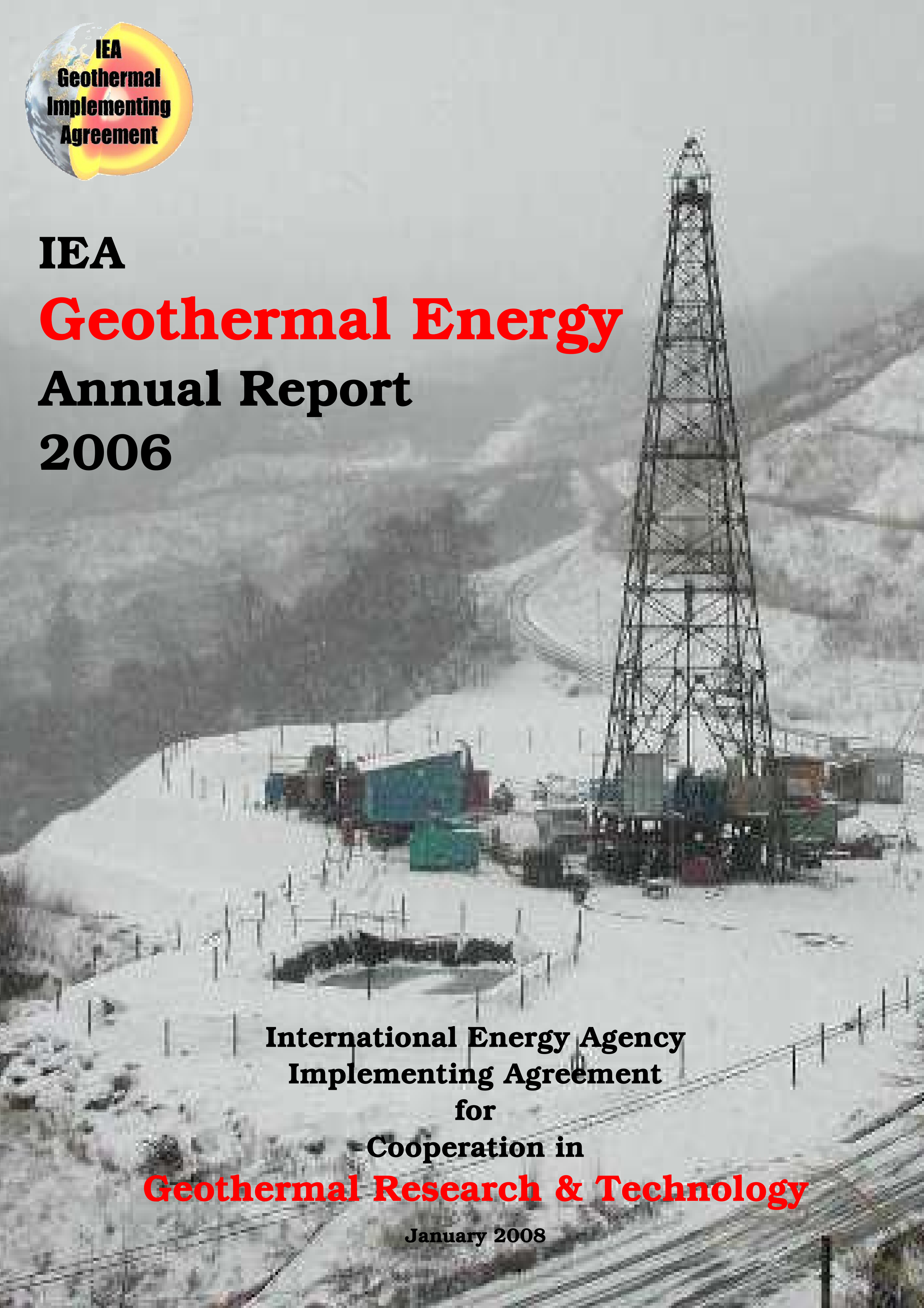

IEA
Geothermal Energy
Annual Report
2006

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: Well N16-TE-2 in Tenei Village, Fukushima Prefecture, Japan. The well was drilled to a depth of 1,400 m and reached a temperature of 112.1 °C for a small-scale power development by NEDO from late 2004 to early 2005. *(Photo by Yuko Kizaki, Geothermal Engineering Co., Ltd)*

Message from the Chair

As the International Energy Agency (IEA) Geothermal Implementing Agreement (GIA) approaches the end of its second five-year term it has been a time for reflection on past accomplishments, pending issues and future directions. During this period, the GIA has grown in membership and consolidated as a group, with sufficient governmental, academic and industrial representation to act as an effective agent for the promotion of geothermal energy utilization around the world. Its membership includes– still with some important exceptions– the geothermal pioneers, the largest geothermal electric power producers, leading users of geothermal heat for direct applications, and companies, countries and institutions associated with the some of the most advanced geothermal research programmes.

Although the coordination of participants' geothermal research programmes remains at the core of its activities, the GIA has evolved in other important dimensions. It has largely increased its visibility to the interested public through the installation in 2004 of the GIA Webpage. In addition, it has joined forces with the IEA Secretariat in order to produce electronic and printed material with reliable statistics and general information on geothermal technology, and to channel it though the Agency's information network and appropriate forums.

Of the pending issues, there is one of particular concern to me and, I am sure, to other members of the Executive Committee. If one observes the pattern of geothermal utilization around the world, one finds enormous contrasts between countries which have long benefited from their geothermal resources– in some cases generating from them a sizable portion of their nation's electricity and their heat for direct use– and those which have not yet developed their resources. The former consider geothermal technology mature and are perfectly aware of its virtues as a reliable, competitive and environmentally benign technology; some of them are even venturing into the commercial application of emerging geothermal technology. Some of the latter have geothermal resources with a potential equivalent to those of the most productive geothermal fields in the world, but still show little inclination to make use of their indigenous resources. This clearly indicates that the barriers to geothermal development are varied in nature, and that the state of development of the technology and availability of indigenous resources are perhaps not the most important factors. A reasonable hypothesis is that there is an acute lack of awareness among some decision-makers of the potential benefits of geothermal technology, as well as of their countries' indigenous resources. I believe that the IEA, the GIA and other organizations which share the mission of promoting the utilization of geothermal energy around the world should adopt, as one of their primary concerns, the task of improving the awareness of geothermal technology amongst decision-makers around the world, at least to the level accomplished by promoters of other renewable energy technologies.

In conclusion, I recommend to you this comprehensive annual report on the GIA activities for 2006. In particular, the executive summary provides an illuminating snapshot of the current worldwide status of geothermal energy development, its rapid acceleration and exciting future. With concerted efforts to remove barriers, both real and perceived, the next five year term should see geothermal taking an even more prominent position in global renewable energy portfolios.

David Nieva
Chairman, IEA-GIA Executive Committee

Executive Summary

Drill rig at the EGS project "Deep Heat Mining" in the city of Basel, Switzerland (photograph courtesy of Geopower AG Basel, Switzerland).

INTRODUCTION

2006 was one of the IEA Geothermal Implementing Agreement's (GIA) most successful years yet. In addition to continuing its international collaborative activities to support and advance geothermal energy use worldwide, the GIA prepared its End of 2nd Term Report and new Strategic Plan as part of the application procedure for extending its operation for a 3rd 5-year term. This

2006 Annual Report describes these activities and the major achievements of IEA Geothermal and its participants for the year. Of particular note is the 25 % growth in GIA membership with the joining of our first 3 industry Sponsor Members: ORMAT Technologies, Geodynamics and Green Rock Energy, thus taking membership to 14. The current status of the Member Countries' geothermal energy policies, uses, market situation, economics, research activities, education and international activities is discussed and our 3 new Sponsor Members are introduced and their activities described.

This Executive Summary begins by setting the context in which the IEA-GIA operates. It presents a brief introduction to the world's current energy situation, the current contribution that geothermal resources are making to the global energy supply, and the potential significant contribution that geothermal resources could make in future. It includes a brief description of the GIA and a synopsis of the information described in detail in the Annex, Member Country and Sponsor reports provided in Chapters 2-6, 8-18 and 19-21, respectively. A few highlights of GIA Members' 2006 activities are provided and the major achievements of the GIA's research pursuits are presented. Finally, the GIA's plans for 2007 are outlined.

Geothermal Energy in the World Energy Scene

The global demand for energy continues to accelerate, while awareness of climate change issues encourage a worldwide desire to greatly expand the use of clean, renewable energy resources. Providing affordable, reliable and clean energy to meet these rapidly expanding needs is an enormous challenge, and geothermal energy can be a very significant part of the solution.

In 2005, the worldwide total primary energy use was estimated to be about 479 EJ_{th}, or 133,000 TWh_{th}, equivalent to 11,435 Mtoe (IEA, 2007a). This energy utilization corresponds to an average annual power consumption of 15.2 TW_{th}, assuming 24 hour per day usage. Current estimates (Stefansson, 2005) indicate the *most likely* worldwide total technical potential for geothermal resources (restricted to the continents) is about 6.5 TW_{th} (205 EJ_{th}/y). Of this total, 210 GW_e (6.5 EJ_e/y or 65 EJ_{th}/y) are for resources with temperatures > 130 °C that can be developed for electricity generation using conventional methods, and 4.4 TWh_{th} (140 EJ_{th}/y) are for resources ≤ 130 °C and considered mainly for direct heat uses. More optimistic estimates increase these numbers by factors of 5-10! It is very important to note that the above estimates do not consider 1) the contribution binary generation can add utilizing the hot water discharged from conventional plants (co-generation) and the water from the lower temperature geothermal resources (100 - 130 °C), 2) the cascaded use of hot water discharged from geothermal power stations for direct heat applications or 3) the huge geothermal energy potential available within drilling depths in the earth's crust via enhanced geothermal systems (EGS) development. Recent studies indicate that over 200,000 EJ are extractable within the USA via EGS techniques (about 2,000 times the USA's 2005 annual primary energy consumption!), with more than 100 GW_e of cost-competitive generating capacity developable within the next 50 years given reasonable R&D investment (MIT, 2006). Similar estimates of 100 GW_e capacity have also been made for the Rehai and Yangbajing geothermal fields of China (Wan, *et al*., 2005) and for regions across India (Chandrasekhar and Chandrasekharam, 2007).

Consequently, geothermal resources have the potential to make a considerable contribution towards meeting the world's current and future energy needs. Geothermal energy also has characteristics which make it extremely valuable for both electricity generation and direct heat use, including: 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 2006

In 2005, 24 countries worldwide were generating electricity from geothermal resources, with a total installed capacity of more than 8,900 MW_e and electricity generation of about 54,330 GWh/y (data from Bertani (2005), revised using 2005 GIA data for Iceland and USA). 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/y (Figure ES1). However, in the last few years, geothermal development has begun to accelerate. In the period 2005-2006, the installed capacity in GIA Member Countries alone increased by 522 MW_e/y (9.5%), to 6,000 MW_e; and generation grew by 2,350 GWh/y (6.7%), to 37,205 GWh/y. Table ES1 presents the 2006 data for GIA Member Countries along with the most recent (2005) published data available for the remaining 16 countries with geothermal generation (Bertani, 2005). Geothermal growth in GIA Member Countries during 2005-2006 amounted to increases of about 5.9% and 4.3%, relative to the 2005 total global capacity and generation, respectively (Table ES2). The lower percentage growth in generation relative to installed capacity is because not all new installed capacity generated power for entire calendar years.

Table ES1 Geothermal power installed capacity and electricity generation for GIA Member Countries in 2006, plus 2005 data for 16 other countries for 2005 (Bertani, 2005).

Country	Installed Capacity [MW]	Annual Energy Produced [GWh/y]	% of National Capacity	% of National Energy
Australia*	***.12***	***.7***	***Negligible***	***Negligible***
Austria	1	3.2	Negligible	Negligible
China- Tibet	28	95.7	30	30
Costa Rica	163	1,145	8.4	15
El Salvador	151	967	14	24
Ethiopia	7	na	1	n/a
France Guadeloupe Island	15	102	9	9
Germany*	***.15***	***0.2***	***Negligible***	***Negligible***
Guatemala	33	212	1.7	3
Iceland*	***422***	***2,631***	***24.9***	***26.5***
Indonesia	797	6,085	2.2	6.7
Italy*	***810***	***5,200***	***1.0***	***1.9***
Japan*	***534.24***	***3,228***	***0.2***	***0.3***
Kenya	127	1,088	11.2	19.2
Mexico*	***953***	***6,685***	***2.2***	***3***
New Zealand*	***450***	***3,210***	***5.5***	***7.6***
Nicaragua	77	270.7	11.2	9.8
Papua New Guinea Lihir Island	6	17	10.9	n/a
Philippines	1,931	9,419	12.7	19.1
Portugal San Miguel Island	16	90	25	n/a
Russia	79	85	Negligible	Negligible
Thailand	.3	1.8	Negligible	Negligible
Turkey	20	105	Negligible	Negligible
USA*	***2,831***	***16,250***	***0.3***	***0.4***
Total	**9,452**	**56,679**	**9.5****	**11.7****
Total GIA Countries	***6,000***	***37,205***	***5.7*****	***6.6*****

na = not available, **** GIA Member Countries***; ** Average values excluding negligible contributions.

Geothermal energy provides a major contribution to the national generation of many countries, with seven countries now having more than 10% of their installed capacity from geothermal and six obtaining 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 5.7 %, with the corresponding average contribution to national generation being about 6.6%. The corresponding worldwide values were 9.5% and 11.7%, respectively (see Table ES1).

