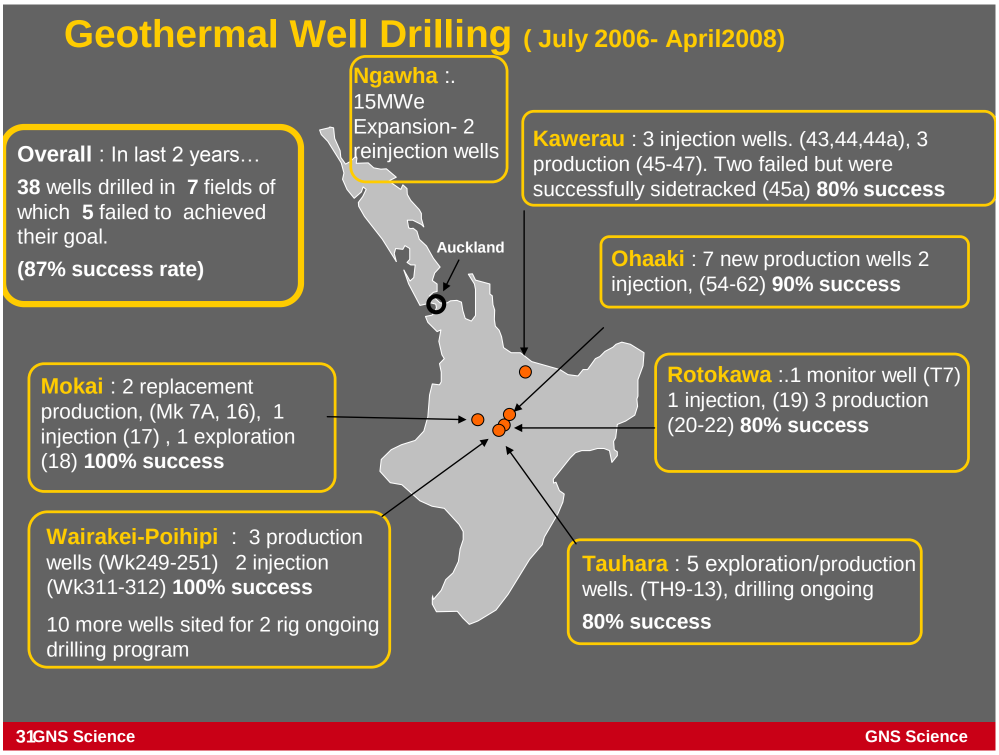

Figure 16.8 Map of NZ geothermal well drilling activities.

16.6 Economics

16.6.1 Trends in Government Investment

Geothermal drilling in known NZ geothermal resources over the past 2 years is achieving a average 87 % success rate in terms of commercially viable production or injection wells. This has reduced the perception of drilling risk and encouraged new investment.

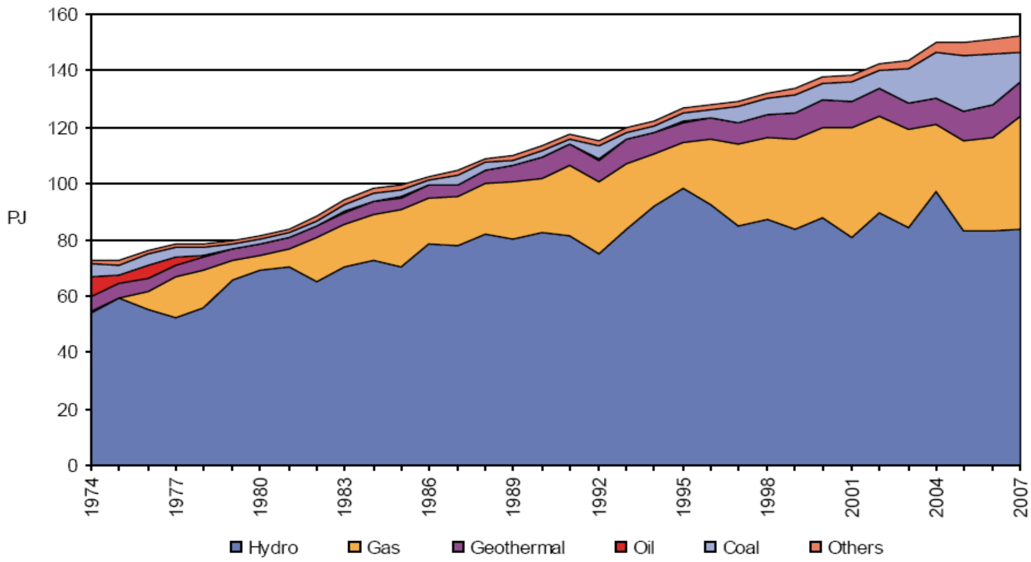

Figure 16.9 NZ mix of electricity generation sources. Demand growth is about 1.2 %/yr. Note any additional growth in geothermal will be aimed at replacing coal or gas.

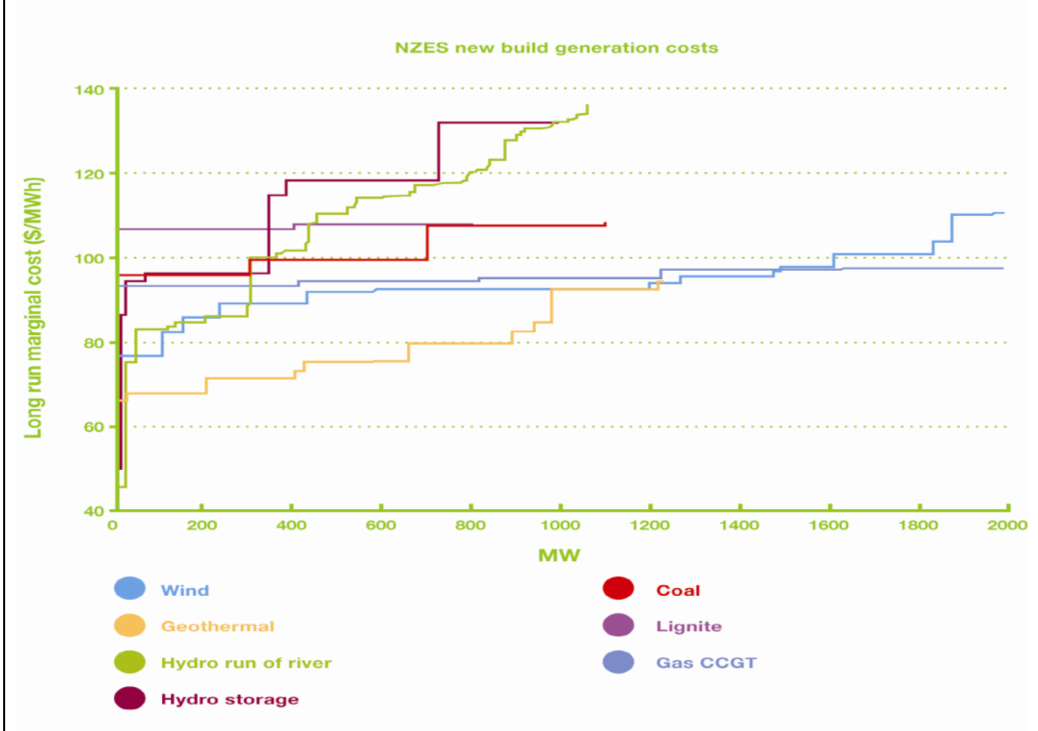

Figure 5.7: Typical costs for new electricity generation (updated August 2007)[24]

Source: Ministry of Economic Development

Figure 16.10 (from MED, 2007) shows that geothermal power is expected to be the cheapest option for the next 1000 MWe of new capacity. Although the fuel is 'free' these long-run marginal new generation costs include the costs of interest on capital, operations and maintenance, and anticipated make-up drilling.

16.6.2 Turbine Costs, Projected Costs, Well Drilling Costs and O&M Costs

Typical new project costs are NZ$ 3M/MW$_e$ total for the Kawerau 100 MW$_e$ power plant. NZ$ 2.6M/ MW$_e$ is expected to be the installed cost for the new Tauhara 23 MW$_e$ binary plant plus drilling and pipelines costs which are estimated to add another 50 % to the total cost, bringing it up to about NZ$ 4M/ MW$_e$.

Well drilling costs are currently about NZ$ 4M each for 2 km deep wells.

O&M costs are typically NZ$ 8.5/MWh (for power plant and steam field) plus a long-term average of NZ$ 2.5/MWh for make-up well drilling, although this varies significantly between fields.

16.6.3 Trends in the Cost of Energy

The average wholesale electricity cost at source is presently about NZ$ 70/MWh (US$ 50/MWh), although the average delivered price for large industrial users in 2007 was NZ$ 92.2/MWhr, and this has increased by an average of 7 % per year since 2000 (almost 3 times the rate of inflation).

New geothermal generation cost is also about NZ$ 70/MWh. Older geothermal generation costs (e.g. 25-50 yr old turbines) are much lower (estimate ~NZ$ 15/MWh) because capital costs have been written down, although maintenance costs increase with age.

16.6.4 Number of People in NZ Geothermal Sector

The number of people employed in the NZ geothermal sector in 2005 was 344, while the estimate for 2007 was about 400.

16.7 Research Activities

The research focus areas in New Zealand include: environmental issues and resource delineation.

Government funded research amounts to some $2M/yr, with a 6-year research programme that commenced in October 2007, and undertaken by GNS Science and Auckland University. In addition, proposals were prepared for new research projects for deep geothermal resource exploration and for enhanced direct use of lower enthalpy resources.

Industry funded research is aimed at H_2S removal through bio-remediation from NCG waste from power plant for glasshouse use; arsenic removal from separated brines and geotechnical drilling, core analysis and modelling to investigate causes of subsidence anomalies.

Figure 16.11 Hot spring monitoring and research at Opaheke, at the undeveloped Reporoa Geothermal Field.

16.8 Geothermal Education

The New Zealand Geothermal Association and the University of Auckland continue to provide relevant annual seminars, the annual New Zealand Geothermal Workshop (held in November), and short courses. In 2007, Auckland University resumed the post graduate training course (as a 5 month course from July to November) through a revitalised Geothermal Institute. One-day geothermal information seminars are also organised annually (in July) by GNS Science for the benefit of members of indigenous Maori Trusts. The New Zealand Geothermal Association also hosts specialised 1-day workshops with invited speakers on topics of interest as required.

Figure 16.12 Thermophylic bacteria research at a geyser mound in Tokaanu, an undeveloped NZ geothermal resource.

16.9 International Cooperative Activities

New Zealand has a significant participation in the IEA-GIA, through Annex I Leadership and participation in Annexes I, III, VII and VIII. Since 2007, Chris Bromley has been Chair of the IEA-GIA Executive Committee.

Scientists and engineers from New Zealand collaborate with geothermal projects throughout the geothermal world including: EGS (USA, Australia), Mutnowsky (Kamchatka), and IDDP high temperature drilling (Iceland). Consulting by New Zealand based geothermal specialist companies is undertaken in all geothermal countries.

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National Activities

Chapter 17

Switzerland

Hotel Dolder, Zurich, Switzerland, excavation for renovation and retro-fitting with geothermal heat pumps (courtesy of L. Rybach).

17.0 Introduction

There is a significant move in 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.

17.1 Major Highlights in 2007

The main achievement is the steady growth of geothermal direct use in Switzerland, mainly due to the advance of geothermal heat pump systems. They are now increasingly being installed in larger complexes for space heating, cooling, and domestic hot water production (e.g. Hotel Dolder, chapter title page).

The total installed capacity for direct use secures Switzerland a prominent international second place rank, right after Iceland (Table 17.1).

Table 17.1 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

17.2 National Policy

17.2.1 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 BCHF (~ US$ 1 B), equivalent to 5,300 person years.

17.2.2 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*. The instruments used include: voluntary measures, measures by decree and flexible mechanisms (Kyoto).

The decreed measures are:

- CO_2 tax on fossil fuel, since 1 January 2008, amounting to 0.03 CHF/l of oil and 0.025 CHF/m^3 gas

- “Klimarappen” (clima cent) on gasoline/diesel amounting to 0.015 CHF/l, since 1 October 2005

17.2.3 Progress towards National Targets

The targets to reach by 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 % for electricity and 5 % for 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 by 2010.