The total GIA geothermal generation of 37,205 GWh/y is "equivalent" to a savings of about 32.0 Mtoe (using IEA (2007b) conversion for geothermal: 1 GWh ~ 8.6 x 10^{-4} Mtoe) and avoided CO_2 emissions of 30.4 Mt (using GIA (Mongillo, 2005) conversion: 1 GWh ~ 817 t of CO_2). The equivalent savings for the worldwide total generation of 56,680 GWh/y is about 48.7 Mtoe and avoided CO_2 emissions of 46.3 Mt.

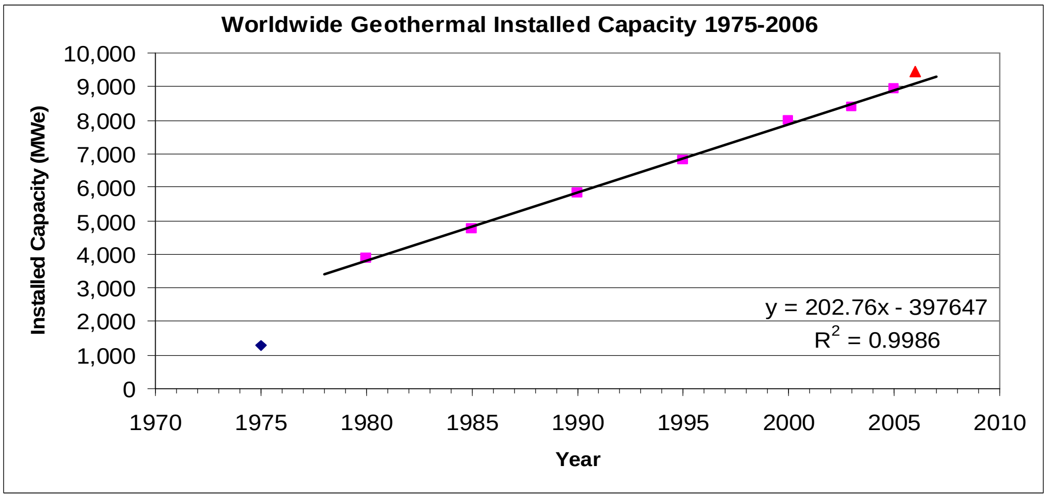

Figure ES1 Worldwide geothermal installed capacity for the period 1975-2006 (the 2006 data point [red triangle] includes GIA data for 2006 and 2005 data for 16 other countries (Bertani, 2005); the trendline was calculated using data for 1980-2005).

Table ES2 Worldwide installed geothermal capacity (1975-2006) and electricity generation (1995-2006).

Year	1975	1980	1985	1990	1995	2000	2005	2006***
Geothermal Installed Generating Capacity (MW_e)	1,300	3,887	4,764	5,832	6,798	7,974	8,930**	9,452
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*)
Electricity Generation GWh/y	-	-	-	-	37,744	49,261	54,329**	56,679
Increase Over Previous Five-Year Period GWh/y (Percent)	-	-	-	-	-	11,517 (30.5)	5,068 (10.3)	2,350* (4.3*)

* Change from 2005 to 2006 (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 and 2005 data for the other 16 countries with geothermal power (Bertani, 2005)

When considering the contributions of renewable energy resources it is not only useful to know their installed capacities; more important is the "contribution efficiency" with which they provide the power, i.e. the ratio of the energy generated to the installed capacity. This ratio takes into account the "availability factor", i.e. the amount of time that the renewable generator is available to produce power. As shown in Table ES3, the contribution efficiencies for the various renewables in the 30 OECD countries in 2005 were: 7.3 GWh/MW_e for geothermal (6.2 for GIA Member Countries in 2006), 5.4 GWh/MW_e for solid biomass, 3.7 GWh/MW_e for hydro, 1.9 GWh/MW_e for tide/wave/ocean, 1.8 GWh/MW_e for wind and 0.4 GWh/MW_e for solar PV (IEA 2007b). Geothermal's very high availability factor makes it valuable for baseload generation. It is interesting to note that though wind installed capacity and generation are both growing at extremely rapid rates, geothermal is 3.4-4 times more "efficient" in its generation, i.e. geothermal provides 3.4-4 times more electricity per installed megawatt.

Table ES3 Installed capacity, electricity generation and contribution efficiency for renewable resources in OECD Countries for 2005 (data from IEA, 2007b) and GIA Members for 2006.

Resource	**Installed Capacity** (MW_e)	**Generation** (GWh)	**Contribution Efficiency** (GWh/MW_e)
Geothermal			
GIA Members 2006	*6,000*	*37,205*	*6.2*
OECD 2005	5,100	37,300	7.3
Solid Biomass	20,000	108,400	5.4
Hydro	345,600	1,270,500	3.7
Tide, Wave, Ocean	300	565	1.9
Wind	50,800	93,700	1.8
Solar PV	3,800	1,605	0.4

As of May 2005, 72 countries were utilizing geothermal energy for direct use applications, including: 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 was 28,269 MW_{th}, and the thermal energy usage 273,372 TJ/y or 75,940 GWh/y (*ibid.*) (Table ES4). Over 50% of direct use installed capacity was contributed by geothermal heat pumps. In 2006, the 10 GIA Member Countries had a total installed thermal power capacity of 16,317 MW_{th} and utilized 137,745 TJ/y.

Table ES4 Worldwide direct use categories and their development 1995-2005 (from Lund *et al.*, 2005).

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

Direct use installed capacity has nearly doubled every 5 years since 1995 and the corresponding energy use has increased by a factor of almost 2.5. The 2005 use is equivalent to an annual savings of about 13.1 Mtoe in fuel oil (using the IEA (2007b) conversion for geothermal: 1 TJ ~ 47.8 toe) and 31.2 Mt in avoided CO_2 emissions (using GIA conversion (Mongillo, 2005): 1TJ ~ 114 t CO_2). GIA Member Country utilization in 2006 was equivalent to an annual savings of 6.6 Mtoe and avoided CO_2 emissions of 15.7 Mt.

THE IEA-GIA- AN OVERVIEW

The IEA-GIA provides a flexible framework for wide-ranging international cooperation in geothermal R&D, with its overall Mission for the 2nd Term (2002-2007) being: *to advance and support the use of geothermal energy on a worldwide scale by overcoming barriers to its development.* It brings together national and industry programmes for exploration, development and utilization of geothermal resources, with a focus on assembling specific expertise and enhancing effectiveness by establishing direct cooperative links among geothermal experts in the participating countries and industries. The GIA's present activities are directed principally toward the coordination of the ongoing national programmes, with contributions from industry members. New studies and activities are initiated and implemented when needs are established.

The GIA's general scope of action, as specified in its fundamental operating 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. Objectives during the 2nd Term have been specifically focused to: expand R&D collaboration, increase the number of participants, increase outreach to non-Member countries with large geothermal energy potential; evaluate market stimulation mechanisms, improve dissemination of information about geothermal energy and use the IEA's reputation to help leverage limited R&D funding.

The 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. The GIA is supervised by an Executive Committee (ExCo) and its decisions are binding on all Members. The ExCo consists of one voting Member from each Member Country and Sponsor.

During the GIA's current term, the Annexes have operated under the "task-sharing" mode of financing, in which 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 per year plus several man-years (GIA, 2006a).

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

2006 was the GIA's last entire year of operation in its current (2nd) 5-year term, which ends on 31 March 2007. The GIA has been very active and achieved a great deal through the particularly successful pursuit of its current mission. However, the GIA recognizes that there is still a considerable amount of work remaining to ensure that geothermal energy makes the significant contribution towards meeting the world's accelerating energy demands it is capable of. Consequently, the GIA ExCo unanimously voted to apply to the IEA to extend its operation for a third 5-year term, taking its activities into 31 March 2012. This request entailed the preparation of a detailed End of 2nd Term (2002-2007) Report (GIA, 2006a), which presented and assessed the GIA's 2nd Term activities and achievements, and the development of a new Strategic Plan (GIA, 2006b) for the 3rd Term period 2007-2012; submitted to the IEA Secretariat on 30 October 2006 and 9 November 2006, respectively. The final decision on the GIA's extension request will be made by the IEA Committee for Energy Research and Technology (CERT) at its next meeting in February 2007.

COLLABORATIVE ACTIVITIES

The Annexes

In 2006, the participants in the IEA-GIA worked in five broad research areas, specified in the following Annexes:

- Annex I- Environmental Impacts of Geothermal Energy Development
- Annex III- Enhanced Geothermal Systems
- Annex IV- Deep Geothermal Resources (closed September 2006)
- Annex VII- Advanced Geothermal Drilling Techniques
- Annex VIII- Direct Use of Geothermal Energy

Annexes I, III and IV 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; while Annex IV was closed as a result of the completion of much of its work, with remaining unfinished studies transferred to the closely allied Annexes III and VII. Annex VIII was officially initiated in 2003, though it did not begin its activities until September 2005, and its first term of operation continues to 2007. Four additional Annexes: II Shallow Geothermal Resources, V Sustainability of Geothermal Energy Utilization, VI Geothermal Power Generation Cycles and IX Geothermal Market Acceleration, were previously drafted; with II and IX subsequently closed. The possibility of initiating Annex V continues to be discussed, and the draft description of Annex VI is being revised. The status of the Annexes is presented in Table 1.1 (Chapter 1).

A brief discussion of some of the GIA's activities and major highlights for the Annexes active in 2006 is presented below. Details are available in Chapter 1 and in the Annex Reports included in Chapters 2-6.

The Geothermal Resources Council Meeting 2006

The Geothermal Resources Council (GRC) Annual Meetings are major international events at which geothermal RD & D topics are discussed, with major emphasis on information dissemination. The GIA presented several papers at this meeting, held in San Diego, California, USA, on 10-13 September 2006, covering topics including: sustainability of geothermal energy use, predicting subsidence, low temperature geothermal development in Korea, geothermal well cost analyses, cooperative research on induced seismicity in EGS and the status and prospects of geothermal energy in Europe. Two of these GIA papers (Rybach and Mongillo (2006) and Bromley (2006)), won ***GRC Best Paper Awards***.

The RE 2006 Japan Congress

The GIA participated at the important 2006 Renewable Energy Congress held in Chiba, Japan, on 9-13 October 2006, in two ways. First, two GIA papers were presented at the forum: one on the growing role and status of the GIA (Muraoka, *et al*., 2006) and the other on utilization strategies to promote beneficial environmental effects (Bromley, *et al*., 2006). Second, three GIA documents which provided information on geothermal energy and described the GIA and its activities were distributed by the IEA Secretariat at their exhibition stand.

GIA Participation in IEA Activities

As mentioned above, the GIA provided the IEA with three documents for distribution at their RE 2006 Japan Congress exhibition booth. In addition, a GIA ExCo representative participated in the IEA RE Heating & Cooling Seminar held in April 2006. Contributions for the IEA Global Energy Technologies Perspectives and the IEA Cutting Edge 2007 (GIA, 2006c) books were also prepared and an article on geothermal energy and the GIA was published in the IEA OPEN Bulletin #35 (Nieva, 2006).

Geothermal Energy Use and the Environment

The environmental impacts of energy use are a global concern. Though geothermal is regarded as benign, there are some environmental effects associated with its use that must be addressed. Annex I- Environmental Impacts of Geothermal Energy Development identifies the possible environmental effects and works to develop and implement techniques to avoid or minimize their impacts.

Enhanced geothermal systems (EGS) are presently seen as a major option for extending the access of geothermal resources to almost anywhere on earth as well as for expanding the capabilities of existing geothermal developments. The development and operation of EGS reservoirs can generate felt induced seismic events, and this “induced seismicity” has been identified as an important issue. Annex I convened its third international workshop on “Geothermal Induced Seismicity” in January 2006, and subsequently produced two important documents: a protocol for dealing with induced seismicity issues (Jelacic, 2006); and a “white paper” (to be published) that presents an up-to-date review of current knowledge of seismicity induced during EGS creation and operation with several EGS case histories (Majer, *et al*., 2006).

Geothermal fluids contain small quantities of CO_2; consequently, it is naturally emitted from thermal areas as well as from geothermal power stations. Annex I is investigating the development of methods for monitoring such emissions in order to help quantify the long-term effects of CO_2 emission from geothermal developments.

Artificial Stimulation to Access Geothermal Resources

Enormous volumes of high temperature, water-poor, rock are globally extensive. In order to access and use the vast amounts of geothermal energy contained in them, Annex III- Enhanced Geothermal Systems (EGS) is investigating the development of new and improved technologies for artificially stimulating these resources 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 applied to enhance energy production at existing conventional geothermal developments.

The successful development of EGS is currently one of the major challenges facing the geothermal community. Many investigations have been conducted in the pursuit of this energy source during the past 30 years. Annex III has collected much of the information obtained during these investigations into a Project Management Decision Assistant (PMDA) handbook, which is a classifier that defines the data needed for and helps guide the developer through, each phase of an EGS power development. International requests for copies of the PMDA continued through 2006.

In 2006, EGS projects involving Annex III were being pursued in Australia, Germany, France, Switzerland and the USA. Success appears imminent at Soultz-sous-Forêts (Alsace, France) where a joint international EC effort, involving Annex III, is being conducted. Three wells have been drilled to about 5,000 m, with good connection between the first two wells. Though further hydraulic fracture stimulation was desired in the third well, this effort was stopped after a magnitude 3.4 induced seismic event caused by this type of stimulation halted the Deep Heat Mining project in Basel, Switzerland, in December 2006. However, construction of the first stage pilot plant is expected in 2008. Successful circulation tests have also been obtained at the Cooper Basin (Australia) EGS project, and drilling of a 3rd well will begin in 2007, with plans to begin installation of the first stage power station in 2008. The Landau project in Germany is also making excellent progress (see below).

Deep Geothermal Resources

Temperatures of geothermal resources increase with depth, so being able to access their deeper realms can potentially extend an existing development's production life, generate more electricity more efficiently, and even allow development of the generally lower temperature geothermal resources available over much larger regions of the world. However, there are many challenges associated with development of deep resources, including: problems with locating and modelling them, technical difficulties in drilling to such depths, problems with producing from low-permeability zones, and complications arising from the chemical nature of the fluids accessed.

Annex IV- Deep Geothermal Resources was designed to tackle these issues so deep geothermal resources could be commercially developed. However, due to the increasing overlap of Annex IV activities with those in Annexes III and VII over the past few years, and the completion of several of the tasks, Annex IV was closed in September 2006, with a redistribution of unfinished studies to Annexes III and VII.

The final 2006 activities associated with this Annex were related to the deep EGS projects at Groß Schönebeck and at Landau, where deep wells were successfully drilled to 4,400 m and 3,170 m, respectively. An ORC binary plant was also ordered for Landau, where a combined 3 MW_e power generation and district heating development is expected to go online by the end of 2007.

Reducing Geothermal Drilling Costs

Drilling geothermal wells is an essential and expensive part of geothermal exploration, development and utilization. Major 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, and Annex VII- Advanced Geothermal Drilling Technology is working to identify, develop and promote ways to do so.

A spreadsheet format well "costing database" containing cost components of wells as planned and as constructed is being developed; data from 9 new wells were added to it, and a cost model was developed. An important step towards helping reduce costs is in progress with Annex VII having finalized the outline for a "best practices" geothermal drilling handbook. Annex VII received several requests related to drilling collaboration and is exchanging information among principal investigators. Results from Annex efforts were published in several papers and presented at three meetings, including the GRC 2006 Annual Meeting and the High Temperature Electronics Conference (HiTEC 2006).

Using Geothermal Heat

Geothermal heat can be used directly for many applications, including: building and district heating; industrial process heating; greenhouse heating; and temperature control for fish farming, bathing and swimming; and snow melting. In fact, the earth's very shallowest depths (< 100 m depth) can be used for home and building heating and cooling by employing geothermal heat pumps- practically anywhere on earth. The growth in geothermal direct use has been outstanding, almost doubling every 5 years since 1995, and there is large scope for its continued growth.

Though many direct use applications are well developed and economically viable, implementation difficulties and unfavourable economics remain and 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.

Efforts have concentrated on the collection of physical and chemical data for the natural features of the participating countries; and their evaluation and comparison has begun as part of the programme to help characterize the geothermal resources. Analysis and interpretation of discharge temperature and discharge rate data for several thousand Japanese hot springs has allowed permeability mapping to depths of 1 km for most of Japan (Muraoka, *et al.*, 2006). Preliminary results demonstrating the use of Google Earth for GIS-type data presentation were very encouraging.

NATIONAL ACTIVITIES

The geothermal programmes of the countries participating in the GIA provide the foundation for the cooperative IEA geothermal activities. These programmes are directed toward the exploration, development and utilization of geothermal resources. A synopsis of the country activities is included in Chapter 7, with a comprehensive description of the current status of geothermal activities for each of the participating countries and the EC provided in Chapters 8-18.

During 2006, Contracting Parties from ten countries and the European Commission (EC) participated in the IEA-GIA. The Member Countries were: Australia, 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 2006, the 8 GIA Member Countries with geothermal generation had an installed capacity of about 6,000 MW_e, or about 63% of the total global geothermal capacity of 9,452 MW_e; and generated 37,205 GWh/y, or about 66% of the total geothermal generation of 56,680 GWh/y (Tables ES5 and 7.1). The United States was by far the largest producer, generating about 16,250 GWh/y, with Mexico second with 6,685 GWh/y and Italy third with 5,200 GWh/y. The percent of national installed capacity provided by geothermal in the 6 IEA-GIA Member Countries with non-negligible power development ranged from 0.2% for Japan to 24.9% for Iceland, with an average of about 5.7%. The contribution of geothermal to national generation in Member Countries ranged from 0.3% for Japan to 26.5% for Iceland, with an average of 6.6%.

All 10 GIA Member Countries utilized geothermal in direct applications, with a total installed capacity of about 16,315 MW_{th} and total thermal energy used approximately 137,745 TJ/y (38,265 GWh/y) (Tables ES4 and 7.2). The three largest users of geothermal heat by far were Japan (43,232 TJ/y), the USA (33,740 TJ/y) and Iceland (25,080 TJ/y). However, the non-high enthalpy geothermal countries, Germany (6,685 TJ/y) and Switzerland (5,987 TJ/y) also had very high utilization, mainly due to the large and growing geothermal heat pump usage.

The equivalent fuel oil savings by GIA Member Countries for geothermal power generation and direct use amounted to 38.6 Mtoe with avoided CO_2 emissions of 46.2 Mt.

Table ES5 Total geothermal installed capacity, electricity generation and direct use in GIA Member Countries in 2006.

Country	Electrical Installed Capacity (MW)	Annual Energy Generated (GWh/y)	% of National Capacity	% of National Energy	Installed Thermal Power (MW_{th})	Annual Energy Used (TJ/y)
GIA Member Countries	6,000	37,205	5.7*	6.6*	16,317	137,745
Worldwide Total**	9,452	56,679	9.5	11.7	31,809	318,224
GIA % of Worldwide Total	63	66	-	-	51	43

* Average % of 6 GIA Member Countries with non-negligible generation.
** Worldwide totals include 2006 data for GIA members (GIA, 2006) and 2005 data for the other 16 countries (GIA, 2006; Bertani, 2005; Lund, *et al.*, 2005).

GIA SPONSORS

As mentioned above, one of the major highlights for the GIA in 2006 was the initiation of industry Sponsor membership, with three companies joining: Ormat Technologies from the USA, and Geodynamics and Green Rock Energy from Australia.

Ormat, based in the USA, is a leading company involved in the geothermal and recovered energy (i.e. electricity generation from "waste heat") business. Ormat not only designs, manufactures and sells equipment (e.g. binary power generators known as Ormat Energy Converters), but develops, builds, owns and operates geothermal and recovered energy power plants. Their strategy is to continue building a geographically balanced portfolio of geothermal and recovered energy assets, and to continue to be a leading manufacturer and provider of products and services related to renewable energy. Ormat has designed and supplied about 900 MW_e of geothermal power plants in the past 25 years in the USA and several other countries, and they currently have nine projects, totaling 169 MW_e generating capacity, under construction in the USA, Guatemala and Kenya. Their revenues in 2006 amounted to US$ 268.9 M.

Geodynamics is an Australia based corporation pioneering EGS development in Australia. Its goal is to produce 1,000 MW_e of baseload electricity from the large known hot fractured rock (HFR) geothermal resource at Cooper Basin, South Australia. To strengthen its aim, the company has acquired the global rights to the Kalina binary cycle technology which it plans to use in the geothermal and industrial waste heat industry. Geodynamics produced the first high temperature (> 200 °C) geothermal flows in Australia at their Habanero site, demonstrating the extraction of deep underground heat in 2005 (15 MW_{th} production). Geodynamics was listed on the Australian Stock Exchange in September 2002 and was awarded the Sustainable Small Company of the Year 2005 Award.

Green Rock Energy is a public company also based in Australia and listed on the Australian Stock Exchange, with funding mainly obtained from shareholders. It is focussed on the development of renewable, clean, conventional and EGS geothermal energy projects with a strong commercial objective. Green Rock is currently involved in two projects, one a joint venture in Hungary to develop geothermal energy (electricity and direct heat) in Hungary using refurbished oil wells; the other aims to develop EGS to supply the electricity needs of BHP Billiton's copper operation at Olympic Dam, South Australia. Promising results have been obtained from a slim exploratory well near the Olympic Dam mine and a hydraulic fracturing programme is planned for the well in 2007.

PLANS FOR 2007 AND BEYOND

Although the final decision regarding the GIA's extension will not be made until the IEA Committee on Energy Research and Technology (CERT) meets in February 2007, the GIA felt confident enough of its prospects for continuation for a 3rd 5-year term, that it developed a new Strategic Plan 2007-2012 (GIA, 2006b), which will not only continue many of the GIA's current tasks, but expand its efforts through revised and new objectives beginning in 2007.

Assuming the GIA will be extended for a 3rd Term (2007-2012), the GIA's efforts over the next 5 years will be guided by its new **Mission**:

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 realize this Mission, the GIA has set the following **Strategic Objectives**:

1. To actively promote effective cooperation in geothermal RD&D through collaborative work programmes, workshops and seminars

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

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

4. To increase membership in the GIA
5. To encourage collaboration with other international organizations and appropriate IEA implementing agreements

6. 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

With the above in mind, the GIA plans that its four active Annexes I, III, VII and VIII, will continue and form the foundation of a very vigorous and full research programme in 2007 and beyond.

The GIA will continue its efforts to improve and enhance the visibility of its work and results, to promote geothermal energy as an important global renewable energy resource, and to encourage its sustainable use worldwide. We recognize the importance of explaining geothermal energy, and stressing the contributions it can, and is making, especially to non-experts, particularly decision makers. Consequently, dissemination of policy and other information will be emphasized.

New national and industry membership will continue to be pursued to help contribute different perspectives and ideas, expand the experience and expertise base, and increase GIA's global influence for growing geothermal energy utilization.

The GIA plans to maintain its participation in IEA Renewable Energy initiatives, like the Renewable Energy Workshops and NEET efforts, and to contribute to the IEA OPEN Bulletin.

The GIA foresees the organization and its future activities to continue growing into the future.

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IEA GEOTHERMAL R&D PROGRAMME

Chapter 1

The Implementing Agreement

50 MW_e well at Salton Sea Geothermal Field, Imperial Valley, California, USA with scientist posing for scale (photograph courtesy of M.A. Mongillo).

1.0 The IEA Geothermal Research and Technology Programme

The IEA's involvement in geothermal energy began in 1978 with the launching of two 3-year long studies which were completed in 1981. There then ensued a 16-year hiatus 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 IEA Renewable Energy Working Party (REWP) and the IEA Committee on Energy Research and Technology (CERT) approved the extension of the GIA for a 2nd 5-year term, taking its activities to 31 March 2007.

In 2006, with the end of the current term of operation less than a year away, the ExCo assessed its 2nd Term efforts and achievements. It was recognized that though significant advancement had been made, considerable work still remained to make geothermal energy the premier source of future energy it is capable of being. Consequently, the GIA ExCo made the unanimous decision to apply to the IEA to extend the GIA's operation for a 3rd 5-year term, which would extend its activities to 31 March 2012. A brief discussion of the GIA's plans for 2007 and beyond is provided in Section 1.5.

The GIA provides a flexible framework for wide-ranging international cooperation in geothermal R&D. It brings together national geothermal programmes for exploration, development and utilization of geothermal resources, and focuses on assembling specific expertise and enhancing effectiveness by establishing direct cooperative links among geothermal experts in the participating countries and industries.

The general scope of GIA's activities was defined in Article 1 of the Implementing Agreement document at the time of its formation in 1997. It continues 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" uses like power generation and direct use of heat, to leading-edge technologies pertinent to enhanced geothermal systems (EGS) and advanced geothermal drilling techniques. New studies are also encouraged and implemented when the needs are established.

As of December 2006, 10 countries: Australia, Germany, Iceland, Italy, Japan, Mexico, New Zealand, the Republic of Korea, Switzerland and the United States, the European Commission (EC), and three industry Sponsors: Geodynamics, Green Rock Energy Limited and ORMAT Technologies Inc. were Members of the GIA.

1.1 Strategy and Objectives

The most likely global technical potential for hydrothermal systems located along tectonic plate boundaries has been recently estimated to be 205 EJ_{th}/y, consisting of about 6.5 EJ_{e}/y for electricity generation and 140 EJ_{th}/y for direct heat use; with more optimistic estimates being 5-10 times larger (Stefansson, 2005). These estimates do not include the potential contribution from low temperature binary generation or the vast potential possible through EGS development, which amounts to about 200,000 EJ in the USA alone. For comparison, the world's total primary energy supply in 2005 was 479 EJ_{th} (IEA, 2007). It is clear that the world's vast and ubiquitous geothermal resources are potentially capable of making a very significant contribution towards meeting the accelerating global energy needs well into the future. The GIA's 2^{nd} Term Strategic Plan 2002-2007 acknowledged this capability and the challenges associated with meeting the IEA World Energy Outlook forecasted growth of 40% in global geothermal electricity production for the 10-year period to 2010, the desire to increase worldwide geothermal direct use, and the consequences of the Kyoto Protocol.

The GIA also recognized the importance of making geothermal energy more cost-effective and overcoming the difficulties associated with characterizing the resource prior to major financial commitment by investors. Barriers to market penetration resulting from the public's general lack of awareness and experience with geothermal technologies, and the institutional barriers linked to the lack of experience with planning, regulation and obtaining public acceptance must also be overcome. Though there are significant positive environmental benefits from using geothermal energy on the global scale, local impacts must be clearly identified and dealt with in an open manner.

To meet these challenges, the GIA set as its 2nd Term (2002-2007) Mission:

To advance and support the use of geothermal energy on a worldwide scale by overcoming barriers to its development.

To accomplish this Mission, the following six objectives were defined:

- **Expand R&D collaboration:** The GIA Executive Committee (ExCo) will implement additional new tasks where new areas of collaboration will be useful. Table 1.1 contains a summary of current collaborative efforts under the GIA.