17.2.4 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 demonstration: 0.13 MCHF
- Supporting the Swiss Geothermal Association SVG: 0.51 MCHF

17.3 Status of Geothermal Energy Use in 2007

17.3.1 Electricity Generation

So far no 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, with 11,000 PJ recoverable over 30 years. For power generation several suitable regions have been delimited.

17.3.2 Direct Use

Thanks to a statistical 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 17.2 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 17.2 Installed thermal power for direct use in Switzerland (2007). From Signorelli, *et al*. (2008).

Usage System	Installed Capacity (MW_{th})
Heat pumps with borehole heat exchangers, horizontal collectors	749.5
Groundwater heat pumps	77.7
Geostructures ("energy piles")	8.9
Deep borehole heat exchanges	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 17.1, 17.2 and 17.3, 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 17.3.

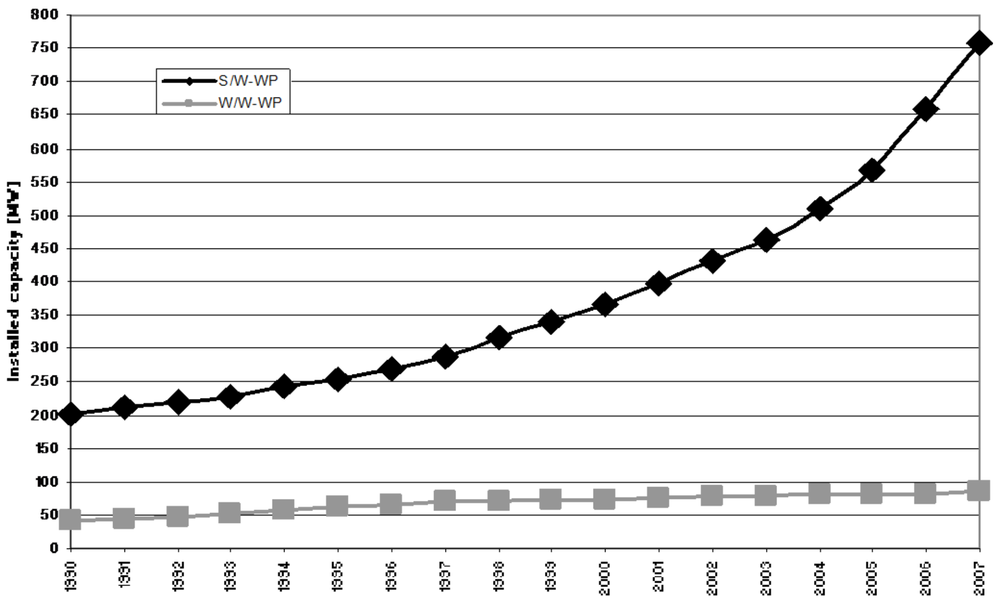

Figure 17.1 Development of ground-coupled heat pump capacity in Switzerland 1990-2007. S/W-WP: BHE or horizontal collector systems; W/W-WP: Groundwater heat pumps. From Signorelli, *et al*. (2008).

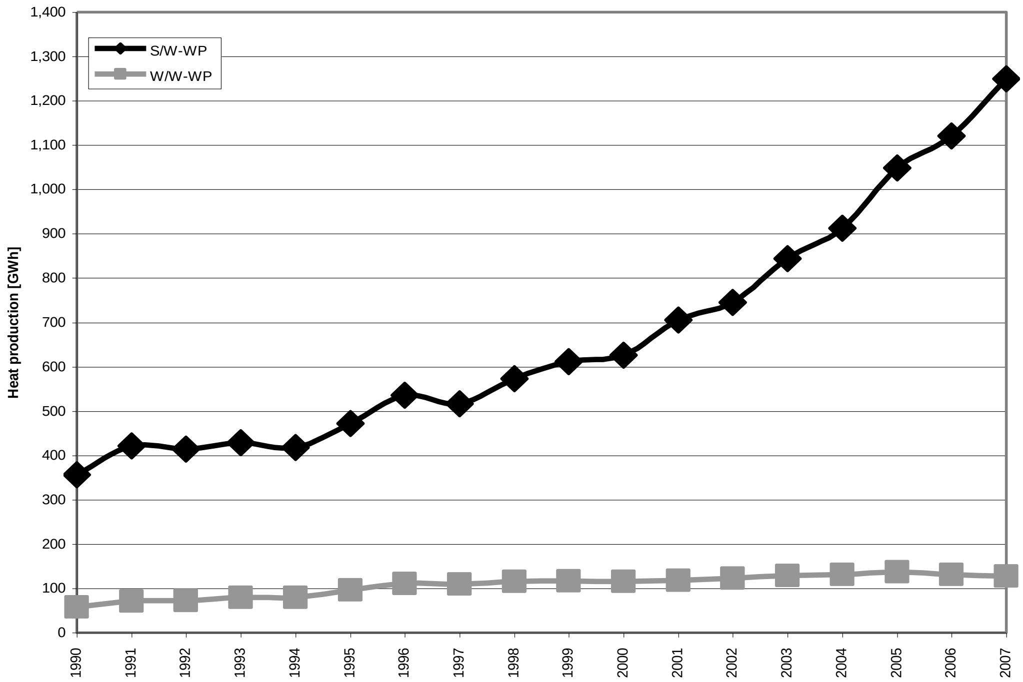

Figure 17.2 Development of heat production by geothermal heat pump systems in Switzerland 1990-2007. S/W-WP: BHE or horizontal collector systems; W/W-WP: Groundwater heat pumps. From Signorelli, *et al.* (2008). The uneven increase is due to meteorological factors (mild/normal winters).

Table 17.3 Development in heat production of Swiss geothermal installations 2004-2007. From Signorelli, *et al*. (2008).

Usage System	2004 (GWh/yr)	2005 (GWh/yr)	2006 (GWh/yr)	2007 (GWh/yr)	% 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. In 2007 alone, the total drilling length (meters) was nearly 1,500 km (see Figure 17.3). 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.

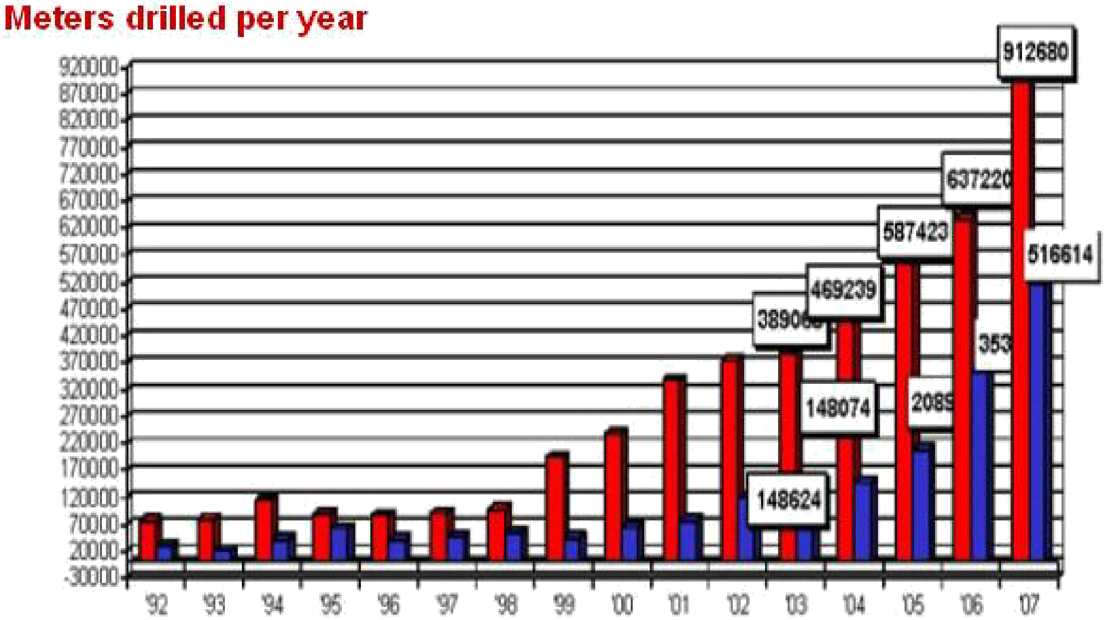

Figure 17.3 Development of total drilling for borehole heat exchanger-coupled geothermal heat pumps in Switzerland 1992 – 2007. Red bars: BHEs for new buildings, Blue bars: for renovation. From Förderverein Wärmepumpen Schweiz (www.fws.ch) .

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 Zürich (see chapter title photo) at was announced. The original space has been more than doubled. Figure 17.4 provides more information.

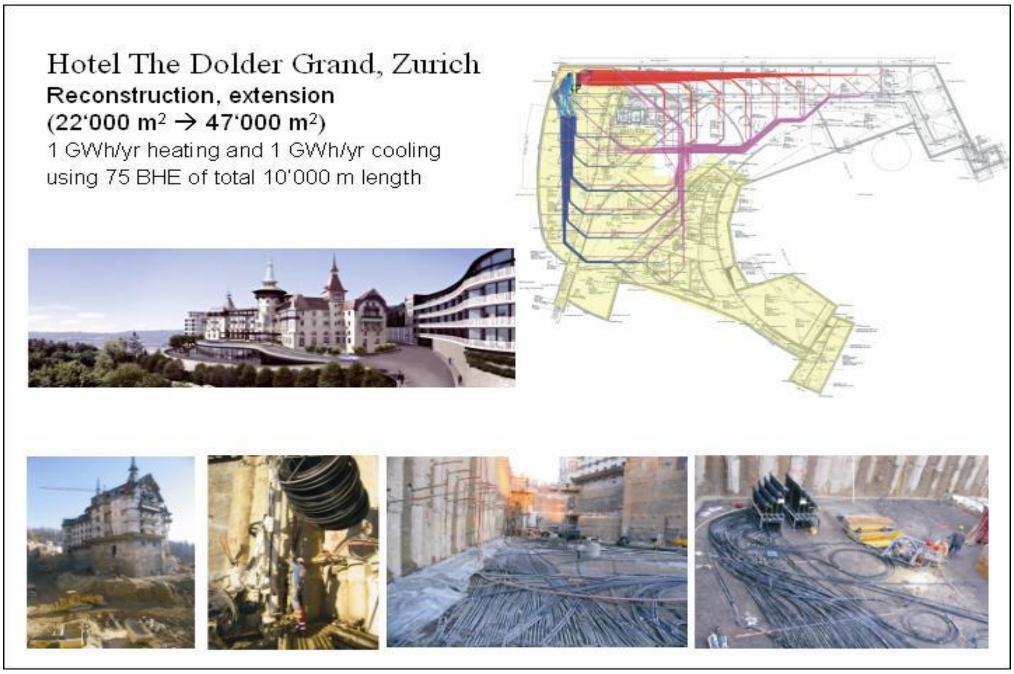

Figure 17.4 Geothermal store with the hydraulic connections (top right) for *Hotel Dolder the Grand*, Zürich. The middle picture shows the completed building complex, the bottom ones various construction changes.

Also in 2007, the ambitious project *Science City* at the Zürich-Hönggerberg campus of the Swiss Federal Institute of Technology (ETHZ) was started, with experimental boreholes to determine site conditions. All together, four large geothermal stores are planned (total store volume: 8 x 10^6 m^3). The heating demand of the complex is 15 GWh/yr, cooling demand 11 GWh/yr. Over 750 BHEs, each 200 m deep, will be needed. Figure 17.5 shows a design sketch of the distribution network with the stores. The design of both projects is with Geowatt AG Zürich.

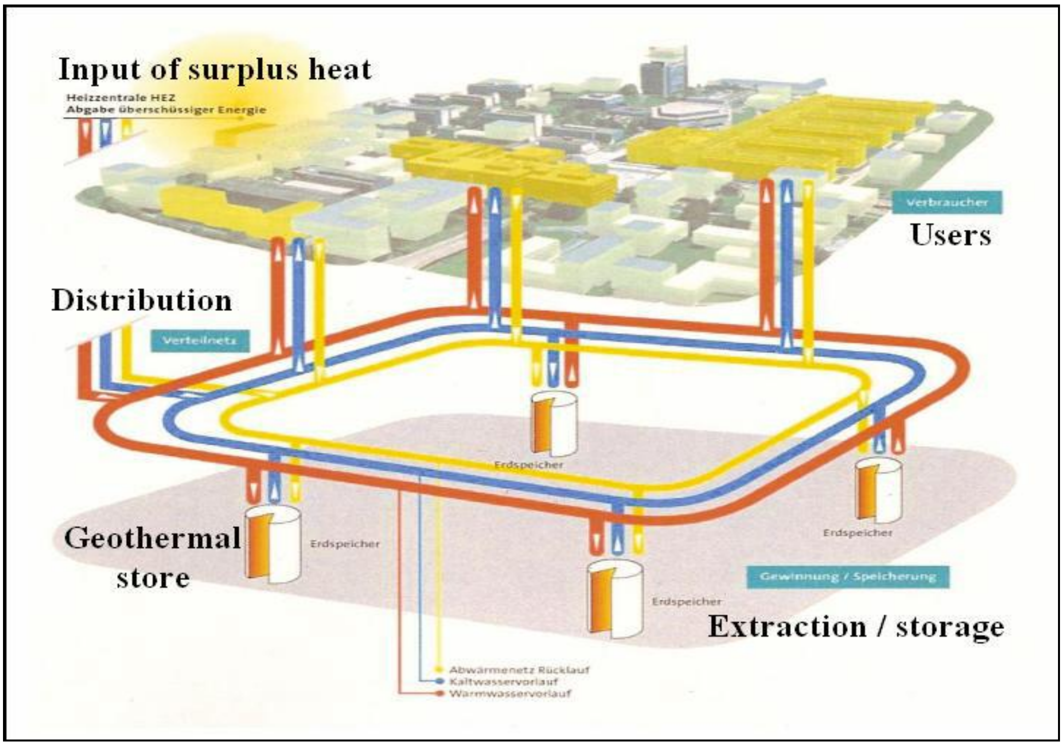

Figure 17.5 Four geothermal stores, built in succession, are designed for *Science City*, Zürich. Besides teaching and research facilities of ETHZ it will have living and recreation facilities. Red circuit: Warm water delivery, blue circuit: Cold water delivery, yellow circuit: Waste heat return.

17.3.3 Energy Savings

The use of emission-free geothermal resources in Switzerland enables the saving of considerable amounts of fossil fuels. The total heat production of 1,684 GWh (6 PJ) in 2007, corresponds to the saving of 140,000 toe/yr.

By this means the emission of additional 445,000 tonnes of CO_2/yr was 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.

17.4 Market Development and Stimulation

In 2007, the only booming development segment in geothermal utilization was that of geothermal heat pumps; Figure 17.3 testifies to 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$ 5,000 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.

17.5 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.

17.6 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 yield 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 hot, 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.

17.7 Research Activities in 2007

17.7.1 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 is mentioned, by resource type:

Shallow: Enhanced Thermal Response Test, Operational experience and optimization Zürich Airport Terminal E, and geo-cooling 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 and 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).

17.7.2 International Cooperative Activities

Switzerland is a GIA Country Member and participates in Annexes I, III and VIII.

In 2007, Switzerland was also 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
- GET
- GROUNDHIT

In addition, Swiss researchers participated in EU project GROUND-REACH.

17.8 Geothermal Education

Basic and post-graduate teaching is organized by the SVG, mandated by the SFOE. The courses are distributed over the whole of Switzerland, *i.e.* courses were held 2007 in the German, French and Italian parts of Switzerland.

The following educational events were also organized:

- Basic education: 10 courses, with 188 participants
- Post-graduate events: 15 courses, 5 excursions (total 644 participants)

17.9 Publications

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

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

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

17.10 Websites

- 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

17.11 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; with a unified appearance as GEOTHERMIE.CH

17.12 References

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.

Signorelli, S., Kohl, T. (2007) Geothermischer Ressourcenatlas der Nordschweiz; Gebiet des nördlichen Schweizer Mittellandes. Contributions to the Geology of Switzerland – Geophysics, Swiss Geophysical Commission, Berne, 94 p.

Signorelli, S., Sonnenfroh, F., Kohl, T., Rybach, L. (2008) Statistik der geothermischen Nutzung in der Schweiz – Ausgabe 2007. Bundesamt für Energie, Bern, 35 S.

Acknowledgement

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National Activities

Chapter 18

United States of America

The 20 MW_e Burdette power plant (courtesy Ormat).

18.0 Introduction

18.0.1 Highlights for 2007

Geothermal Power: The geothermal industry in the United States continues to grow. The Geothermal Energy Association (GEA) reported that 2,936.5 MW_e of geothermal capacity is on line in the United States, with an additional 3313.8 MW_e under development, if projects in the initial development phase are included. The 13 MW_e Raft River geothermal plant, commissioned in December 2007, is the first commercial plant in Idaho, and the first plant in the northeastern Basin and Range of the western United States. As of January 2008, 373 MW_e were under construction at nine projects in California and Nevada. Major drivers for this capacity expansion include state-specified Renewable Portfolio Standards and the Federal Production Tax Credit.

EGS Project at Desert Peak: In conjunction with the US Department of Energy (DOE), Ormat has begun work on the first US Enhanced Geothermal System (EGS) application at Desert Peak, its commercial geothermal field in the state of Nevada. EGS could boost generation from the current 11 MW_e to more than 50 MW_e. Support includes $1.6 M in direct DOE funding.

Restoration of Funding for Federal Geothermal Research: DOE's Geothermal Technologies Program is funded by Congress at US$20 M for FY 2008 (1 October 2007 through 30 September 2008). DOE has requested US$30 M for FY 2009.

Energy Independence and Security Act of 2007: The Energy Independence and Security Act of 2007 (EISA), passed by the US Congress in September 2007, authorizes expenditures of up to US$95 M for a wide range of geothermal activities. Because the actual appropriation is less, and is directed toward EGS activities, other GTP activities will be limited to a subset of those covered by EISA.

New Leasing and Royalty Regulations: On 2 May 2007, the US Department of Interior released new leasing and royalty regulations, as mandated by the Energy Policy Act of 2005, to accelerate leasing and development of federal geothermal resources. A Programmatic Environmental Impact Statement (PEIS) under development by the Bureau of Land Management (BLM) in partnership with the US Forest Service should result in more geothermal projects moving forward.

18.1 National Policy

18.1.1 Strategy

The United States seeks to improve energy security by fostering diverse sources of reliable and affordable energy. The DOE Strategic Plan states that keeping America economically strong requires reliable, clean, and affordable energy. The Department believes that the best way to achieve this is through competitive energy markets, science-driven technology, and supportive government policies. The principal tool for advancing technology is investing in high-risk, high-payoff energy research and development that the private sector would not or could not develop alone. DOE supports development of a suite of electricity generation options that can promote reasonable and stable prices in all sectors of the American economy.

18.1.2 Legislation and Regulation

18.1.2.1 Energy Independence and Security Act Of 2007 (EISA)

EISA, signed into law on 19 December 2007, authorizes expenditures of up to US$95 M for a diverse set of geothermal activities, including research and development, education and outreach, and technology demonstration (Table 18.1).

Table 18.1 EISA Authorized Activities

Section	Title
613	Hydrothermal Research and Development
614	General Geothermal Systems Research and Development Program Support (Components and Systems)
615	Enhanced Geothermal Systems Research And Development
616	Geothermal Energy Production From Oil and Gas Fields and Recovery and Production of Geopressured Gas Resources
617	Cost Sharing And Proposal Evaluation
618	Center For Geothermal Technology Transfer
619	Geopowering America – Communication and Outreach
620	Educational Pilot Program
621	Reports
623	Authorization Of Appropriations
	Intermountain West Geothermal Consortium
624	International Geothermal Energy Development
625	High Cost Region Geothermal Energy Grant Program

18.1.2.2 Renewable Portfolio Standards

Arizona: In November 2006, the Arizona Corporation Commission adopted final rules to expand the state's Renewable Energy Standard to 15 % by 2025, with 30 % of the renewable energy to be derived from distributed energy technologies (~ 2,000 MW_e). In June 2007, the state attorney general allowed the new rules to go forward.

New Hampshire: New Hampshire's Electric Renewable Portfolio Standard, enacted in May 2007, requires electricity providers to acquire renewable energy certificates equivalent to 23.8 % of retail electricity sold to end-use customers by 2025. Of this, 16.3 % is to be derived from sources installed after 1 January 2006.

New Mexico: In March 2007, New Mexico passed legislation which directs investor-owned utilities to generate 20 % of total retail sales to customers from renewable energy resources by 2020, with interim standards of 10 % by 2011 and 15 % by 2015. The bill also establishes a standard for rural electric cooperatives of 10 % by 2020.

North Carolina: North Carolina's Renewable Energy and Energy Efficiency Portfolio Standard (REPS), enacted in August 2007, requires investor-owned utilities in the state to supply 12.5 % of 2020 in-state retail electricity sales from eligible energy resources by 2021. Municipal utilities and electric cooperatives must supply 10 % renewables by 2018.

North Dakota: In March 2007, North Dakota enacted legislation establishing an objective that 10 % of all retail electricity sold in the state be obtained from renewable energy and recycled energy by 2015. This objective is voluntary; there is no penalty or sanction for a retail provider of electricity that fails to meet the objective.

Oregon: As part of the Oregon Renewable Energy Act of 2007 the state established a renewables portfolio standard (RPS) for electric utilities and retail electricity suppliers. Different RPS targets apply depending on a utility's size. The legislation also established a goal that by 2025 at least 8 % of Oregon's retail electrical load will come from renewable energy projects with a capacity of 20 MW_e or less.

Virginia: Virginia enacted a voluntary renewable energy portfolio goal. In addition to allowing for RPS program cost recovery to participating utilities, the Virginia State Corporation Commission will provide the incentive of an increased rate of return (profit) for each RPS Goal attained.

18.1.3 National Targets

The DOE Geothermal Technologies Program (GTP) strives to establish geothermal energy as an economically competitive contributor to the Nation's energy supply. The FY 2007 DOE operating plan provided only US$5 M to support technical evaluation of EGS; to investigate geothermal power production from oil and gas wells; and to complete selected projects in order to close out the program. However, program funding was reinstated in FY2008 and new program targets are currently under development.

18.1.4 Government Expenditure on Geothermal Research and Development

The Fiscal Year 2007 budget allocation is presented in Table 18.2.

Table 18.2 Geothermal program budget for Fiscal Year 2007.

Activity	FY 2007 Continuing Resolution	FY 2008 Appropriation
Technology development	2,000	20,000
Technology application	3,000	0
Congressionally directed Activities	0	2,300
Total	5,000	22,300

18.1.5 Industry Expenditure on Geothermal Research and Development

US geothermal industry cost sharing on geothermal R&D totaled approximately US$163.5 M from 1994 through 2007. The industry's cost share was approximately $1.5 M in 2007, falling from approximately $2.8 M in 2006 due to the closeout of many federal R&D activities. No information is available on industry R&D undertaken independent of DOE research efforts.

18.2 Geothermal Energy Use in 2007

18.2.1 Electricity Generation

18.2.1.1 Installed Capacity

In 2007, geothermal electric power was generated in six US states: Alaska, California, Hawaii, Idaho, Nevada, and Utah. Total installed capacity was 2,936.5 MW_e. Commercial sales from the plant in Idaho did not begin until 7 January 2008.

Table 18.3 Existing geothermal capacity by state (MW_e).

Alaska	California	Hawaii	Idaho	Nevada	Utah	Total
0.4	2,541.3	35	13	309.8	37	2,936.5

18.2.1.2 Electricity Generated

Total electricity generation in the United States in 2006 was 4,159.5 TWh (*Electric Power Monthly*, 10 June 2008, Table 1.1, EIA). Renewable energy electricity generation in 2007 was 340.66 TWh (*Annual Energy Outlook 2008 Early Release*, Table 16, EIA), of which geothermal was 14.5 TWh and conventional hydropower, 258.56 TWh.

18.2.1.3 New Developments

A competitive geothermal lease sale was held on 20 June 2007 for parcels in Utah and Idaho. Three parcels in the Cove Fort-Sulphurdale area in Utah sold for a total of $3,685,986. Bids ranged from $20 to $850 per acre. All bonus bid, rental and royalty monies collected are shared equally with the State of Utah and the Federal government. Idaho offered five parcels totalling 8,904 acres. Bids on these parcels ranged from $130 to $875. Total revenue from the Idaho parcels was $5,726,208.

A competitive geothermal lease sale was held 14 August 2007 in Reno, Nevada, offering 43 parcels in Nevada and six in California. The 43 parcels brought almost $11.7 million. A record bid of $11,000/acre was offered by Binkley Geothermal of Santa Monica for a 470 acre parcel in The Geysers, CA. The second highest bid for a parcel in California was $420/acre, and the highest bid for a parcel in Nevada was $510/acre.