- **Increase the number of participants:** Many countries with significant geothermal resources are not yet Members of the GIA. Many of them could make important contributions to the GIA and assist with expanding worldwide geothermal development. The GIA encourages new membership and encourages interested parties to contact the ExCo or GIA Secretariat for information about joining.

- **Increase outreach to non-Member countries with large geothermal energy potential:** New regions are opening up as international energy markets expand, and the GIA will embrace this opportunity to invite these non-Member countries to participate in its programmes and explore ways to help accelerate development of their geothermal resources.

- **Evaluate market stimulation mechanisms:** The ExCo realizes that efforts to expand geothermal heat and power markets in both OECD and non-OECD countries require market stimulation to create an increased market for geothermal energy. (Note: the GIA's draft Geothermal Market Acceleration Annex (Annex IX) was closed in October 2004 before being initiated, when the IEA announced its intention to establish the Renewable Energy Technology Deployment (RETD) Implementing Agreement. The GIA is investigating various options for working with the RETD.)

- **Improve dissemination of information about geothermal energy:** The ExCo recognizes that more emphasis is needed on the distribution of high quality and attractive information products in order to promote the use of geothermal energy. The GIA is actively pursuing this issue, and as a part of its effort, is continuing to develop its public website, annual reports, brochures, *etc*. in order to provide information in a more accessible, understandable and appealing manner.

- **Leverage limited R&D funding:** The R&D budgets of many of the GIA participants have been declining, and the need for cost-shared collaboration is increasing. An affiliation with the IEA brings added value to activities rather than funding. The IEA's reputation for technical competence and unbiased excellence can provide leverage to obtain support from industry and other multilateral organizations and financial institutions.

1.2 Collaborative Activities

The GIA's programme operates through participation in collaborative projects called "tasks", which are specific investigations incorporated 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 2-6). Each Annex, referred to by its annex number, is managed by an Operating Agent organization from one of the Member Countries or Sponsor industry members.

In 2006, participants worked on five broad research tasks, specified in Annexes: I- Environmental Impacts of Geothermal Energy Development; III- Enhanced Geothermal Systems, IV- Deep Geothermal Resources; VII- Advanced Geothermal Drilling Techniques; and Annex VIII- Direct Use of Geothermal Energy.

Annexes I, III and IV were part of the original GIA and have continued programmes into the 2nd Term, as has Annex VII, which was started in 2001. In addition, Annexes I, III and VII were extended by the ExCo in September 2005 for further 4 years, to 2009; and Annex VIII will continue through at least 2007. Annex IV was closed in September 2006 as a result of the successful completion of much of its work, with the transfer of unfinished studies to other Annexes. Four additional Annexes were previously drafted, though two of these, Annexes II and IX, were subsequently closed. Annex V is still being considered and Annex VI's draft description is being revised for future consideration.

Table 1.1 Annex Title, Operating Agent and Status of GIA Annexes at December 2006.

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: EC, Iceland, Italy, Japan, Mexico, New Zealand, USA	Active since 1997, Continuing through 2009
II	Shallow Geothermal Resources	Closed
III	Enhanced Geothermal Systems OA: New Energy & Industrial Technology Development Organization (NEDO), Japan TL: I. Matsunaga; AIST, Japan; matsunaga-isao@aist.go.jp Participants: Australia, EC, Geodynamics, Germany, Green Rock Energy, Italy, Japan, ORMAT, Switzerland, USA	Active since 1997, Continuing through 2009
IV	Deep Geothermal Resources OA: Forschungszentrum Jülich (F-J), Germany TL: Dieter Rathjen; F-J, Germany; d.rathjen@fz-juelich.de Participants: Germany	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, Geodynamics, Green Rock Energy, Iceland, Mexico, New Zealand, ORMAT, 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: Iceland, Japan, New Zealand, Republic of Korea, Switzerland, USA	Active since 2003, Continuing through 2007
IX	Geothermal Market Acceleration	Closed

Discussions regarding the initiation of Annex V- Sustainability of Geothermal Energy Utilization continued, with a preliminary decision made to add a sustainability task to Annex I, rather than begin a completely new Annex at this time. A list of Annexes, Operating Agents and indication of their status as of December 2006 is provided in Table 1.1; more complete details of objectives, results and work planned for 2007 for the active Annexes are presented in the Annex Reports included in Chapters 2-6. Table 1.3 presents a brief summary for the current draft and the closed Annexes.

Participants must participate 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 1.2.

Table 1.2 Country participation, funding sources and periods of operation for the Annexes as of December 2006.

Annex	**I**	**III**	**IV**	**VII**	**VIII**
Participating Country	**Environmental Impacts of Geothermal Development**	**Enhanced Geothermal Systems**	**Deep Geothermal Resources**	**Advanced Geothermal Drilling Techniques**	**Direct Use of Geothermal Energy**
Australia	G	G			
EC	G	G		G	
Germany		G	OA, G		
Geodynamics†		I		I	
Green Rock Energy†		I		I	
Iceland	G, I			G	OA, G
Italy	I	I			
Japan	R	OA, R			R
Mexico	G			G	
New Zealand	OA, R, I			I	R
ORMAT Technologies†		I		I	
Republic of Korea					R
Switzerland		G			
USA	N	N		OA, N	U
Start Date	1997	1997	1997	2001	2003
Date Current Term of Annex Continuing To	2009	2009	2006	2009	2007
End Date*	Ongoing	Ongoing	September 2006	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; † Sponsor (Industry) Members.

During the 2nd Term of the GIA, 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 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, 2006).

Table 1.3 Annex number, name, description and status for draft and completed Annexes as of December 2006.

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

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 Chapter 1, 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 7, with details reported in the individual Country and Sponsor Reports making-up Chapters 8-18 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. 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.

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 2006, 10 countries, one international organization and three industries formally participated in this programme (Table 1.2).

1.4 The Executive Committee

Officers

In 2006, Dr David Nieva (Mexico) served as Chairman, and Dr Ladislaus Rybach (Switzerland) and Dr Allan Jelacic (USA) served as Vice-Chairs for Policy and Administration, respectively.

Membership

There were several changes in the ExCo composition in 2006. The ExCo Member from Italy, Aldo Baldacci, changed his job position, leaving the ExCo Member position vacant; Guido Cappetti, the Alternate Member, will fill in until a replacement is appointed. The Alternate Member from Germany, Norbert Stump retired and was replaced by Lothar Wissing. A new Alternate Member for Australia, Tony Hill, was appointed following the 2005 change in Australia's Contracting Party to PIRSA. The joining of three new Sponsor Members in 2006 increased the ExCo accordingly, with ORMAT Technologies appointing Dan Schochet as ExCo Member and Zvi Krieger as Alternate; Geodynamics appointing Doone Wyborn as ExCo Member, with an Alternate to be appointed in future; and Green Rock Energy appointing Adrian Larking as ExCo Member and Alan Knights as Alternate.

The list of ExCo Members and Alternates as at December 2006 is provided in Appendix B.

Meetings

The ExCo held two Meetings in 2006 to conduct business, including the discussion and review of ongoing tasks and planning of future activities.

15th ExCo Meeting 16-17March 2006, Paris, France

The 15th ExCo Meeting was held on 16-17 March 2006, at IEA Headquarters in Paris, France, with the excellent support of the IEA Secretariat. There were 25 attendees, including eight ExCo Members and three Alternate Members, five ExCo Annex Member Observers, two IEA Legal Office representatives, the IEA Secretariat participant, 5 invited Guests and the GIA Secretary.

One of the ExCo's initial decisions was to unanimously agree to apply to the IEA for extension of GIA operations for a 3rd 5-year term. Consequently, continuity of ExCo Officers was deemed important for the preparation of the End of 2nd Term Report (EoT) and development of the 3rd Term Strategic Plan. The 2005 Officers therefore agreed to continue in 2006, and the ExCo unanimously approved the re-election of David Nieva as Chairman and Allan Jelacic and Ladislaus Rybach as Vice-Chairmen.

The IEA Secretariat representative informed the ExCo about the requirements for application to extend the GIA for a 3rd Term. Consequently, plans were made for the distribution of work associated with the production of GIA EoT report and the new Strategic Plan for 2007-2012, both due in October 2006.

Annexes I, III and VII held meetings on Wednesday 15 March 2006. These three Annexes and Annexes IV and VIII reported on their activities at the ExCo meeting, as did the European Commission and the 10 Country Members. ORMAT Technologies, who became the first GIA industry member in February 2006, presented a Sponsor report on the hurdles and key factors for successful investment in geothermal development. A report on the Groβ Schönebeck project, a German EGS project in a deep sedimentary environment, was presented as the major contribution in Annex IV. The importance of sustainability in geothermal development was reiterated and it was decided to keep the draft Annex V- Sustainable Geothermal Energy Production "open" for possible future initiation. It was also decided to produce a draft GIA policy paper on sustainability, to be presented at the Geothermal Resources Annual Meeting in September 2006. The ExCo again discussed geothermal marketing and decided to pursue communications with the IEA RETD IA regarding participation.

Induced seismicity associated with EGS was recognized as an important issue, and an outline for a white paper on induced seismicity was produced as an outcome of Annex I's 3rd workshop held in February 2006, in Stanford, California, USA. A new webpage for EGS induced seismicity was also set up through the Lawrence Berkeley National Laboratory at: http://esd.lbl.gov/EGS.

The issue of increasing GIA membership was discussed and France's possible membership was reviewed by a senior BRGM representative. Geodynamics and Green Rock Energy, two Australian geothermal companies, submitted letters of interest to join the GIA at the meeting, and the ExCo unanimously invited both to join. At the request of the IEA Legal Office, the ExCo unanimously renewed the invitations to governments of China, France, Indonesia, Turkey, Russia, Poland, Sweden, the Philippines, and India to join the GIA.

The GIA agreed to provide a comprehensive geothermal article, in the form of an "interview" with the GIA Chairman, for the IEA OPEN Bulletin (Nieva, 2006). The GIA also confirmed its participation in the IEA REWP Heating and Cooling Seminar being held in Paris, in April 2006. The ExCo agreed to the GIA's participation at the Japan Renewable Energy Conference 2006 (RE 2006 Japan) with the presentation of a paper on the GIA and its activities.

The Secretary provided a report on the operation (work accomplished and budgets) of the Secretariat for the 2005-year and the 2006-year to March 2006, presented a work plan and revised budget for the remainder of 2006, and gave an update on the Common Fund. The IEA Secretariat report was presented and CERT's approval of ORMAT's GIA Sponsor Membership was mentioned. The GIA was thanked for its input to the *Renewable Energy RD&D Priorities* book.

The ExCo agreed to hold the 16th ExCo Meeting in Reno, Nevada, on 7-8 September 2006. However, the ExCo later decided to change the venue to San Diego, California, in order to allow meeting attendees to participate in the Geothermal Resources Council 2006 Annual Meeting.

A new format for the 15th ExCo Meeting Minutes was developed to reduce their file size. All presentations/reports are now linked to their corresponding files stored in the GIA Members Section of the GIA website, thus avoiding the need for them to be included as Appendices in the Minutes document. This allows the Minutes to remain fully complete, but reduces their physical size by ~ 40%.

16th ExCo Meeting 7-8 September 2006- San Diego, California, USA

The 16th ExCo Meeting was hosted by ORMAT Technologies, at the Town and Country Hotel, San Diego, California, USA, on 7-8 September 2006. The meeting was held in conjunction with the Geothermal Resources Council 2006 Annual Meeting (GRC 2006), thus allowing ExCo Meeting participants to take part in this large international conference. There were 25 attendees, including 9 ExCo Members and 3 Alternates, 12 ExCo Observers including the IEA Secretariat representative and the GIA Secretary, plus 1 invited Guest. A fieldtrip to several geothermal developments in California's Imperial Valley was also provided by ORMAT.

Membership in the GIA continued to grow in 2006, with 2 new companies joining as Sponsors since the last ExCo Meeting: Geodynamics and Green Rock Energy, both based in Australia. In addition, a BRGM representative informed the meeting that France's membership in the GIA was looking very positive, with BRGM as the Contracting Party.

The preparation for GIA's application for extension was a major activity and was reviewed. The GIA End of 2nd Term (EoT) report was reported to be proceeding well and would be submitted to the IEA on 30 October 2006. Ideas for the 3rd Term Strategic Plan were discussed, including Vision and Mission statements; and objectives would be aimed at education and outreach, policy positions on topics like induced seismicity, and continued efforts in R&D coordination.

Annexes VII and VIII held meetings on 6 September 2006. Reports from Annexes I, III, VII and VIII, and the Country and Sponsor Members were presented and discussed. Much of the Annex work since the last ExCo Meeting had been related to preparation of Annex contributions for the GIA EoT report. The decision was made to close Annex IV- Deep Geothermal Resources, and redistribute unfinished activities appropriately, mainly to Annexes III and VII. Discussion of Annex V- Sustainability of Geothermal Energy Utilization continued and data from several developed fields was offered for use by some Members. A decision was made to set up a Task in Annex I to initiate sustainability studies and see what developed before opening a new Annex. Since there was growing interest in power generation cycles, the decision was made to update the draft Annex VI- Geothermal Power Generation Cycles description for further discussion. An induced seismicity white paper and draft protocol document were circulated and discussed and it was noted that the white paper was already being used to develop policy for Australian EGS activities.