The year 2007 has continued to be very active for the United States geothermal industry. Some of the projects completed, under construction, or announced include the following.

Idaho

- **Raft River-** US Geothermal began operation of a 13 MW_e net Ormat binary-cycle power plant at the Raft River geothermal field in southeastern Idaho. The plant, which is the first commercial plant in Idaho and the most northeastern plant in the Basin and Range Physiographic Province, is eligible for the Federal Production Tax Credit, which is worth approximately $1.7 M/yr at $19 per MWh for the next 10 years. Expansion of this field has begun under a Power Purchase Agreement with Idaho Power.

California

- **The Geysers-** The Geysers Geothermal Field, located 75 miles north of San Francisco, generates about 900 MW, having declined from a peak of about 1,900 MW in 1988. Following the injection of treated wastewater into The Geysers from Lake County starting in 1997 and the City of Santa Rosa starting in 2003, the decline in productivity has been abated, with an estimated potential increase of 100 MW_e of capacity and an extension to the life of the field. In 2007, the City of Santa Rosa and Calpine Corporation agreed to a 50% increase in wastewater deliveries to The Geysers.

- On 10 May, 2007, Western GeoPower Corporation announced the signing of a Power Purchase Agreement (PPA) between its wholly-owned subsidiary, Western GeoPower,

- Inc. and Pacific Gas & Electric Company of San Francisco, California (PG&E) for approximately 212,000 MWh/yr from a 25.5 MW_{net} geothermal power plant scheduled to come on line in 2010 at The Geysers. The contract allows for an increase in net capacity to a maximum of 31.5 MW_e, which could accommodate the potential from a recently-acquired leasehold extension. By the end of 2007, the first commercial well had been completed and tested.

- **Brawley-** In July 2007, Ormat Technologies, Inc. signed a 20-year PPA with Southern California Edison to deliver 50 MW_e (with an option to increase to 100 MW_e) of geothermal power from the Brawley I Project, currently under construction in the Imperial Valley.

- **Imperial Valley-** On 17 December 2007, Ormat Technologies announced that its subsidiary signed a 20-year PPA with Southern California Edison for the sale of energy to be produced by a new plant to be built in the Imperial Valley, California. The plant is expected to come on line by mid-2012 and is expected to have a total output of 30 MW_e. The agreement includes an option to increase capacity to 100 MW_e. Several other exploration projects are underway near the margins of the Valley at Truckhaven and west of the southern end of the San Andreas Fault.

Nevada

- **Blue Mountain-** Well testing indicates that Blue Mountain is a major new geothermal discovery. Using conventional pumping technology, a single production well is producing over 9.6 MW_e gross output. The initial binary cycle power plant at Blue

Mountain, to be named "Faulkner 1", will use greater than 150 °C (300 °F) water from seven production wells. The project is scheduled for completion in 2009.

- **Grass Valley-** In May 2007, Ormat Technologies, Inc. announced that one of its subsidiaries signed a 20-year PPA with Nevada Power Company, a subsidiary of Sierra Pacific Resources, for energy from the Grass Valley Geothermal Power Plant to be built in Lander County in northern Nevada. The project is expected to come on line in late 2010, with a total output between 18 and 30 MW_e.

- **Other Areas:** Expansion of geothermal production in Nevada is underway at the Steamboat and Stillwater geothermal fields. Active exploration and drilling is also underway at Salt Wells, Fallon Naval Air Station, Warm Springs, Tuscarora, Fireball ridge, Pumpernickel Valley, Grass Valley, Carson Lake, Buffalo Valley, Jersey Valley, Reese River, and Big Smoky Valley.

18.2.1.4 Rates and Trends in Development

The GEA reports that 3,313.8 MW_e of new geothermal power plant capacity is under development in the United States (including projects in the initial development phase). Up to 373 MW_e of capacity is under construction at 9 projects in Nevada and California. These plants are modest in size (10-30 MW_e), at least in the initial stage. This approach reduces capital requirements and facilitates obtaining capital. The Western Governors Association, in its *Geothermal Task Force Report* (2006), stated that 5,600 MW_e are viable for commercial development by about 2015. The next steps in geothermal development will most likely be 1) additions to existing projects, 2) expansion at or within the boundaries of producing hydrothermal reservoirs using stimulation techniques, and 3) development at identified, but as yet undeveloped, geothermal resources.

The existence of a market for geothermal electricity is evidenced by Power Purchase Agreements, which are often utility responses to state Renewable Portfolio Standards. PPAs may offer a premium above what the utility might pay for natural gas and coal. Other revenue sources for the developer may be the PTC at US$ 0.019/kWh and the selling of Renewable Energy Credits. Most power plants will use binary-cycle energy conversion. Even for high-temperature resources, power costs may optimize for shallow wells with lower temperatures, which can use a binary conversion cycle.

A comprehensive assessment of Enhanced Geothermal Systems (EGS), released in January 2007 by an 18-member panel of experts assembled by MIT, concluded that EGS could provide 100,000 MW_e or more of cost-competitive generating capacity in the next 50 years (MIT, 2006). The study generated substantial interest in continued geothermal development, particularly EGS, in the United States and worldwide. Details of the report were included in the IEA-GIA 2006 Annual Report, Chapter 18.

The DOE Geothermal Technologies Program undertook an evaluation of the MIT report's assumptions and conclusions in a series of workshops from June through September of 2007. A report on the workshops and their conclusions is available at: www1.eere.energy.gov/geothermal/pdfs/tech_eval_draft.pdf . The primary conclusions were that the report's assumptions were reasonable and within the bounds of a balanced systems analysis. However, conclusions about the amounts of investment needed to achieve competitiveness and produce 100,000 MW_e were not supported.

18.2.1.5 Geothermal Wells

Summary information is not available for production, injection and gradient wells drilled for geothermal electric power in the United States. However, two states, California and Nevada, provide information on geothermal wells on their Internet sites. The California Geothermal Annual Report at www.conservation.ca.gov/dog/Pages/Index.aspx is an excellent source for wells drilled, completed, re-drilled or deepened, and plugged and abandoned. The most current report is for the year 2006, although preliminary data for ten months of 2007 is also available. California also provides an online database of geothermal well records (called GeoSteam) at: geosteam.conservation.ca.gov/WellSearch/GeoWellSearch.aspx .

Utah's Internet site has an interactive map of the state's geothermal wells and springs at: geology.utah.gov/geothermal/interactive/index.html.

Nevada's Bureau of Mines and Geology has links to databases on Nevada well chemistry, siting, and other data at: www.nbmg.unr.edu/geothermal/gthome.htm.

18.2.1.6 Contribution to National Demand

Geothermal electricity is currently being generated in Alaska, California, Hawaii, Idaho, Nevada, and Utah. Geothermal electricity generation in 2007 was 14.5 TWh, which was 0.3 % of the total US electricity generation of 4,159.5 TWh. Geothermal electricity generation was 4.3 % of all renewable electricity production, which includes hydropower (*STEO, AEO 2008*).

18.2.2 Direct Use

18.2.2.1 Installed Thermal Power

Lund, *et al.* (2005) reported total installed direct-use capacity for 2004 at 7,817.4 MW of thermal power (MW_{th}), utilizing about 31,239 TJ/yr. Of this capacity, 617 MW_{th} and 9,024 TJ/yr corresponded to traditional direct use and the remainder to heat pumps (7,200 MW_{th} and 22,215 TJ/yr). Lund's estimates for 2006 were approximately 653 MW_{th} traditional direct use utilizing about 9,601 TJ/yr, and 9,437 MW_{th} of heat pumps utilizing 29,119 TJ/yr (EIA Geothermal Survey, Table 3.8 citing Lund). Using Lund's overall escalation factor of 8 %/yr for all direct use categories, the total installed capacity for 2007 is estimated to be about 10,897 MW_{th}.

18.2.2.2 Thermal Energy Used

Annual thermal energy use in 2004 reported by Lund was 31,239 TJ/yr (8,675 GWh/yr) at a capacity factor of 0.13 (Lund, *et al*., 2005). Lund's estimate for 2006 was 38,720 TJ/yr (corresponding to 10,752 GWh/yr). Using an overall escalation factor of 8 %, the annual energy use for 2007 is estimated to be 41,817 TJ/yr (11,612 GWh/yr).

18.2.2.3 Category Use

Direct utilization of geothermal energy in the United States includes heating of pools and spas, greenhouses and aquaculture facilities, space and district heating, snow melting, agricultural drying, industrial applications and geothermal heat pumps. Space heating and agricultural drying have shown the largest annual growth rate of the direct-use categories, increasing by 9.3 and 10.4 %/yr respectively, compounded (Lund, *et al*., 2005). The combined capacity factor was 0.46 (excluding heat pumps). The largest annual growth has been in geothermal heat pumps, comprising 71 % of total use in 2004. For the period 2000-2004, the annual growth rate for heat pumps was 11.0 %, and for the combined total of all applications, 8.0 %. In the United States, most units are sized for the peak cooling load and are oversized for heating, except in the northern states; and are estimated to average only 1,200 full-load hours/yr for a capacity factor of 0.14 (Lund, *et al*., 2005). Lund estimated heat pump capacity in 2006 to be 9,437 MW_{th}, and geothermal energy use at 29,119 TJ/yr (EIA Geothermal Survey, Table 3.8 citing Lund). Using Lund's annual increase factor of 11 %, the geothermal heat pump capacity in the United States in 2007 was approximately 10,475 MW_{th} and energy use was 32,031 TJ/yr.

18.2.2.4 New Developments during 2007

Noteworthy new geothermal heat pump projects in 2007 included:

- **The Friends Center-** In Philadelphia, the Friends Center is installing geothermal heat pumps. The wells cost $1.3 M, but the system will cut energy costs by an estimated 46 %. The payback period is expected to be six to eight years. Because there is not enough space in the urban setting to install a horizontal heat exchanger field, vertical wells will be drilled. Each hole will be six inches in diameter with a four-inch inner pipe.

- **Prairie Crossing Charter School-** The Prairie Crossing Charter School in Grayslake, Ill., is heated and cooled by geothermal heat pumps using a geothermal vertical loop consisting of 36 vertical wells averaging 53 m deep. The building has an in-slab radiant loop connected to the geothermal loop for heat. The cooling capacity of the system is estimated at 45 tons. The Illinois Clean Energy Community Fund provided a $62,500 grant for the geothermal heat pump system, or about $49/m^2$. The school uses approximately 77 $kWh/m^2/yr$. The project began in March 2004, and was completed in 2007.

18.2.2.5 Rates and Trends in Development

Geothermal heat pump installations slowed in 2007 as the US housing market declined. New houses had been accounting for a significant portion of heat pump installations, leading to high numbers of installations from 2004-2006. However, installations are less affected than the housing market as a whole because the value of geothermal heat pumps to businesses and homeowners is increasing as energy prices rise.

18.2.3 Energy Savings

18.2.3.1 Fossil Fuel Savings/Replacement

- **Power Plants-** The United States generated 14.5 TWh (52,200 TJ) of electricity from geothermal hydrothermal resources in 2007 (*AEO 2008 Early Release*). This amount of geothermal electricity would displace about 3.675 Mtonnes of oil (Mtoe) equivalent, assuming an efficiency of 35 % for the production of electricity from oil. The factor used was 1 TJ ~ 70.4 toe.

- **Direct Use-** Annual thermal energy use for 2007 is estimated to be 41,817 TJ/yr (11,612 GWh/yr) (section 18.2.2.2). The fuel oil savings is estimated to be 2.944 Mtoe, assuming an efficiency factor of 35 % for electricity production, for all categories of direct use including geothermal heat pumps, which are discussed separately below.

  Using an assumed average unit size of 12 kW_e, the installed capacity of geothermal heat pumps in the US in 2007 was 10,475 MW_{th}. Based on approximately 1,200 full-load equivalent operating hours/yr and a coefficient of performance (COP) of 3.5 (Lund, 2005); the annual energy removed from the ground was 8,975 GWh (32,031 TJ/yr). The energy displacement in the heating mode was at least 2.275 Mtoe assuming that the displaced energy was generation from oil at 35 % efficiency. Energy displacement was not estimated for the cooling mode.

18.2.3.2 Reduced/Avoided CO_2 Emissions

- **Power Plants-** In 2006, the electric power sector (total for sector) emitted 2,386 Mtonnes of carbon dioxide (*AEO 2008 Early Release*, Table 18). Geothermal generation in the US annually offsets the emission of approximately 13.82 Mtonnes of carbon dioxide if it is assumed that geothermal electricity would offset electricity generated by coal. The calculation assumes 14.5 TWh of geothermal electricity at a net offset of 953 kg/MWh. Equivalent offsets would be 11.6 Mtonnes for oil and 2.80 Mtonnes for natural gas. Net offset factors are from Lund, *et al.* (2005).

- **Direct Use-** Annual thermal energy use for 2007 was estimated to be 11,612 GWh/yr (41,817 TJ). The carbon dioxide savings from this thermal energy use is estimated to be 9.486 Mtonnes of carbon dioxide for electricity produced from oil. For coal generation of electricity, the carbon dioxide savings from using geothermal energy for direct use applications is 11.065 Mtonnes of carbon dioxide.

18.3 Market Development and Stimulation

18.3.1 Support Initiatives and Market Stimulation Incentives

Renewable energy initiatives and incentives at the federal, state, and local government levels are catalogued by the Database of State Incentives for Renewables & Efficiency (DSIRE) at www.dsireusa.org, an ongoing project of the North Carolina Solar Center and the Interstate Renewable Energy Council (IREC) with funding by the US Department of Energy.

18.3.1.1 The Energy Policy Act of 2005

Under EPAct 2005, the US Geological Survey was directed to update its 1978 assessment of geothermal resources (*Circular 790*). The new assessment will consider the use of lower temperature resources, binary technologies, and other advances that have occurred in the past 25 years. The USGS will complete its report by September 2008.

EPAct 2005 provided for a rebate program for renewable energy systems installed in a dwelling unit or small business. The rebate is 25 % of the qualifying expenditures made by the consumer or $3,000, whichever is less. An Energy Information Administration (EIA) analysis indicates that rebates could increase 2006 renewable residential energy consumption between 1 and 3 trillion British thermal units (Btu) above the EIA Reference Case levels in its *Annual Energy Outlook 2006* (AEO 2006). By 2010, the estimated increase ranges from 7 to 14 trillion Btu. EIA estimates total residential energy consumption in its Reference Case to be about 12,000 trillion Btu from 2006 through 2010. Geothermal heat pumps account for the largest share of the increase.

A Programmatic Environmental Impact Statement (PEIS) is under development for the major geothermal areas of the western United States by the BLM in partnership with the US Forest Service. The USGS will provide geological and analytical support. The final PEIS will be completed concurrently with the updated USGS assessment in September 2008. The development of the PEIS is driven by industry interest in exploring and developing geothermal resources and reducing the leasing backlog on federal lands, and by the need for greater renewable generation in a manner consistent with the laws governing public lands. The PEIS should result in more geothermal projects moving forward without the holdups and backlogs of the past.

Under Section 225 of the Energy Policy Act of 2005, the Departments of the Interior and Agriculture, on behalf of BLM and the Forest Service (USFS), produced a Memorandum of Understanding (MOU) to coordinate geothermal leasing and permitting on public lands and National Forest System lands between the two agencies. The MOU outlines the agencies' respective roles, responsibilities and authorities. It also includes a 5-year program for geothermal leasing of lands on National Forest lands as well as a program to reduce the geothermal lease application backlog 90 % by 2010.

18.3.1.2 EPA Green Power Program

The EPA Green Power Partnership encourages voluntary purchases of ‘green’ power (from environmentally preferable energy sources) as a way of reducing environmental impacts associated with electricity generation. The EPA ‘Top 25 Partners’ are partners whose annual green power purchase is the largest nationwide. Combined, their purchases amount to almost 4.4 TWh annually, which is approximately 60 % of the green power commitments made by all the Partners. Number 3 on the list in 2007 was the US Air Force at 899,143,000 kWh green power usage in 2007, which was 4 % of its total electricity use. The sources were biomass, geothermal, solar and wind.

18.3.1.3 Federal Purchases of Renewable Energy

EPAct 2005 requires that the Secretary of Energy seek to ensure that of the total amount of electric energy the Federal Government consumes during any fiscal year, the following amounts are to be renewable energy; 1) not less than 3 % in fiscal years 2007 through 2009, 2) not less than 5 % in fiscal years 2010 through 2012 and 3) not less than 7.5 % in fiscal year 2013 and each fiscal year thereafter. DOE last reported on federal purchases of electricity from renewable energy sources in May of 2007, stating at that time that renewable energy use in the Federal government was expected to exceed the 3 % goal in 2007, based on data from 2006. Summary information is not yet available for 2007. In May 2007, the DOE Federal Energy Management Program (FEMP) reported that FY2006 renewable energy consumption by Federal agencies totaled 2,383,219.6 MWh, or 4.35 % of total facility electricity use.

18.3.1.4 Renewable Energy Systems and Energy Efficiency Improvements Loan and Grant Program - USDA

The 2002 Farm Bill established the Renewable Energy Systems and Energy Efficiency Improvements Loan and Grant Program to encourage agricultural producers and small rural businesses to create renewable and energy efficient systems using technologies including biomass, geothermal, hydrogen, solar, and wind energy. Between 2003 and 2007, $223,267,169 was provided for renewable energy grants and loans, of which $88,985,109 was provided in 2007 alone. There were no geothermal loans or grants.

18.3.1.5 Bureau of Land Management (BLM) - Department of the Interior

Half of the Nation’s geothermal energy production occurs on Federal land, much of it in California and Nevada. The BLM currently administers about 350 geothermal leases. Currently, 29 geothermal power plants are operating under BLM authorization on Federal lands in California, Nevada and Utah.

18.3.1.6 National forest Service- Department of Agriculture

Renewable energy development plays a significant role in the USFS implementation of EPAct 2005. The BLM and the USFS coordinate geothermal resource leasing activities on National Forest lands. The USFS provides the consent to lease and the BLM issues the leases. The USFS serves as lead agency for geothermal leasing availability analyses and decisions and conducts analysis of geothermal activities on National Forest lands. As of July 2006, there were 116 geothermal leases on National Forest lands.

18.3.1.7 Renewable Portfolio Standards (RPS)

At the state level, the most popular and effective policy tools have been Renewable Portfolio Standards, which generally mandate that utilities must provide a designated amount or percentage of power from renewable sources. These have been adopted by 25 states and the District of Columbia as of the end of 2007. Many of them explicitly include geothermal electricity, and some mention geothermal heat pumps. States anticipate economic development benefits from promoting renewables through development of local energy resources. States are also attracted to RPS by the prospect of greater reliability of electricity supply and the prospect of reducing air pollutants through a shift toward expanded use of renewables (Pew Center Report: *Race to the Top: The Expanding Role of U.S. State Renewable Portfolio Standards* (2006)).

18.4 Development Constraints

Growth in geothermal electricity development in the United States continues to be constrained by high front end costs, delays in leasing and permitting, high capital costs, financial risk, local opposition to development, and the potential for adverse environmental impacts. The best hydrothermal geothermal sites are often in scenic areas. As residential development intrudes into these areas, land uses will come into conflict.

Induced seismicity may be an impediment to development. Natural microearthquakes occur in both undeveloped and developed hydrothermal reservoirs; for example, a magnitude 4.4 earthquake at The Geysers in May 2006 tripped three Calpine geothermal plants offline. However, most geothermal fields in the Basin and Range and the Imperial Valley have no noticeable seismicity associated with operations.

18.5 Economics

18.5.1 Trends in Geothermal Investment

In its handbook *(A Handbook on the Externalities, Employment, and Economics of Geothermal Energy*, GEA, October 2006*)* the GEA stated that the California Energy Commission had estimated the levelized generation costs from new geothermal plants at 4.5-7.3 US¢/kWh. The lower-end price figures cited for geothermal power likely rely on lower than average upfront financing agreements, or consider only projects that are built as expansions of existing projects.

In its *Geothermal Task Force Report* (2005), the Western Governors Association (WGA) reported that the Western States have a capacity of almost 13,000 MW_e of geothermal energy that can be developed within a reasonable timeframe. Of this total, 5,600 MW_e are considered viable for commercial development by 2015 at busbar costs at levelized costs of energy (LCOE) of about 5.3-7.9 US¢/kWh, assuming commercial project finance and the use of the production tax credit (PTC). Without the PTC, LCOE values would be 2.3 US¢/kWh higher. The 3,313 MW_e of potential capacity cited by the GEA as currently under consideration will be strongly affected by the price offered under Renewable Portfolio Standards, actual development costs, and the availability of a PTC.

18.5.2 Geothermal Power Plant Costs

Costs for a 50 MW_e geothermal power plant in 2004 are presented in Table 18.3. The GEA estimated that a typical 50 MW_e power plant cost approximately $140 M in 2004, including site development and exploration costs, (*A Handbook on the Externalities, Employment, and Economics of Geothermal Energy*, GEA, October 2006). Although drilling, materials, and employment costs have led to substantial increases in geothermal project costs, reliable estimates of those increases are not available.

Table 18.3 Typical costs for a geothermal power project (GEA)

Phase	Sub-phase (if applicable)	2004 cost/ kW	Cost for 50 MW plant (US$ millions)
Exploration		$150	7.5
Site development	Permitting	$20	1
	Drilling	$750	37.5
	Steam gathering	$250	12.5
	Power plant equipment & construction	$1500	75
	Transmission	$100	5
Total			**138.5**

18.5.3 Employment in the Geothermal Sector

A geothermal employment survey conducted by the GEA (*Geothermal Industry Employment: Survey Results and Analysis*, Hance, 2005) determined that the United States geothermal industry supplied about 4,583 direct jobs in 2004, corresponding to 1.7 jobs per megawatt of installed power capacity. The GEA assumed a multiplier of 2.5 and concluded that the direct, indirect, and induced impact of the industry in 2004 would have been 11,460 jobs. The GEA further stated that achieving the 5,600 MW_e of additional geothermal capacity projected by the WGA by 2015 would result in 9,580 new full-time jobs from geothermal power facilities, and an additional 36,064 person-years of manufacturing and construction employment. Also according to the GEA (*A Handbook on the Externalities, Employment, and Economics of Geothermal Energy*, October 2006), a typical 50 MW_e geothermal power plant costing approximately US$140 M would produce an economic output of nearly US$750 M over 30 years, of which over US$20 M would be delivered directly to the federal, state, and county governments. The same 50 MW_e plant would produce 212 fulltime jobs and 800 person-years of construction and manufacturing work.

18.6 Research Activities

18.6.1 Focus Areas

The DOE Geothermal Technologies Program is conducting research under the Energy Independence and Security Act of 2007. The current focus of research is Enhanced Geothermal Systems (EGS). Planned program activities include demonstration of stimulation techniques for commercial EGS production; R&D to develop tools and techniques useful at up to 300 °C and depths to 10,000 m; and communications and outreach activities in partnership with stakeholders. Critical technologies that are being pursued include fracture detection capability; stimulation prediction models; zonal isolation technology; high-temperature monitoring tools and sensors, technologies to identify flow paths; and submersible pumps.

18.6.2 Government Funded Research

18.6.2.1 Geothermal Technologies Program- Department of Energy

The GTP is currently planning research activities with a budget of US$ 20 M for FY08, after operating on a reduced budget of US$5 M in 2007.

18.6.2.2 United States Geological Survey- Department of the Interior

The new USGS national geothermal resource assessment, now underway, will present a detailed estimate of electrical power generation potential and an evaluation of the major technological challenges and environmental impacts of increased geothermal development. The results of the assessment will support the development of geothermal energy by quantifying uncertainties and highlighting ways for future research to better constrain those uncertainties and advance the state of geothermal knowledge.

18.6.2.3 United States Navy- Department of Defence

Although the primary mission of the Navy's Geothermal Program Office is to develop and manage geothermal resources for the military, the Program Office and the Geothermal Technologies Program of DOE cooperated in research on Enhanced Geothermal Systems using wells at the Coso power plant at China Lake, California. The Navy's Geothermal Program Office, located at the China Lake Naval Air Weapons Station in California, assesses, and manages geothermal resources for the military.

18.6.3 Industry Research

The United States geothermal industry conducts little research and development since it is focused on developing and operating currently defined hydrothermal geothermal resources. For 30 years, the DOE geothermal research program has filled this role and has coordinated closely with the industry to insure that the research supported by the federal government is directed toward the critical needs of the industry and the country.