The Common Fund report was presented; and work plans and budgets for the remainder of 2006 and for 2007 were submitted and unanimously accepted by the attending ExCo Members. The GIA had continued its active relations with the IEA Secretariat, having produced a revised draft version of the GIA IA document with the assistance of IEA Legal Office; completed a geothermal article for IEA OPEN Bulletin #35 (Nieva, 2006); provided comments on the IEA Energy Technologies Perspectives book and contributions to the IEA Renewable Energy: RD&D Priorities book; and participated in the IEA Seminar on RE Heating and Cooling in April 2006. The GIA also provided several documents to the IEA for distribution at their Japan RE 2006 exhibition booth.

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 in the RE Heating and Cooling Seminar.

ExCo Publications, Conference Participation, Etc.

The ExCo recognizes the importance of disseminating information on geothermal energy and promoting the GIA and its activities in order to encourage geothermal energy utilization and increase the organization's membership. In 2006, the GIA ExCo was very active in support of these goals. The GIA helped initiate a series of 3 international Induced Seismicity Workshops in 2005-2006, participating in the 3rd held in February 2006. Two major outputs were: a paper on *Induced Seismicity Associated with Enhanced Geothermal Systems* (to be published in the international journal ***Geothermics***) and a draft discussion document *Protocol for Induced Seismicity Associated with Enhanced Geothermal Systems*. The GIA participated in the RE 2006 Japan Conference held in Makuhari, Japan, in October 2006, presenting 2 papers: *The IEA Geothermal Implementing Agreement – its growing role and status toward the new (3rd) term* (Muraoka, *et al*., 2006) and *Geothermal resources- utilization strategies to promote beneficial environmental effects and to optimize sustainability* (Bromley, *et al*., 2006). There was also GIA representation at the GRC 2006 Annual Meeting, with papers presented on sustainability, subsidence and cooperative research on induced seismicity; two of these papers: *Geothermal sustainability- a review with identified research needs* (Rybach and Mongillo, 2006) and P*redicting subsidence in New Zealand geothermal fields- a novel approach* (Bromley, 2006), won GRC Best Paper Awards. Additionally, as the result of GIA efforts, a session on induced seismicity was included in the GRC conference.

The GIA provided the IEA with three documents which described the GIA and discussed geothermal energy, for distribution at their RE 2006 Japan Congress exhibition booth. A GIA ExCo representative also participated in the IEA RE Heating & Cooling Seminar in April 2006. Contributions for the IEA Global Energy Technologies Perspectives and the IEA Cutting Edge 2007 (GIA, 2006c) books were also prepared and an article on geothermal energy and the GIA was published in the IEA OPEN Bulletin #35 (Nieva, 2006).

A comprehensive End of 2nd Term report and a Strategic Plan for 2007-2012 were written, and are very useful documents describing the GIA and its future plans.

The GIA's public website (www.iea-gia.org), continued to grow as a source for information dissemination and discussion. A new topic entitled "Papers/Reports for Review and Comment", was added in Publications Section, and several draft reports and papers were posted for review and discussion. Another new section, Geothermal Information/Data, was also added under the Geothermal Information Section.

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. This 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.

In 2005, the cost per Common Fund share was set by unanimous ExCo decision at US$ 3,500/y, and it remained at this level for 2006. 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 2006.

Australia	2	New Zealand	1
European Commission	4	Republic of Korea	2
Germany	4	Switzerland	2
Iceland	1	United States	4
Italy	2	Geodynamics	1
Japan	4	Green Rock Energy	1
Mexico	1	ORMAT	2
Total = 31 shares			

1.5 GIA Plans for 2007 and Beyond

As stated above, the GIA ExCo unanimously decided to apply to the IEA to extend its operation for a 3rd 5-year term, thus taking its activities to 31 March 2012. This necessitated the preparation of a detailed End of Term Report for the period 2002-2007 (GIA, 2006a) and development of a new Strategic Plan for 2007-2012 (GIA, 2006b).

Assuming the GIA will be extended for a 3rd Term, the GIA's future efforts will be guided by its new **Mission for 2007-20012**:

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.

This Mission is supported by six **Strategic Objectives**:

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

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

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

4. To increase membership in the GIA

5. To encourage collaboration with other international organizations and appropriate implementing agreements

6. 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

With the above in mind, the GIA plans that its four currently active Annexes: I, III, VII and VIII, will continue as the basis of a very vigorous and full research programme in 2007 and beyond.

The GIA will continue its efforts to improve and enhance the visibility of its work and results, to promote geothermal energy as an important global renewable energy resource, and to encourage its sustainable use worldwide. We recognize the importance of explaining geothermal energy, and stressing the contributions it can, and is making, especially to non-experts, particularly decision makers, consequently, dissemination of policy and other information will be emphasized.

The GIA will continue to pursue new national and industry membership, which will contribute additional perspectives and ideas, expand its experience and expertise base, and increase its global influence for growing geothermal energy utilization.

The GIA plans to maintain its regular participation in IEA Renewable Energy initiatives, including: Renewable Energy Workshops, NEET efforts, and contributions to IEA publications such as the IEA OPEN Bulletin.

The GIA foresees that the organization and its activities will continue to growing into the future.

1.6 References

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Rybach, L. and Mongillo, M.A. (2006) Geothermal sustainability- a review with identified research needs. GRC Transactions, vol. 30, 1083-1090.

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Strategic Plan (2006) GIA Strategic Plan 2007-2012, 9 November 2006, 26 p.

IEA GEOTHERMAL R&D PROGRAMME

Chapter 2

Annex I- Environmental Impacts of Geothermal Energy Development

Craters of the Moon thermal area, Wairakei geothermal field, New Zealand (courtesy GNS Science)

2.0 Introduction

Although geothermal is generally regarded as a benign renewable energy resource, with significant advantages over fossil fuels with respect to carbon emissions, there are some environmental problems associated with its utilization. To further the use of geothermal energy, possible environmental effects, both adverse and beneficial, need to be identified, and measures devised and adopted to avoid or minimize the adverse impacts. 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.

During 2006, the EC and eight Member Countries participated in Annex I: Australia, Iceland, Italy, Japan, Mexico, New Zealand, Switzerland and the USA.

The Operating Agent for Annex I is GNS Science, Wairakei, New Zealand, a Crown Research Institute owned by the New Zealand Government. The Annex Leader is Chris Bromley (GNS Science, New Zealand).

2.1 Tasks of Annex I

There are currently four tasks in this Annex.

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

This Task focuses 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.

The participants in this Task are Iceland, New Zealand and the USA.

2.1.2 Task B- Discharge and Reinjection Problems (Task Leaders: Trevor Hunt and Ed Mroczek, GNS Science, Wairakei, New Zealand)

Work in this Task focuses on identifying and determining methods of overcoming the impacts of geothermal developments on aspects of the environment other than natural features. 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.

Iceland, Italy, Mexico, New Zealand and the USA participate in this Task.

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

The objective of the Task is to contribute to the future of geothermal energy development 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 being identified, documented and promoted.

Participants in this Task include Iceland, Japan and New Zealand.

2.1.4 Task D- Seismic Risk from Fluid Injection into Enhanced Geothermal Systems (Task Co-Leaders: Ernie Majer, Lawrence Berkeley National Laboratory, Department of Energy, United States; Roy Baria and Andre Gerard, European Commission)

This Task addresses the issue of the occurrence of large (i.e. felt) induced seismic events, particularly in conjunction with EGS reservoir development, but also in connection with regular geothermal operations. The aim 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.

Australia, the EC, Geodynamics, Green Rock Energy, Japan, New Zealand, Switzerland and the USA participate in this Task.

2.1.5 Task E- Sustainable Utilization Strategies (Task Leaders: To be appointed)

This new Task was initiated in September 2006, with Iceland, New Zealand, Switzerland and the USA identified as participants.

The aim of this Task is to collate case histories of models of geothermal developments to see what strategies have worked and what have not. The activities will include: modelling of long term reservoir behaviour to select optimum future strategies given different recharge and resource size scenarios; comparing environmental gains with economic gains from different sustainable development scenarios; comparing different conceptual and hypothetical reservoir model predictions; and investigating (with agreed scenarios) long term reservoir behaviour, recharge factors, recovery times, and optimised cyclic or staged operation strategies.

2.2 Work Performed in 2006

2.2.1 General

- Papers were presented by Task participants on improved resource and environmental sustainability strategies at the annual New Zealand Geothermal Workshop (NZGW) in November 2006 (Auckland, New Zealand) and at the International Renewable Energy Conference (RE2006) held in October 2006 (Chiba, Japan). Interest in sustainability issues led to agreement at the September 2006 IEA GIA Executive Committee Meeting to establish a new task (Task E) and seek more participants in this area.

- At international conferences (Annual Stanford Geothermal Workshop [SGW]), Geothermal Resources Council (GRC) Annual Meeting, NZGW and RE2006 longer-term research and development needs were discussed with industry representatives, including research into: induced seismicity, monitoring natural CO_2 and convective heat flux, classifying thermal feature vulnerability, testing mitigation and remediation methods, and developing bioremediation methods to remove toxic elements from geothermal water discharges.

- Collaboration between geochemical researchers in Iceland, Italy, New Zealand and the USA to study means of monitoring natural CO_2 emissions from thermal areas, in order to quantify the net long-term effects of geothermal development on global warming through CO_2 emissions, culminated in a draft paper.

- Application of surface heat loss methods from steaming ground were adapted for underground coal fire research and presented at a conference in China.

- Annex I participants took part in GIA Executive Committee Meetings and in the associated Annex I meetings held in April 2006 (Paris, France), and in September 2006 (San Diego, USA) to discuss progress on the existing tasks and planning for new tasks.

2.2.2 Task A- Impacts on Natural Features

Thermal feature impacts due to geothermal development in various countries were compared. Submitted further commentary on appropriate geothermal policy and planning regulations 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 refined and results submitted to the Journal of Volcanology and Geothermal Research (JVGR).

2.2.3 Task B- Discharge and Reinjection Problems

Waste water disposal options, including groundwater disposal, deep injection, shallow injection, and chemical treatment were debated at various international conferences including: GRC 2006, NZGW 2006 and New Zealand Environment Court hearings for the Waikato Regional Council geothermal policy and plans.

Potential causes of subsidence in geothermal fields were investigated and methods to improve predictive capabilities of subsidence models were further investigated and presented at the GRC 2006. The use of interferometric synthetic aperture radar (INSAR) for geothermal subsidence monitoring was investigated and a paper submitted to JVGR.

2.2.4 Task C- Methods of Impact Mitigation and Environmental Manual

A draft position paper for GIA Executive Committee consideration titled *The Benefits of a Balanced Approach to Geothermal Environmental Management* was reviewed and improved.

2.2.5 Task D- Seismic Risk from Fluid Injection into Enhanced Geothermal Systems

The multi-party collaboration, mainly among Australia, EC-France, New Zealand and the USA, continued its efforts to advance understanding of induced seismicity mechanisms, and to provide strategies and robust hazard assessment methods to address the issue of large induced earthquakes from injection/production activities. Workshops were held in February at the 2006 SGW, in Stanford (USA), and in September at a special session of the GRC 2006, in San Diego (USA). A white paper on induced seismicity associated with EGS was completed and a protocol proposed for dealing with induced seismic events was proposed that points out some possible steps the geothermal developer can take to handle these issues. The protocol includes a proposed “traffic light” system for monitoring and reacting to different levels of induced seismicity.

2.3 Highlights of Annex I Programme Work for 2006

The highlights of Annex I activities in 2006 included:

- The induced seismicity workshop convened at the SGW in Stanford, USA, in 2006
- The special session on induced seismicity organised at the GRC 2006, San Diego, USA
- The environmental and resource sustainability strategies presented and discussed at NZGW 2006 and the RE2006 Japan congress

2.4 Work Planned for 2007

2.4.1 Task A- Impacts on Natural Features

- Examine changes in gas and steam emissions from natural features
- Distinguish natural and induced variations in thermal discharges
- Model causes of groundwater effects from deep pressure change

- Develop methods of ranking thermal features and ecosystems for protection
- Classify vulnerability of thermal features to reservoir pressure changes

2.4.2 Task B- Discharge and Reinjection Problems

- Investigate cost-effective H_2S and Hg removal from production steam
- Examine geothermal CO_2 capture for horticulture or bottling
- Study CO_2 sequestration by injection or chemical fixing
- Look into arsenic/boron removal from waste water by biological or chemical processing
- Investigate protection of potable water aquifers from outfield reinjection effects
- Improve methods for prediction of subsidence and effects avoidance or mitigation

2.4.3 Task C- Methods of Impact Mitigation and Environmental Manual

- Provide environmental policy advice
- 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

2.4.4 Task D- Seismic Risk from Fluid Injection into Enhanced Geothermal Systems

- Determine mechanisms for induced seismicity
- Differentiate induced from natural causes
- Predict likelihood of damaging induced earthquakes
- Devise avoidance or mitigation schemes

2.4.5 Task E- Sustainable Utilization Strategies

The exact studies to be conducted in this new task are currently being considered, and may include:

- Comparison of development histories to learn from previous mistakes
- Modelling of long term reservoir behaviour to select optimum strategies given different recharge and resource size scenarios

2.4.6 Discussion of Task Efforts

The task work proposed above is dependant on the time and resources being made available by participants and on the cooperation of geothermal development companies. Progress in any particular task would be accelerated by the following:

- Improved availability of funding, the availability of donated time of participants, and securing the interests and motivations of those 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

The following Annex I activities would especially benefit from supportive direct or in-kind funding:

- Preparation of an international geothermal environmental protocol document (elaborate on existing documents)
- Induced seismicity and/or sustainability workshop and proceedings 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 2006

2.5.1 Reports Lodged on IEA-GIA Website for Comment and Review

- Hunt, S. and M. Malavazos (2006) *Draft Report- Cooper Basin HDR Hazard Evaluation: Predictive Modelling of Local Stress Changes due to HFR Geothermal Energy Operations in South Australia.*
- Majer, E. and R. Baria (2006) *Draft Protocol for Induced Seismcity Associated with Enhanced Geothermal Systems.*
- Majer, E. and R. Baria (2006) *Induced Seismicity Associated with Enhanced Geothermal Systems.*
- Rybach, L. and M. Mongillo (2006) *Geothermal Sustainability- A Review with Identified Research Needs.*

2.5.2 Publications

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Hole J.K., C.J. Bromley, N.F. Stevens, G. Wadge (2006) Subsidence in the geothermal fields of the Taupo Volcanic Zone, New Zealand, measured by InSAR. *Journal Volcanology & Geothermal Research* (submitted).