18.6.4 Other

The following organizations conduct geothermal research and education:

18.6.4.1 Great Basin Center for Geothermal Energy, University of Nevada, Reno

The Great Basin Center for Geothermal Energy, part of the University of Nevada, Reno, conducts research directed towards establishing geothermal energy as an economically viable energy source within the Great Basin. The Center specializes in collecting and synthesizing geologic, geochemical, geodetic, geophysical, and tectonic data, and using Geographic Information System (GIS) technology to map geothermal potential.

18.6.4.2 Geothermal Laboratory, Southern Methodist University

The SMU Geothermal Laboratory is an educational and research arm of the Department of Geological Sciences. The Geothermal Laboratory measures various parameters relating to the thermal field of the Earth and applies these observations to geothermal resources, plate tectonics, and the mapping of Earth's surface and subsurface thermal properties. In 2007, SMU sponsored a workshop on co-production of petroleum and geothermal energy.

18.6.4.3 Geo-Heat Center, Oregon Institute of Technology

The Geo-Heat Center, Oregon Institute of Technology, established in 1975, is active in research, technical assistance and information services in geothermal direct-use and ground-source heat pumps. The Center provides technical assistance for geothermal projects. The Center publishes the *Quarterly Bulletin*, technical papers, software and monographs on geothermal energy.

18.6.4.4 Stanford Geothermal Program, Stanford University

The Stanford Geothermal Program focuses on the development of reservoir engineering techniques. Stanford sponsors an annual workshop for engineers, scientists and managers that provides a forum for the exchange of ideas on the exploration, development, and use of geothermal resources. More than 100 attendees from 22 countries participated in the 32nd Stanford Geothermal Workshop (January 22-24, 2007).

18.6.4.5 MIT Energy Initiative (MITEI), Massachusetts Institute of Technology (MIT)

MITEI, established in September 2006, is an Institute-wide initiative designed to help transform the global energy system to meet the needs of the future and to help build a bridge to that future by improving today's energy systems. The MIT geothermal program focuses on Enhanced Geothermal Systems.

18.6.4.6 Energy and Geoscience Institute, University of Utah

The Energy & Geoscience Institute (EGI) is an applied earth science research and training organization focused on global hydrocarbon and geothermal energy exploration and development.

18.7 Geothermal Education

18.7.1 Geothermal Education Office

The Geothermal Education Office (GEO) promotes public understanding of geothermal resources. The GEO produces and distributes geothermal educational materials to schools, energy and environmental educators, libraries, industry, and the public. The GEO collaborates with education and energy organizations with common goals, and, through its website, responds to requests and questions from around the world.

18.7.2 Geothermal Resource Council

The Geothermal Resources Council (GRC) is a tax-exempt non-profit educational association with members in 30 countries. It serves as a primary professional educational association for the international geothermal community, convening special meetings, workshops, and conferences on a broad range of topics pertaining to geothermal exploration, development and utilization. In addition, the GRC periodically schedules a basic introductory course about geothermal resources and development. The GRC 2007 Annual Meeting had 724 attendees, with approximately 100 oral presentations and 37 poster presentations.

18.7.3 Geothermal Energy Association

The Geothermal Energy Association (GEA) is a trade association of US companies supporting expanded use of geothermal energy and developing geothermal resources for electrical power generation and direct-heat uses. The GEA also conducts education and outreach projects. In May 2007, the organization co-sponsored a Geothermal Energy Development and Finance Workshop with Ormat Technologies and Glitnir Bank. The GEA provides periodic updates on geothermal power production and development.

18.8 International Cooperative Activities

The DOE Geothermal Technologies Program and its research organizations participate in and host international conferences and meetings. Alexander Karsner, Assistant Secretary for Energy Efficiency and Renewable Energy, visited Iceland in July 2007 to explore avenues of increased bilateral cooperation and collaboration on topics in renewable energy, with a strong focus on geothermal energy.

18.9 Websites of Interest

Internet websites on US geothermal energy are listed below (in no particular order).

- Federal geothermal program: www.eere.energy.gov/geothermal/.
- Nevada Geothermal Update: minerals.state.nv.us/programs/prog-ogg.html
- California geothermal wells: www.consrv.ca/dog/geothermal/index.html.
- Database of renewable energy incentives for renewable energy: www.dsireusa.org
- Geothermal Energy Association (GEA): www.geo-energy.org
- Direct use; Geo-Heat Center: www.geoheat.oit.edu
- Geothermal Legacy Project: www.osti.gov/geothermal
- Geothermal resource maps: geothermal.inel.gov
- Geothermal wells and springs in Utah: geology.utah.gov/geothermal/interactive/index.html
- MIT EGS study: web.mit.edu/newsoffice/2007/geothermal.html and geothermal.inel.gov.
- EIA Annual Energy Outlook: www.eia.doe.gov/oiaf/aeo/index.html
- EIA Short Term Energy Outlook: www.eia.doe/emeu/steo/pub/contents.html
- EIA Geothermal Energy Web Page: www.eia.doe.gov/cneaf/solar.renewables/page/geothermal/geothermal.html

- Geothermal Heat Pump Consortium: www.geoexchange.org
- New geothermal regulations for leasing and royalties:
  www.blm.gov/wo/st/en/info/regulations/final_rules_by_topic.html#Geothermal
- Nevada/California 2007 lease sale results and 2008 schedule:
  www.blm.gov/nv/st/en/prog/minerals/leasable_minerals/geothermal0/ggeothermal_leasing.html
- Utah/Idaho lease sale: www.blm.gov/ut/st/en/prog/energy/geothermal0.html
- BLM geothermal web page: www.blm.gov/wo/st/en/prog/energy/geothermal.html
- Geothermal Resource Council: geothermal.org/
- Geothermal Education Office: www.geothermal.marin.org/
- SMU geothermal program: www.smu.edu/geothermal/
- Stanford geothermal program: pangea.stanford.edu/ERE/research/geoth/
- Geothermal Energy Association reports: www.geo-energy.org/publications/reports.asp

18.10 References

Lund, J., Freeston, D.H. and Boyd, T.L. (2005) Direct application of geothermal energy: 2005 Worldwide review. *Geothermics* 34 (2005) 691-727.

MIT (2006) The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st century, MIT, 2006.

STEO, AEO 2008 Energy Information Administration: Short-term Energy Outlook: http://www.eia.doe.gov/emeu/steo/pub/contents.html

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Sponsor Activities

Chapter 19
Geodynamics

Figure 19.2 Jolokia 1 being drilled at Cooper Basin, Australia (courtesy of Geodynamics Limited).

19.0 Introduction

19.0.1 Geodynamics

Geodynamics is the largest geothermal company in Australia and its specific focus is in the economic extraction of heat from hot rocks using enhanced geothermal systems (EGS) technology. The company uses the term "hot fractured rock (HFR)" for this process. Geodynamics is focused on drilling into fractured granite 3.6-4 km below the Cooper Basin in northern South Australia, where the temperature at the top of the granite is in the order of 235-250 °C. Wells drilled so far have intersected large fracture sets deep within the granite which extend sub-horizontally for many kilometres as indicated by stimulation and associated micro-seismicity. These fracture sets are highly over-pressured with water and when connected to a well produce shut-in well head pressures of more than 34 MPa.The company's tenements in the Cooper Basin cover 2,000 km^2 and hold a total energy resource of 400,000 PJ down to a depth of 5 km. At a proven temperature of 250-300 °C, the resource has a potential generating capacity of more than 10,000 MW_e. Currently, Geodynamics estimates its HFR reservoirs, as developed using a concept of nine wells from a single well pad, have a life span in excess of 50 years.

The company successfully raised $11.5 M via an IPO in 2002, as well as further funds totalling $142 M for the 5 years to December 2007. In late 2007, Origin Energy Limited also provided a significant financial boost to the company through a farm-in deal worth $105.6 M in which Origin now own 30 % of the South Australian tenements. Geodynamics purchased a Le Tourneau 'Lightning Rig' in 2007, using funds raised through a $50 M rights issue. The advanced 3000 hp rig features great mobility and the capacity to operate at extreme depths, in this case up to 6,000 m. Origin took 30 % ownership of the rig as part of its farm-in.

The rig began drilling its first production-scale well, Habanero 3, in August 2007. To date, the company has drilled three wells: Habanero 1, Habanero 2 and Habanero 3. Of these, Habanero 1 and 2 are not of commercial scale; Habanero 2 is not sufficiently connected to the reservoir because of lost equipment in the hole. Geodynamics is currently drilling the fourth well, Jolokia 1, that is 9 km west of Habanero, a move designed to further prove and extend geothermal reserves the company has in its tenements. Jolokia 1 is known to be 10 °C hotter than the Habanero wells at the top of the granite and will be drilled to a maximum depth of 5,000 m. Habanero 3's target depth of 4,221 m (13,850 ft) was reached on January 22, 2008.

19.0.2 Geodynamics Vision

Geodynamics vision is to become a world-leading geothermal energy company supplying competitive zero-carbon energy and base load power to the Australian market.

19.1 Highlights for 2007

- The Company completed a very successful rights issue which raised $49.8 M. These funds were applied to the purchase of the new rig and the drilling of Habanero 3. The company also successfully raised $37.4 M from the exercise of previously listed shareholder options.

- Mr Gerry Grove-White was appointed as Managing Director, and took up his position on 27 August 2007. Previous interim CEO, Dr Adrian Williams, remains with the Company in a consultancy role.

- The spudding of Habanero 3 on 15 August 2007

- The merger of Geodynamics Power Systems with European company Exorka ehf to create Exorka International Limited-Geodynamics then held a 46 % shareholding in Exorka International

- Completion of a $105.6 M joint venture farm-in agreement with Origin Energy for Geodynamics' South Australian tenements. This agreement received Shareholder approval at a meeting in December 2007.

- The completion of drilling Australia's first commercial scale well, Habanero 3 to a depth of 4,221 m on 5 February 2008

- The positive temperature results from shallow drilling in the Hunter Valley, NSW

19.2 Status of Geodynamics' Geothermal Activities in 2007

Geodynamics completed the production well for the Habanero doublet in February 2008. The well intersected the fracture network stimulated from the Habanero 1 well which is 550 m to the SSW. Upon drilling into the fracture zone a pressure communication was detected indicating that a circulation loop could be established.

In Geodynamics' geothermal exploration license in the Hunter Valley, NSW, shallow wells to 300 m and 400 m were drilled and indicated relatively high temperature gradients above 50 °C/km in coal measures. The indications are that deeper drilling is warranted.

19.3 Planned Activities for 2008 and Beyond

Geodynamics has a very active program for 2008. A circulation test will be carried out at the Habanero 1 and 3 doublet leading to the building of a 1 MW_e demonstration plant. Figure 19.1 shows the venting of steam from Habanero 3 through an 11 mm choke with a flowing wellhead pressure of 29 MPa. The high pressure pipeline being constructed between Habanero 1 and 3 for the circulation test can be seen in the background of Figure 19.1. The power plant is expected to be in production by early 2009. A second hand steam turbine of around 2.5 MW_e capacity has been purchased for the job.

Figure 19.1 Steam venting from Habanero 3 (courtesy of Geodynamics Limited).

The Lightning Rig is being deployed at a new well, Jolokia 1, at 9 km west of Habanero and a another well is expected to commence after Jolokia 1 is completed a further 10 km west again. This well will be called Savina 1. Like Habanero wells, these two wells are targeting overpressured fractures in basement granite in the depth range 4-5 km. Following the drilling of Jolokia 1, the well will be stimulated with the expected injection of 16,000 m^3 of water. A microseismic monitoring network of an additional 5 wells each 100 m deep has been added to the seven wells previously drilled for the Habanero stimulation. Figure 19.2 shows the Lightning Rig at Jolokia 1 in a desert rainstorm.

Beyond 2008, the plans are to build multi-well platforms of wells from the one location and power stations of approximately 50 MW_e net. The aim is to have five production wells and four injection wells at each platform. Current understanding of the fracture network dictates that the well spacing between injection and production wells needs to be 1 km at reservoir depth, and this will be provided by drilling directional wells.

19.4 Comments on the Geothermal Market, Opportunities and Constraints from Geodynamics' Viewpoint

19.4.1 Marketing Initiatives and Market Stimulation Incentives

Australia is developing a very favourable position and expectation for geothermal development both from Federal and State governments and from industry in an environment where CO_2 emissions will be regulated by 2010. However this favourable position must be followed by good results. Geodynamics has the weight on its shoulders to deliver these results.