Hunt S., C. Morelli, P. J. Boult, M. Malavazzos, T. Hill, S. Sinadinovski (2006) Seismic hazard assessment through predictive modelling of local stress changes due to hot fractured rock (HFR) geothermal energy operations in South Australia. *Transactions Geothermal Resources Council, Vol 30. 2006 Annual Meeting*, September 11-13. San Diego, USA. (CD).

Kaya E., M. O'Sullivan (2006) Modelling of injection into geothermal systems. *Proceedings 28th NZ Geothermal Workshop* (CD), 6p.

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Sorey M., R. Sullivan R. (2006) Quantitative analyses of warm spring waters at the Hot Creek Fish Hatchery, Mammoth Lakes, California. *Transactions Geothermal Resources Council, Vol 30. 2006 Annual Meeting*, September 11-13. San Diego, USA. (CD).

2.6 Websites Related to Annex I Studies

- IEA-GIA website: www.iea-gia.org
- Website hosting the results of the 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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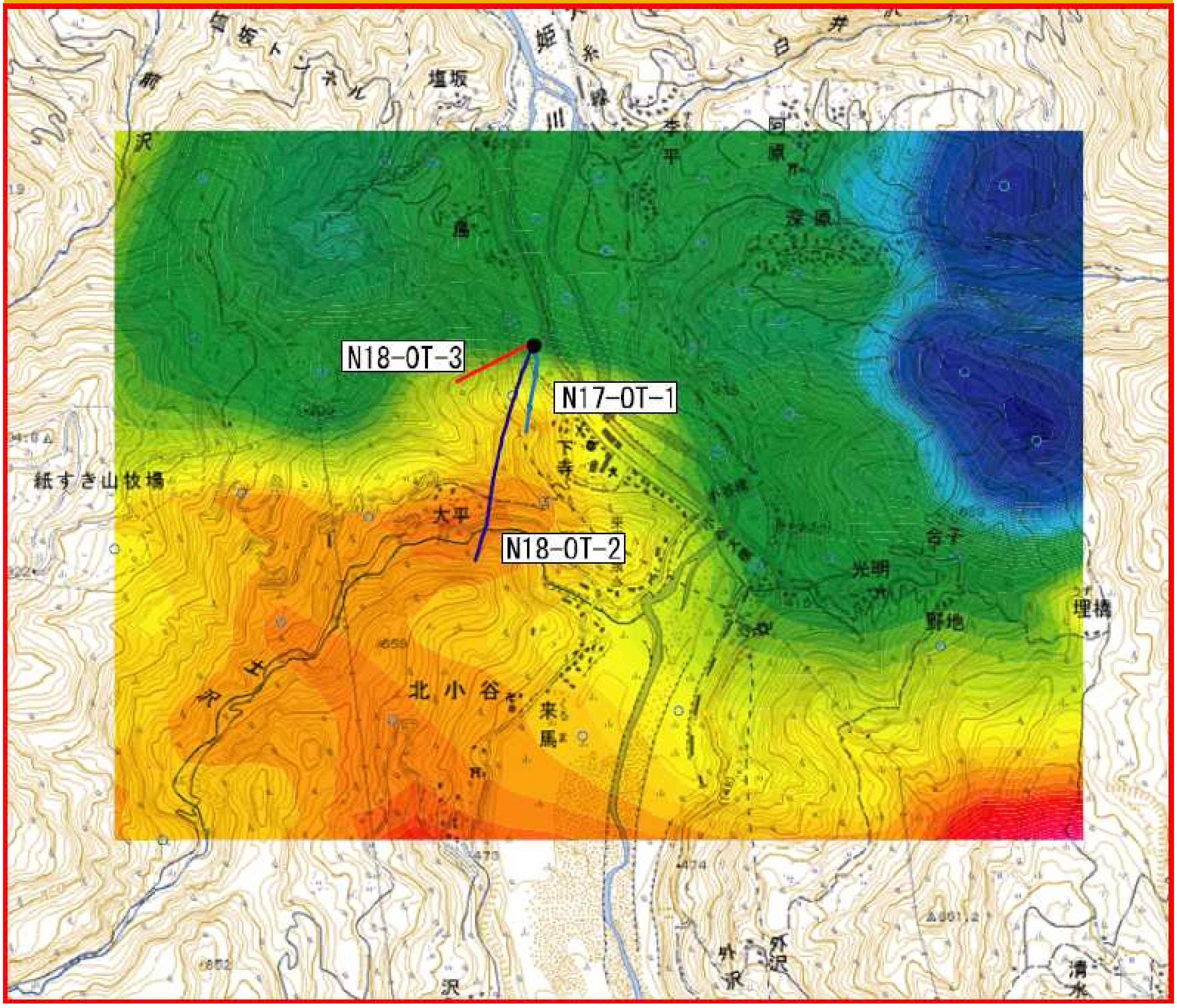
Chapter 3

Annex III- Enhanced Geothermal Systems



Resistivity contour map and well trajectories, EGS investigations during second year of NEDO Geothermal Development Promotion Survey at Otari geothermal field, Japan (courtesy NEDO).

3.0 Introduction

Enhanced Geothermal Systems (EGS) energy technologies have been conceived to extract the natural heat contained in high temperature, water-poor rocks in formations that are either too dry or too impermeable to transmit available water at useful rates. Necessary permeability can be created by hydraulic fracturing or stimulation, which involves the high-pressure injection of a fluid into the reservoir to crack and enlarge pre-existing fractures. The objective of the EGS Annex is to address new and improved technologies, which can be used to artificially stimulate a geothermal resource to enable commercial heat extraction.

The countries and organizations that participated in Annex III in 2006 were: Australia, Germany, Italy, Japan, Switzerland, USA, the EC, Geodynamics, Green Rock Energy, and Ormat Technologies.

The Operating Agent for Annex III is the New Energy and Industrial Technology Development Organization (NEDO), Japan. The Annex Leader is Isao Matsunaga (AIST, Japan).

3.1 Tasks of Annex III

The work undertaken in Annex III is divided among four active Tasks. Task A, which involved the evaluation of the economics of EGS systems, was successfully completed in 2001.

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

This Task is aimed to modify conventional geothermal development technology, such as horizontal drilling, fracture detecting and mapping, and pumping, for application to EGS energy development.

3.1.2 Task C- Data Acquisition and Processing (Task Leader: Thomas Mégel, Geowatt AG, 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.

3.1.3 Task D- Reservoir Evaluation (Task Leader: Tsutomu Yamaguchi, AIST, Japan)

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.

3.1.4 Task E- Field Studies of EGS Reservoir Performance (Task Co-Leaders: Peter Rose, EGI University of Utah, USA; Andre Gerard, EEIG, 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-analysis, hydraulic and chemical stimulation, fluid-flow modelling of hydraulic and chemical stimulation processes, tracer technologies, and geophysical methods. This is a collaborative task between the EGS projects at Soultz-sous-Forêts (France) and Coso, California (USA).

3.2 Work Performed in 2006

3.2.1 Task B- Application of Conventional Geothermal Technology to EGS

The US Department of Energy continues to fund research projects bridging between hydrothermal technology and technology that is more specific to Enhanced Geothermal Systems development. Results of these projects are summarized in "EGS Program Review" (see Highlights of Annex below), and also described in the EGS sessions of the *Transactions Geothermal Resources Council Annual Meeting 2006* and the Proceedings of the *Thirty-Second Workshop – Geothermal Reservoir Engineering* held at Stanford University, USA.

Spreadsheet methods of analysis of tracer tests in hydrothermal and EGS systems have been completed and are available under publications at http://geothermal.inl.gov.

DOE research continues studies of fractures in existing hydrothermal systems to gain a better understanding of the structural and geochemical changes that may occur in artificially generated geothermal systems.

The TOUGH family of reservoir simulators continues to be modified to include chemical reactions and mechanical properties of the reservoir rock. TOUGH-REACT is being coupled to FRAC-3D to provide a coupled flow-chemical mechanical code that can be used in hydrothermal and EGS.

The DOE, in conjunction with the US Navy and the US Geological Survey, is funding the development of improved methods for determining locations of microearthquakes caused by operations in existing hydrothermal fields or resulting from well stimulation. These methods will be utilized in the planned EGS stimulation project at the Coso, California geothermal field.

DOE is also funding several projects that will provide an up-to-date review of current petroleum industry stimulation practices.

Both laboratory studies and theoretical considerations suggest that hydraulic stimulation of rocks produces electric currents in surrounding rocks that can be detected through properly instrumented SP studies. The DOE is funding several projects bearing on the phenomena in collaboration with researchers in Japan.

3.2.2 Task C- Data Acquisition and Processing

During the year 2006 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 was completed in 2005. This Enhanced Geothermal System Project Management Decision Assistant, or EGS-PMDA, is described on the IEA-GIA website under http://www.iea-gia.org/geothermal_information.asp, where a downloadable flyer is also available. Approximately 10 copies of the PMDA have been ordered by various institutions.

3.2.3 Task D- Reservoir Evaluation

A final report of Task D activities was compiled and made available on CD-Rom and has been distributed to many IEA members. 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. The Task D has now fulfilled its mission and finished its activities. Task D participants believe that this final report will be a great help in developing new EGS sites.

3.2.4 Task E- Field Studies of EGS Reservoir Performance

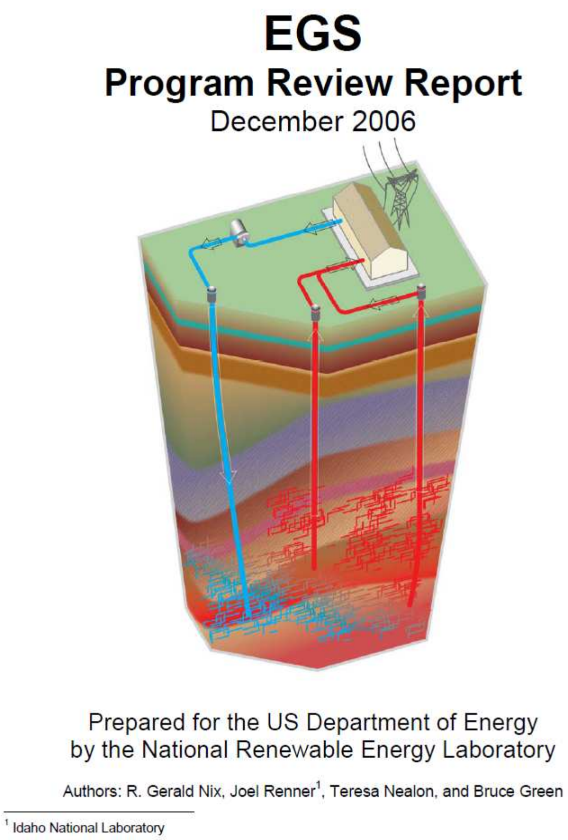
Work in this task focused on the development and demonstration of novel mineral dissolution agents for use in the chemical stimulation of near-well bore geothermal formations. Laboratory-derived data were used to calibrate reactive-transport flow models. Laboratory and numerical simulation studies of calcite and silica dissolution indicate that the combination of sodium hydroxide and the chelating agent nitrilotriacetate (NTA) is effective for simultaneously dissolving amorphous silica and calcite near the well bore.

Field experiments to verify the laboratory findings were conducted at the Coso, California, and Soultz, France, geothermal fields. On 16 June 2006, 15,000 gal of a 10 wt% solution of NTA was injected into Coso producer well 32A-20, which had recently failed due to calcite deposition. Electric output of the well recovered to the same level as it was at the beginning stage of production. These experiments indicate that NTA can be an effective chemical agent for the dissolution of well bore calcite.

Comparison between various parameters and costs for calcite dissolution experiments using NTA and HCl indicates the use of NTA can be more cost effective, when the entire test costs are compared.

Experiments at the Soultz-sous-Forêt geothermal field in France are continuing.

3.3 Highlights of Annex III Programme Work for 2006



DOE funded research related to the application of conventional geothermal technology as well as EGS specific research is summarized in "EGS Program Review" (http://www1.eere.energy.gov/geothermal/egs_prog_review.html.).

3.4 Work Planned for 2007

3.4.1 Task B- Task B- Application of Conventional Geothermal Technology to EGS

Most of the DOE research will be completed by the end of September 2007.

3.4.2 Task C- Data Acquisition and Processing

In 2007, discussion and review of the EGS-PMDA will be performed. There was a strong wish expressed at the Annex III meeting in Nice, France, on 21 March 2007, to have basic information on EGS technology available among the interest groups. Although some of the interest groups in EGS are now private companies/institutions, an exchange of basic information is seen as very important since fundamental R&D work is still needed to bring the EGS technology to a breakthrough.