19.4.2 Development Cost Trends

All costs have risen sharply over the last year. This is estimated to be in the order of 20 %. In addition, procurement of materials and parts has become much harder, with off-the-shelf items generally not available.

19.5 Geodynamics' Research Activities

Geodynamics is investigating the need for what is called multi-fracture drilling and multi-fracture stimulation in an over-pressured environment. These studies are at a leading edge of knowledge. There is also a focus internally on reservoir management and understanding using fast computers.

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Sponsor Activities

Chapter 20

Green Rock Energy

Figure 20.1 Drillrig at Green Rock's Ortaháza Project, Zala County, Hungary, January 2007 (courtesy of A. Larking).

20.0 Introduction

20.0.1 Green Rock Energy

Green Rock Energy Limited ("Green Rock"), a sponsor member of GIA since 2006, is a public company listed on the Australian Stock Exchange. The Company aims to explore, develop and produce geothermal reservoirs from both hydrothermal geothermal systems and engineered geothermal systems (EGS) for electricity generation and direct heat use. This requires locating and proving reservoirs with sufficient size, temperature and permeability or water flow capacity to deliver the hot water to the surface over a long time frame. The chief challenges for both types of geothermal resources relate to the substantial depth of the operations and hence costs required to prove the capacity of the geothermal reservoir to deliver enough energy at the surface to justify the investment.

In Australia, hotter generally means deeper, with associated risks such as:

- A higher risk of inadequate primary permeabilities or permeabilities which have been destroyed by chemical precipitation at depth
- Expensive seismic and drilling costs means individual well yields greater than 30 to 100 l/s are required depending on the economic circumstances of the project

To assist in resolving these issues associated with depth of operations, Green Rock Energy is participating in Annexes III- Enhanced Geothermal Systems and VII- Advanced Geothermal Drilling Techniques.

20.1 Geothermal Energy Projects

In 2007, the Company's main activities were in Australia and Hungary. In Hungry, Green Rock pursued a conventional geothermal energy project in Ortaháza (32 % interest) and in Australia it continued with activities at its principal project, Olympic Dam (100 % interest) and acquired additional areas in the Cooper Basin region and Upper Spencer Gulf.

20.1.1 Hungary

In Hungary, which is not yet a member country of the GIA, there is no electricity production from geothermal energy but the region in and around Hungary, the Carpathian Basin, is considered to have a high geothermal potential as hot layers underground are closer to the surface than the World average. While the takeover price of electricity is expected to rise in Hungary to achieve desired renewable energy production targets, major investments in geothermal energy in Hungary will require improvements in certainty and transparency of the laws regulating ownership and use of geothermal energy.

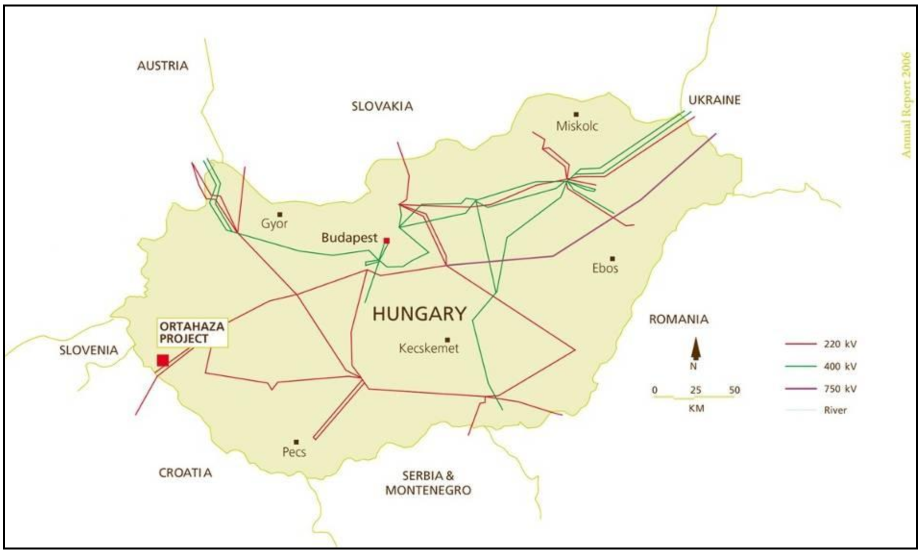

Figure 20.2 Location of Ortaháza Project, Hungary.

In 2007, Green Rock Energy participated in an unincorporated joint venture with one of Hungary's largest companies, the Hungarian Oil and Gas Company (MOL), and with Enex, the Icelandic geothermal consulting company, to develop geothermal energy in Hungary. The joint venture re-entered and flow tested geothermal water in two existing oil wells drilled and owned by MOL at the Ortaháza Project in western Hungary (Figure 20.2) with the objective of using the energy to produce electricity and for direct heating applications. Production testing of the geothermal waters yielded insufficient flows for commercial electricity production without further expenditure and the participants received a refund of part of their expenditures from the Geofund. The wells have been suspended for possible future geothermal energy use. However, the production testing, and the understanding the joint venture has of the geology of this region, and Hungary generally, has encouraged the joint venturers to move onto the selection of the next project sites.

To achieve this, Green Rock Energy recently established a new geothermal energy company with MOL and Enex hf. This new joint company, Central European Geothermal Energy Private Company Limited (CEGE), consolidates the strong relationship between the three companies for the exploration and development of geothermal energy resources in Hungary. The companies each have an equal one third share in CEGE.

CEGE's mission is to become the market leader in geothermal energy production in Hungary with the goal of providing a significant contribution to Hungary's plans for renewable energy sources. Two project areas, with substantial hot geothermal water encountered from existing wells drilled by MOL, have been selected for the initial focus of the new company.

20.1.2 Australian Projects

Green Rock held geothermal exploration licences in three major project areas in Australia. During the year, two new project areas were added to the portfolio of geothermal exploration licences in South Australia, namely, the Patchawarra Project and the Upper Spencer Gulf Project.

20.1.2.1 Olympic Dam

Green Rock Energy holds a 100 % interest in an area of nearly 3,000 km² at BHP Billiton's world class Olympic Dam mine in South Australia.

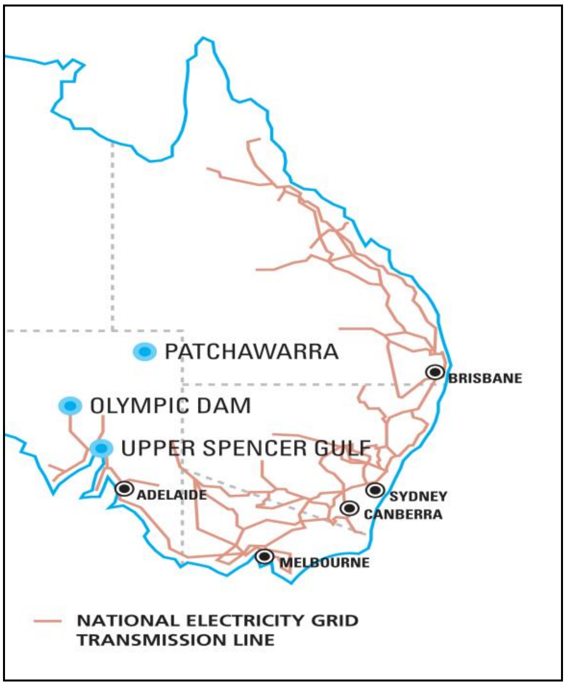

Figure 20.2 Location of Green Rock's South Australia projects.

In early 2008, Green Rock successfully completed a hydraulic-fracing test program in its exploratory well Blanche No 1. The well had been drilled into hot granites to a depth of nearly 2 km and is located only 5 km from a high voltage power transmission line connected to the national power grid which supplies electricity to eastern Australia's major cities. The hydro-fracture testing successfully opened fractures in the hot granites and confirmed that the stress regime at Olympic Dam is compressional and likely to favour the formation of sub-horizontal fractures for generating a heat exchange reservoir in the granites.

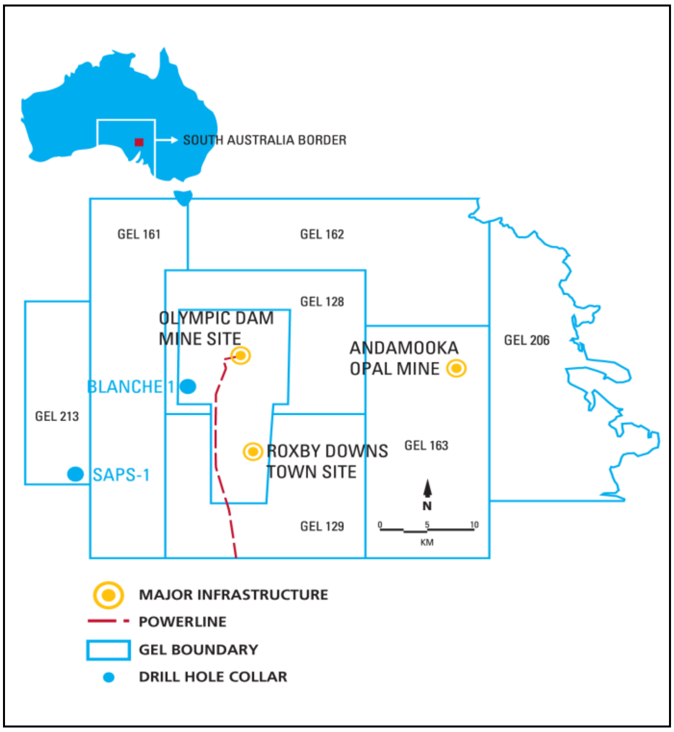

Figure 20.3 Hydraulic Fracture testing in Blanche No 1. exploratory well (by MeSy, Germany).

The data gathered from this program is being used to assist the design of the first of two deeper water flow evaluation wells to be drilled nearby, and the fracture stimulation program to set up a water circulation system between those wells.

20.1.2.2 Patchawarra (100 %)

Three Geothermal Exploration Licences covering an area of 1,483 km^2 were granted in 2007 over the Patchawarra Trough in the Cooper Basin, South Australia. The area contains sedimentary formations which could be prospective for high flows of hot geothermal water and potentially suitable for generation of geothermal electrical energy on a large scale in conjunction with the future construction of a high voltage electrical transmission line linking the Cooper Basin to the national power grid.

Sedimentary formations in parts of the Cooper Basin are known to be underlain by hot granite and to have high heat flows.

Data evaluation and the modelling of sediment thickness and water flow potential is being undertaken based on data from previously drilled hydrocarbon wells on the Geothermal Exploration Licences. This evaluation is concentrating on rocks with temperatures greater than 140 ºC and with potential high water flow capacity (known as permeability) at depths between 3,000-4,000 m, with the immediate objective of defining specific geothermal energy target areas for evaluation drilling. A combination of well log analysis, detailed seismic assessment and temperature modelling are being used to locate the suitable geothermal targets to be tested by drilling.

20.1.2.3 Upper Spencer Gulf (100 %)

The Spencer Gulf project, covering 1,938 km^2 along the Upper Spencer Gulf coast of South Australia, provides the potential for geothermal energy resources which can produce the energy for seawater desalination projects. A geothermal project has the potential to provide a green, renewable, energy source for a distillation desalination plant. A 27 5kW_e power-line is situated along the eastern edge of the geothermal licences and two 275 5kW_e lines are situated at the northern edge. Parts of the tenements are underlain by the prospective Hiltaba Suite granitic rocks. These granites, the same radiogenic hot granite suite which Green Rock is exploiting at Olympic Dam, provide the heat source for the geothermal energy.

A record of all drilling results in the tenements has been compiled and during 2008 on-site field work will be conducted to survey any available open holes for temperature measurement. In combination with this work, temperature will be measured in holes to be drilled on the western side of Spencer Gulf. Available total magnetic intensity, gravity and radiometric datasets have been compiled and will be interpreted to assist target selection.

20.2 Current National Situation

An independent expert analysis of geothermal energy’s potential role in electricity generation in Australia was commissioned and carried out in the first half of 2008 by the newly formed Australian Geothermal Energy Association of which Green Rock is a foundation member. This analysis showed that geothermal energy which delivers base load electricity with a high availability can be very competitive with other forms of renewable energy but requires incentives such as carbon trading offsets or renewable energy certificates to be competitive with existing coal fired power. In this respect, Australia signed the Kyoto protocol in 2007, and is setting a national target of 20 % of energy output to be obtained from renewables by 2020. In addition, the Federal government of Australia has recently released a report setting out the background for a carbon emissions trading scheme to be introduced in 2010.

For geothermal energy, the Federal Government has also announced that AUS$ 50 M will be allocated from Federal Funds to assist funding of proof-of-concept geothermal energy drilling for geothermal projects in Australia.

The general situation in Australia is further detailed in the Australia Country report section GIA.

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Sponsor Activities

Chapter 21

Ormat Technologies, Inc.

12.4 MW_e Galena II Geothermal Power Plant, installed in 2007 Part of the 104 MW Steamboat Complex, which supplies sufficient electricity for all households in Reno, NV (courtesy of Ormat Technologies).

21.0 Introduction

21.0.1 Ormat Technologies, Inc.

As of August 2008, Ormat presently owns and operates 410 MW_e of geothermal and recovered energy generation (REG) facilities in four countries, including 301 MW_e of geothermal and 22 MW_e of REG in the United States. In total, Ormat has built approximately 1,000 MW_e of geothermal, REG, and solar installations worldwide, in more than 20 countries. Geothermal represents over 90 % of the total installation.

Ormat has grown to a team of nearly 1,000 employees worldwide, with approximately 400 in the United States. Ormat has a dedicated staff of approximately 100 geologists, resource managers, and drilling engineers to confirm and develop new geothermal fields. In the United States, Ormat has acquired leases for approximately 140,000 acres of land in California, Nevada, and Alaska in the past two years. We are actively pursuing additional land in these and other states where prospective geothermal resources remain untapped.

21.1 New Projects

Ormat continued its rapid growth in the United States and abroad in 2007 and 2008. In this period Ormat added approximately 130 MW_e of gross geothermal capacity and 30 MW_e of gross REG capacity worldwide; approximately one-half of which we own and operate. The same type of ORMAT ORC power technology is used for both geothermal and REG.

Examples of some of the 2007 projects are shown below in Figures 21.1 and 21.2:

Figure 21.1 The 3.2 MW Landau Geothermal Power Plant is the first commercial plant in Germany, and the first implementation of EGS technology in an injection well (courtesy of Ormat Technologies).

Figure 21.2 Geothermal power plant at Blundell,Utah, USA (Supplied EPC to third party: PacifiCorp.) (courtesy of Ormat Technologies).

Ormat-installed REG capacity has increased by approximately 50 % since year-end 2006. New projects are under construction and development in North America and Europe that are expected to add more than 50 MW_e of new REG capacity worldwide over the next two years.

Beyond 2008, Ormat has a project pipeline for both third party sales and for ownership and operation. There are 200 MW_e of new geothermal power plants that we will own and operate in California and Nevada. We recently signed a third party sales agreement with Nevada Geothermal Power to provide them with a 49.9 MW_e power plant in Nevada, expected to be online by the end of 2009. Internationally, Ormat recently signed third party deals for power plants in New Zealand and Turkey. We also have a 12.75 % interest in a 340 MW_e geothermal power project at Sarulla, Indonesia using Ormat's equipment.

21.2 Revenues

Revenues were US$ 296 M in 2007, an increase of 10 % over 2006, and we expect 2008 annual revenues to reflect a growth of approximately 10 % over 2007. Figure 21.3 shows revenue growth in recent years, with Figure 21.5 illustrating Ormat's geothermal power plant activities from 2006-2008.

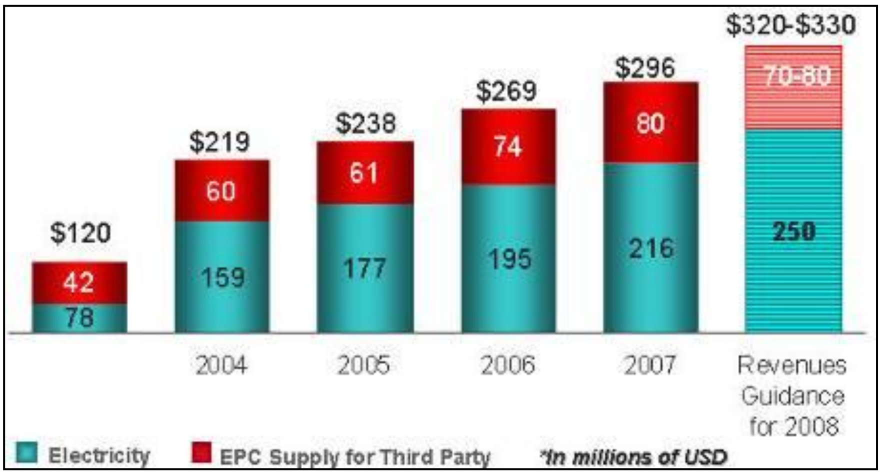

Figure 21.3 Ormat's recent revenues.

21.3 GeoDrill

Ormat established a wholly-owned drilling company, GeoDrill, in 2007, with four rigs to help us ramp up production to meet market demand (Figure 21.4).

Figure 21.4 Ormat's GeoDrill Staff
(courtesy of Ormat Technologies).

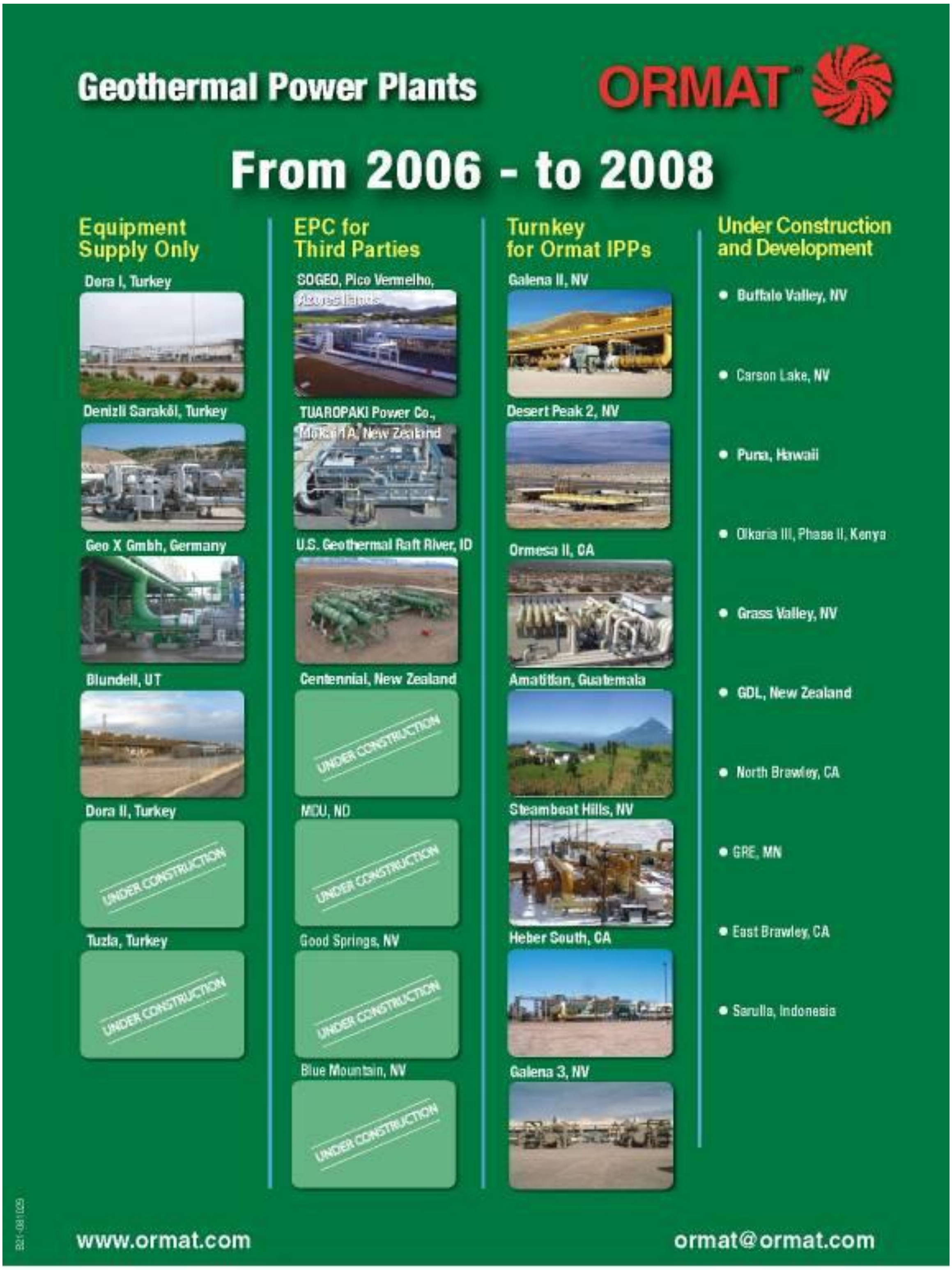

Figure 21.5 Ormat's geothermal power plants from 2006 to 2008.

21.4 Research and Development

21.4.1 C0-production of Electricity at Oil and Gas Fields

Ormat, in a joint project with the Department of Energy (DOE) at the Rocky Mountain Oil Test Center (RMOTC), validates the feasibility of proven technology already used in Geothermal and Recovered Energy Generation (REG) for the production of commercial electricity using hot water produced during the process of oil and gas field production. This project marks the first of its kind by providing on-site fuel free power that will increase the productivity and possibly extend the longevity of existing US oil fields.

The oil fields in the United States could provide an additional 200 to 5,000 MW_e of electricity through this technology, according to United States Senator Mike Enzi (Wyoming).

The Ormat ORC unit being used (Figure 21.6) is similar to the 250 kW_e air-cooled unit that has been producing electricity from 210 ºF geothermal water at an Austrian resort since 2001. Additionally, there are similar units in Nevada (700 kW_e) and Thailand (300 kW_e) that have been in continuous commercial operation without overhaul since 1984 and 1989, respectively.

Figure 21.6 Hot water co-produced from oil wells a the Rocky Mountain Oilfield Testing Center (RMOTC), Wyoming, USA (2008) (courtesy of Ormat Technologies).

21.4.2 Enhanced Geothermal Systems (EGS)

21.4.2.1 Desert Peak

Ormat is also working with research institutions to create an engineered geothermal system (EGS) at our Desert Peak geothermal field in Northern Nevada (Figure 21.7). Ormat currently operates an 11 MW_e geothermal power plant at Desert Peak. Heat flow through the field is significant and temperatures in excess of 200 ºC have been measured at relatively moderate depths. However, these heat anomalies lack interconnectivity with the existing geothermal reservoir. Thus, much of the heat energy in the field cannot be captured through conventional hydrothermal technology. For this reason, this project serves a dual purpose. By employing and practicing advanced methods to help commercialize EGS technology, this project serves to move forward scientific understanding and applied technology. Because this project is being tested at an existing geothermal field, a successful EGS could be quickly adapted into additional generation capacity for commercial sale.

Figure 21.7 Desert Peak, Nevada, USA
(courtesy of Ormat Technologies).

21.4.2.2 Brady

The US Department of Energy (DOE) has once more chosen Ormat to demonstrate the viability of Enhanced Geothermal Systems (EGS) with a grant for US$3.4 M to improve hot, non-commercial wells located within a stress environment and in formations favourable for permeability enhancements using EGS techniques.

Ormat, the DOE, GeothermEx Inc. and other stakeholders will apply EGS stimulation techniques at Ormat's Brady facility near Reno, Nevada, to develop fracture networks that will enable currently non-commercial wells to communicate with the productive reservoir and enhance generation.

21.4.2.3 Landau, Germany

Ormat technology has been applied to another commercial project with EGS injection in Landau, Germany, where a 3.2 MW_e power plant has been in operation for more than a year.

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APPENDIX A: **Attendees at the 18th GIA Executive Committee Meeting, Kandel, Germany, 25-26 October 2007 (courtesy of Patrick Ledru).**

Front (left to right): Hirofumi Muraoka, Yoonho Song, Nobuyaki Hara, Guido Cappetti, Mike Mongillo, Adrian Larking, Ladsi Rybach, Patrick Ledru, Barry Goldstein, Michael Malavazos
Back (left to right): Jörg Baumgärtner, Guðni Axelsson, Chris Bromley, Jonas Ketilsson, John Lund, Lothar Wissing, Elisa Boelman, Yoshinori Makino, Alan Knights, Roy Baria, Allan Jelacic

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