3.4.3 Task E- Field Studies of EGS Reservoir Performance

Laboratory work will continue to investigate the dissolution of calcite and silica under a wider range of simulated geothermal conditions. After the characterization of each reactant is studied separately, experiments will be conducted with both reactants present within the reactor in order to verify that the dissolution process is unchanged when both minerals are present simultaneously.

Work will continue to complete the analysis of the performance of the chelating agent NTA and other mineral dissolution agents used in the 2006 field experiment at the Soultz-sous-Forêt geothermal field.

3.5 Outputs for 2006

The EGS-PMDA was covered by two presentations in the framework of the launching conference of the European ENGINE program.

Other publications include:

Carlson S. R., J. J. Roberts, L. R. Benedetti, and R. L. Detwiler (2006) Rapid fluid flow experiments in Desert Peak quartz monzonite. *GRC Transaction*, 30, pp.327-332.

Garg S. K., J. W. Pritchett, and J. Combs (2006) Characterization of geothermal reservoir conditions using electrical surveys: some preliminary results. *GRC Transaction*, 30, pp.419-424.

Ghassemi A., and S. Tarasovs (2006) Fracture slip in response to water injection. *GRC Transaction*, 30, pp.333-336.

Ghassemi A. and S. Tarasovs (2006) Fracture slip and opening in response to fluid injection into a geothermal reservoir. *Proceedings, 31st Workshop on Geothermal Reservoir Engineering*, Stanford University SGP-TR-179.

Karner S. L. (2006) Correlating laboratory observations of fracture mechanical properties to hydraulically-induced microseismicity in geothermal reservoirs. *Proceedings, 31st Workshop on Geothermal Reservoir Engineering*, Stanford University SGP-TR-179.

Kovac K. M., T. Xu, K. Pruess, and M.C. Adams (2006) Reactive chemical flow modeling applied to injection in the Coso EGS Experiment. *Proceedings, 31st Workshop on Geothermal Reservoir Engineering*, Stanford University SGP-TR-179.

McLin K.S., K.M. Kovac, J.N. Moore, M.C. Adams, and T. Xu (2006) Modeling the geochemical effects of injection at Coso geothermal field, CA; comparison with field observations. *Proceedings, 31st Workshop on Geothermal Reservoir Engineering*, Stanford University SGP-TR-179.

McLin K. S., J.N. Moore, J. Hulen, J.R. Bowman1, B. Berard (2006) Mineral characterization of scale deposits in injection wells; Coso and Salton Sea geothermal fields, CA. *Proceedings, 31st Workshop on Geothermal Reservoir Engineering*, Stanford University SGP-TR-179.

Maris V., P. Wannamaker, and Y. Sasaki (2006) Three-dimensional inversion of magnetotelluric data on a PC; methodology and applications to the Coso geothermal field. *GRC Transaction*, 30, pp.145-149.

Mella M., K. Kovac, T. Xu, P. Rose, and J. McCulloch (2006) Calcite dissolution in geothermal reservoirs using chelants. *GRC Transaction*, 30, pp.347-351.

Mella M., P. Rose, J. McCulloch, and C. Buck (2006) A Tracer test using ethanol as a two-phase tracer and 2-naphthalene sulfonate as a liquid-phase tracer at the Coso geothermal field. *GRC Transaction*, 30, pp.919-921.

Mella M., P. Rose, M. Adams, N. Dahdah, J. McCulloch, and C. Buck (2006) The Use of n-propanol as a tracer at the site of the Coso engineered geothermal system. *Proceedings, 31st Workshop on Geothermal Reservoir Engineering*, Stanford University SGP-TR-179.

Moller N., C. Christov and J. Weare (2006) Thermodynamic models of aluminum silicate minerals solubility for application to enhanced geothermal systems. *Proceedings, 31st Workshop on Geothermal Reservoir Engineering*, Stanford University SGP-TR-179.

Nicholas C., N.C. Davatzes and S. H. Hickman (2006) Stress and faulting in the Coso geothermal filed: update and recent results from the East Flank and Coso Wash, *Proceedings, 31st Workshop on Geothermal Reservoir Engineering*, Stanford University SGP-TR-179.

Park J., D. Norman, K. McLin, and J. Moore (2006) Modeling amorphous silica precipitation near Coso injection wells. *Proceedings, 31st Workshop on Geothermal Reservoir Engineering*, Stanford University SGP-TR-179.

Pritchett J. W. (2006) Using electrical survey techniques to identify drilling targets in basin and range geothermal prospects. *GRC Transaction*, 30, pp.453-457.

Pruess K. and M. Azaroual (2006) On the feasibility of using supercritical CO_2 as heat transmission fluid in an engineered hot dry rock geothermal system. *Proceedings, 31st Workshop on Geothermal Reservoir Engineering*, Stanford University SGP-TR-179.

Rose P., M. Mella, and J. McCullough (2006) A Comparison of hydraulic stimulation experiments at the Soultz, France and Coso, California engineered geothermal systems. *Proceedings, 31st Workshop on Geothermal Reservoir Engineering*, Stanford University SGP-TR-179.

Tang C., J. A. Ria, and J. M. Lees (2006) Shear-wave splitting: a diagnostic tool to monitor fluid pressure in geothermal fields. *Proceedings, 31st Workshop on Geothermal Reservoir Engineering*, Stanford University SGP-TR-179.

Wannamaker P. E., W. M. Doerner, and D. P. Hasterok (2006) Cryptic faulting and multi-scale geothermal fluid connections in the Dixie Valley- Central Nevada Seismic Belt Area, implications from MT resistivity surveying. *Proceedings, 31st Workshop on Geothermal Reservoir Engineering*, Stanford University SGP-TR-179.

Wannamaker P. E., D. P. Hasterok, and W. M. Doerner (2006) Possible magmatic input to the Dixie Valley geothermal field, and implications for district-scale resource exploration, inferred from magnetotelluric (MT) resistivity surveying. *GRC Transaction*, 30, pp.471-475.

Weijers L., P. E. Van Dyke, and A. Robertson-Tait (2006) Creating extensive and complex fracture networks for enhanced geothermal systems: an overview of oilfield stimulation and diversion techniques. *GRC Transaction*, 30, pp.367-373.

3.6 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/

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IEA GEOTHERMAL R&D PROGRAMME

Chapter 4

Annex IV- Deep Geothermal Resources

Production test at Groß Schönebeck, Germany (from Huenges, *et al.*, 2006).

4.0 Introduction

The Deep Geothermal Resources Annex began as one of the original Annexes in 1997. It was initiated as a four-year international collaborative program under the IEA Geothermal Implementing Agreement. In 2001, the GIA Executive Committee approved the continuation of this Annex to 2006. Review of Annex VI activities in 2006 resulted in its closure.

The aim of the Deep Geothermal Resources Annex was to address the issues associated with commercial development of deep geothermal resources at depths greater than 3,000 m.

Activity in this Annex declined considerably since 2003, with the only major projects pursued in 2006 being the joint effort at Soultz-sous-Forêt (an EC project in Alsace, France) and those in Germany. This situation evolved as a consequence of a growing "overlap" of Annex IV investigations with those in Annexes III and VII.

The work of Annex IV was very closely related to that of Annex III (EGS) because enhanced geothermal systems studies are being pursued in several regions where the desired high temperatures are reached at much greater depths (> 4,000 m) than in the "normal" high-temperature geothermal fields. Also, the major work in Annex IV began to concentrate on the "creation" of geothermal reservoirs at depths greater than 3,000 m, e.g. the application of EGS to create deep geothermal resources in Germany's sedimentary basins. In addition, studies associated with "drilling and logging technology" for deep geothermal resources moved into the realm of Annex VII. The effect of this evolution was a decline in Annex IV activities, with a concurrent growth in those of Annexes III and VII.

As a result, the ExCo officially decided at its 16th Meeting, held on 7-8 September 2006, that since 2006 was the last year of the Annex's current term, it was appropriate to close it and transfer the remaining continuing investigations appropriately into other Annexes. The final decisions on which Annexes the continuing Annex IV activities will be moved to are being considered by the ExCo and Annex Leaders.

During 2006, only Germany actively participated in Annex I.

The Operating Agent for Annex IV is Forschungszentrum Jülich GmbH, Germany. The Task Leaders for 2006 were Dieter Rathjen and Lothar Wissing.

4.1 Tasks of Annex VII

The investigations in this Annex were divided into three subtasks.

4.1.1 Task A- Exploration Technology and Reservoir Engineering

The objective of Subtask A is to carry out collaborative research on exploration technology, including geothermal modelling; geophysical, geological and geochemical exploration; and on reservoir engineering, including reservoir characterization and reservoir modelling.

4.1.2 Task B- Drilling and Logging Technology

The objective of Subtask B is to carry out collaborative research on drilling and logging technologies, including the reviews of drilling and logging reports of deep geothermal wells; and exchange of information on improvements in drilling and logging tools.

4.1.3 Task C- Reservoir Evaluation

Subtask C seeks to exchange experience on materials and chemistries among the group. Published and unpublished information is gathered on past, present and planned experiences, and tests and research on materials in deep and aggressive geothermal systems. The information is then summarized in a database.

4.2 Work Performed in 2006

4.2.1 Germany

The most significant work was conducted in the North German Basin on the Groß Schönebeck project and at Landau.

- **Groß Schönebeck**

The Groß Schönebeck study is part of an interdisciplinary project that seeks to develop geothermal technologies required for extracting hot fluids (> 100 ºC) at rates (> 50 t/h) sufficient to economically generate electricity in sedimentary basins. The goal is to build a geothermal power demonstration plant that will run a 750 kW binary generator and demonstrate sustainable production. The initial results from this ongoing investigation were described in the 2004 and 2005 GIA Annual Reports. In 2006, the second well was drilled to a depth of ~ 4,200 m and there are plans to conduct stimulation tests in 2007.

- **Landau**

The second borehole was completed in 2006 to a depth of 3,170 m, and stimulation tests between the first and second boreholes were successful. A binary ORC plant was ordered, with plans to install it in 2007.

4.2.2 EC Soultz-sous-Forêt (Alsace, France)

Germany continued its participation on the European Soultz-sous-Forêts project in 2006, working with France, Italy, Switzerland and the EC to develop a scientific geothermal pilot plant.

4.3 Work Planned for 2007

None, since the Annex has been closed.

4.4 References

Huenges, E., Saadat, A., Brandt, W., Legarth, B., Tischner, T., Moeck, I., Holl, H., Zimmermann, G. (2006) Current status of the EGS Groß Schönebeck project within the North German Basin: main achievements and perspectives. Presentation made at 16th GIA Executive Committee Meeting held in Paris, France, 16-17 March 2006.

4.5 Websites Related to Annex IV Work

Germany

- Bad Urach project: http://www.geotermie.de/bad_urach.htm
- EU-Project in Soultz-sous-Forêts: www.Soultz.net
- Federal Institut for Geosciences and Natural Resources in Hannover, Germany: www.bgr.bund.de
- Federal Ministry for the Environment, Nature Conservation and Nuclear Safety: www.bmu.bund.de
- Forschungszentrum Jülich, Project Management: www.fz-juelich.de/ptj/
- GeoForschungsZentrum Potsdam, GFZ: www.gfz-potsdam.de
- GeneSys-Project, Germany: http://www.bgr.de/
- Germany's Resources: http://www.tab.fzk.de/
- Institut für Energetik Leipzig: www.ie-leipzig.de

EC Soultz-sous-Forêts (Alsace, France)

- Soultz European HDR Project: http://www.soultz.net/

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IEA GEOTHERMAL R&D PROGRAMME

Chapter 5

Annex VII- Advanced Geothermal Drilling Technology

Drilling the Magma Energy exploratory well in 1989 at Long Valley, California, USA, showing the 26-inch bit with the 36-inch hole-opener above it (courtesy of John Finger).

5.0 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 Task will address aspects of geothermal well construction, which include:

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

The objectives of the Advanced Geothermal Drilling Annex are:

- 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 (Sandia National Laboratories, USA) is the Annex Leader.

5.1 Tasks of Annex VII

Annex VII has three Subtasks, described below. As specified in the Annex VII Charter, all Participants in the Annex are considered to participate in all Subtasks.

5.1.1 Task A- Compile Geothermal Well Drilling cost and Performance Information
(Task Leader: Jaime Vaca, Comisión Federal de Electridad (CFE), Mexico)

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

5.1.2 Task B- Identification and Publication of "Best Practices" for Geothermal Drilling (Task Leader-High Temperature Drilling: Jaime Vaca, Comisión Federal de Electridad (CFE), Mexico)

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.

5.1.3 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.

5.2 Work Performed in 2006

5.2.1 General

- Completed IEA-GIA Annex VII Contribution for GIA End of 2nd Term (2002-2007) Report
- Completed written reports for spring and autumn Annex VII meetings held in association with the ExCo Meetings

5.2.2 Review of Annex VII Activities as Discussed at Spring Annex Meeting (Paris, France)

Parties interested in Annex VII of the IEA Geothermal Implementing Agreement met at the IEA Headquarters, Paris, France on 15 March 2006.

Key Points from Meeting:

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

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

A costing database system is being developed by CFE. The system is spreadsheet based and includes details of cost components of wells as planned and constructed. New CFE wells will be incorporated into the database system first (about 36 for this year and the next 1-2 years), and older wells will be entered into the database in time. A progress report was to be presented at the September meeting.

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

The outline for the Handbook was finalized, and has been placed on the web, commented upon internationally, and responded to. The outline was fleshed out; case histories are to be collected, in part being solicited through web. A draft was to be presented at September meeting.

5.2.2.3 Task C- Advanced Drilling Collaboration

Requests for collaboration have been received; and were discussed, and information exchanged between principal investigators.

Roy Baria, representing the Soultz HDR Project, visited Sandia National Laboratories in January 2006 and presented a talk: *Current Status of EGS Technology with a Particular Reference to the European HDR Programme*. An information exchange took place pertinent to the geophysical response observed during the Soultz injection testing.

A Geothermal Research Session was organized at the American Rock Mechanics Association Annual Meeting held in June 2006, at Golden, Colorado, USA.

5.2.2.4 Meetings Announced

High Temperature Electronics Conference **(HiTEC 2006)**, sponsored by the International Microelectronics and Packaging Society (IMAPS); the U.S. Air Force Research Laboratory, WPAFB; and Sandia National Laboratories. To be held on 15-18 May 2006, in Santa Fe, NM, USA. Contact was: Randy Norman (Sandia National Laboratories); contact: ranorma@sandia.gov.

ENhanced Geothermal Innovative Network for Europe **(ENGINE**, **http://engine.brgm.fr)** is a co-ordination action supported by the 6th Research and Development framework of the European Union. The main objective is a co-ordination of the present European research and development initiatives for **Unconventional Geothermal Resources** and **Enhanced Geothermal Systems**, from resource investigation and assessment stage through to exploitation monitoring.

5.2.2.5 Technical and Programme Presentations

Three presentations were made during the spring Annex VII Meeting in the spirit of fostering international communications and technology sharing:

- *European Union Program: ENGINE* presented by S. Thorhallsson, Iceland GeoSurvey
- *Downhole Motors and Ideas Concerning Geothermal Drilling* presented by Evgeny Murtola, Swiss Federal Institute of Technology (ETH)
- *Current Direction of Sandia's Drilling Research Efforts* presented by S. Bauer, SNL, USA

5.2.3 Review of Annex VII Activities as Discussed at Autumn Annex Meeting (San Diego, USA)

Key Points from Meeting:

- Annex meeting attendees: Barry Goldstein (Australia), Mike Malavazos (Australia); Adrian Larking (Green Rock Energy), Doone Wyborn (Geodynamics); Lothar Wissing (Germany); Yoonho Song (Korea); Jaime Vaca (Mexico), David Nieva (Mexico); Chris Bromley (New Zealand); Lucien Bronicki (Ormat Technologies), Matlick (Ormat Technologies); Ladsi Rybach (Switzerland); Allan Jelacic (United States), Steve Bauer (United States), Douglas Blankenship (United States), Randy Normann (United States).
- Each task was discussed, with a view towards maintaining a substantive path forward

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

Jaime Vaca presided. The Costing Database system being developed by CFE (includes data for the first 9 wells of 30) was presented by Jaime Vaca. The database will incorporate older wells in time. Jaime Vaca also presented a Cost Model. Ormat has shared recent well cost data. The database of well data has been significantly expanded with this new information.

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

Jaime Vaca presided. The Handbook Outline has been finalized. The magnitude of task of completing the draft realized, as such, the draft has not been completed as planned. Significant contributions relative to Mexico have been submitted.

5.2.3.3 Task C- Advanced Drilling Collaboration

Steve Bauer presided. Requests for collaboration were received and discussed, and information was exchanged between principal investigators.

5.2.3.4 Meetings Participated In

- A Geothermal Research Session was organized and held at American Rock Mechanics Association Annual meeting 2006.

- The High Temperature Electronics Conference (HiTEC 2006), sponsored by International Microelectronics and Packaging Society (IMAPS), the U.S. Air Force Research Laboratory, WPAFB and Sandia National Laboratories was held on 15-18 May 2006. The co-organizer was Randy Norman: ranorma@sandia.gov.

- The European Union Program *ENGINE* (http://engine.brgm.fr) workshop was attended by some Annex VII participants. A link from the IEA-GIA website to the *ENGINE* website was setup.

5.2.3.5 Technical and Programme Presentations

Three presentations were made during the autumn Annex VII Meeting in the spirit of fostering international communications and technology sharing:

- *Diagnostics while Drilling and Advances in Rock Reduction Methods* by Douglas Blankenship, Sandia National Laboratories.

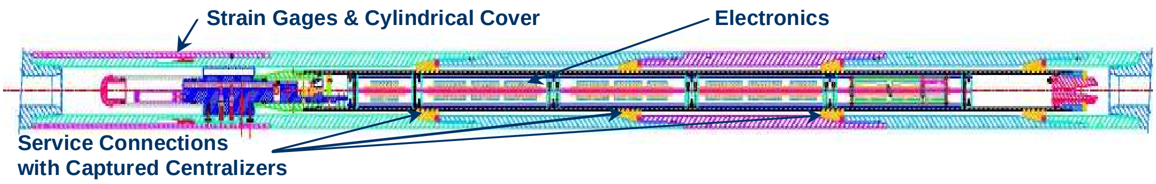


Figure 5.2 Diagnostics while drilling measurement sub featuring bottom hole assembly dynamics measurements of weight on bit, torque on bit, 2-axis bending, 3-axis acceleration, rotary speed (magnetometers), pipe and annulus pressure and temperature and high-temperature electronics (225 °C sustained operation).

- *Cost Model Geothermal Wells Project (Cerro Prieto Geothermal Field Case)* by Jaime Vaca, CFE (Mexico).

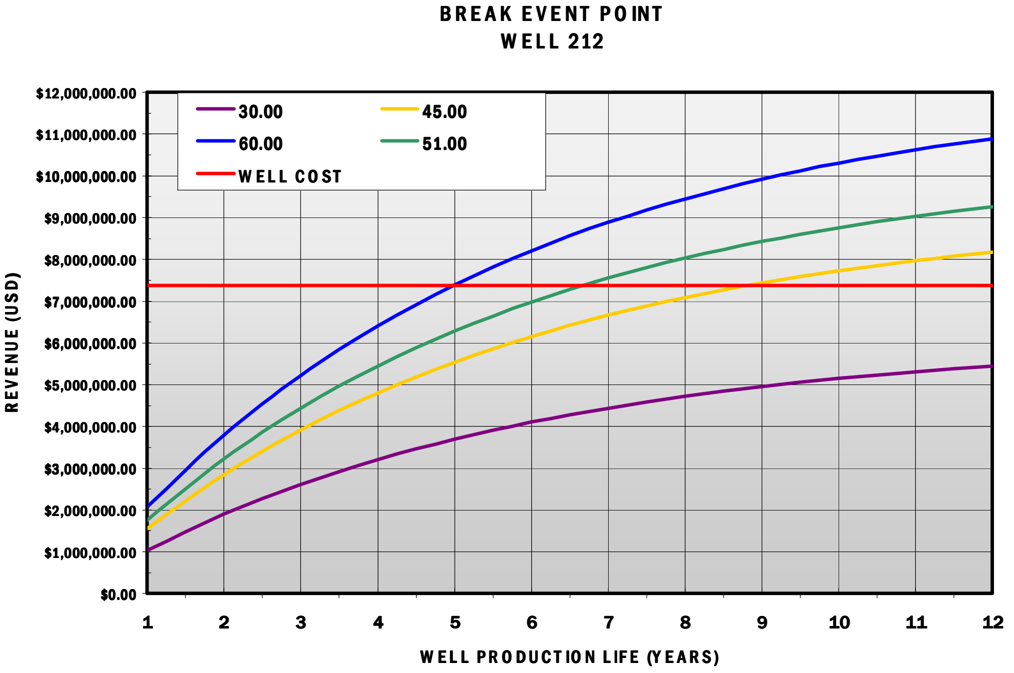
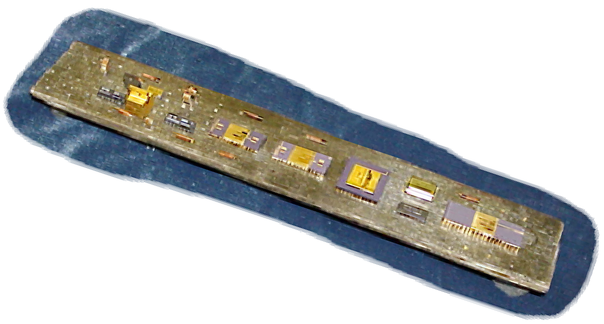


Figure 5.1 Example of well cost versus production for Cierro Prieto well.

- *High Temperature Electronics: Tools, Techniques and Perspectives on the Future* by Randy Normann, Sandia National Laboratories.



(a) (b)

Figure 5.3 (a) 315 °C microprocessor circuit on ceramic board; (b) solid-state, explosion-proof, 25-350 °C battery technology.

The meeting ended with a general discussion on "Thoughts for the Future". The following continuing issues facing geothermal drilling were identified with requests for them to be addressed: (1) Drilling in hard hot rock (better bits?); (2) Drilling in deep in granitic basement; and (3) Flat time.

5.3 Highlights of Annex VII Programme Work for 2006

- Progress in each of the Tasks was recognized; with the receipt of new well cost data on recent wells identified as important
- The association of *ENGINE* with Annex activities
- The continuation of Annex VII studies as a result the IEA-GIA being extended to 2012

5.4 Work Planned for 2007

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

CFE will continue to solicit performance data from operators. CFE and Annex VII participants will begin to discuss, assimilate and analyze information.

The outputs will consist of a more comprehensive compilation of cost data as it continues to be collected and a report will be made to the GIA Executive Committee.

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

A full draft of the Handbook will be developed for review and comment, and a report produced for the GIA Executive Committee.

5.4.3 Task C- Advanced Drilling Collaboration

International collaborations for technology sharing will be solicited, coordinated, and planned. Examples of possible collaborations include: instrumentation demonstrations and evaluations, information exchanges through visits to foreign sites (ongoing for each year). Organize international exchange programs, possibly in association with other international travel activities, for information exchange and sharing. The results will be reported to the GIA Executive Committee.

5.5 Outputs for 2007

Results from Annex VII studies were presented at three meetings:

- *High Temperature Electronics Conference* (HiTEC 2006), Santa Fe, New Mexico, USA
- *ENhanced Geothermal Innovative Network for Europe (ENGINE)*
- Geothermal Research Council Annual Meeting 2006, San Diego, California, USA

Publications for 2006 included:

Blankenship, D. A. (2006) Development of a high-temperature diagnostics-while-drilling system. *DEA Workshop*, Galveston TX, USA.

Blankenship, D.A., J.A. Henfling, A.J. Mansure, R.D. Jacobson, S.D. Knudsen, and D.J. Chavira (2006) High-temperature diagnostics-while-drilling system. *Transactions Geothermal Resources Council, Vol 30. 2006 Annual Meeting,* September 11-13. San Diego, USA. (CD).

Boro, H., and G.E. Melosh (2006) Application of real-time digital rig data to wellbore stability at Awibengkok geothermal field, West Java, Indonesia. *Transactions Geothermal Resources Council, Vol 30. 2006 Annual Meeting,* September 11-13. San Diego, USA. (CD).

Garcia-Gutierrez, A., E. Santoyo, and and G. Espinosa (2006) Non-Newtonian convective heat transfer coefficients of Newtonian geothermal drilling fluids. *Transactions Geothermal Resources Council, Vol 30. 2006 Annual Meeting,* September 11-13. San Diego, USA. (CD).

Henfling, J. A. (2006) Development of a HT diagnostics-while-drilling (DWD) tool. *High-Temperature Electronics Conference,* Santa Fe, NM USA.

Jaimes-Maldonado, J.G., and S. Cornejo Castro (2006) Case study: underbalanced or mud drilling fluids at Tres Virgenes geothermal field. *Transactions Geothermal Resources Council, Vol 30. 2006 Annual Meeting*, September 11-13. San Diego, USA. (CD).

Knudsen, S.D. (2006) Conformal coatings for 225° C applications. *High-Temperature Electronics Workshop*, Santa Fe, NM, USA.

Mansure, A.J., S.J. Bauer, B.J. Livesay, and S. Petty (2006) Geothermal well cost analyses 2006. *Transactions Geothermal Resources Council, Vol 30. 2006 Annual Meeting,* September 11-13. San Diego, USA. (CD).

Normann, R.A., D.A. Blankenship, A.J. Mansure, J.A. Henfling, S.D. Knudsen, and D.J. Chavira, (2006) Applications for HT power electronic systems within the drilling industry. *2006 SAE Power Systems Conference*, New Orleans LA, USA.

Normann, R.A. (2006) 225ºC MWD tool electronics including HT batteries. *DEA Workshop*, Galveston TX, USA.

Normann, R.A. (2006) Update: high-temperature electronics and testing. *Drilling Engineering Association 4th Quarter 2006 Meeting*, Houston, TX, USA.

Philippacopoulos, A.J., P. Gutierrez, L. Capuano, and M. Berndt (2006) Structural integrity of well cements. *Transactions Geothermal Resources Council, Vol 30. 2006 Annual Meeting,* September 11-13. San Diego, USA. (CD).

Raymond, D.W. (2006) Advanced drilling dynamics simulator. *Drilling Engineering Assoc. Quarterly Meeting,* Houston, TX, USA.

Raymond, D.W., J.W. Grossman, G. Chahine, K. Glass, A. Black, and K. Bertagnolli (2006) Development and testing of a PDC bit with passively pulsating cavitating nozzles. *Transactions Geothermal Resources Council, Vol 30. 2006 Annual Meeting,* September 11-13. San Diego, USA. (CD).

Raymond, D.W. (2006) Laboratory simulation of drill bit dynamics. *DEA Workshop*, Galveston TX. USA.

Salazar-Mendoza, R., and A. Garcia-Gutierrez (2006) Results from the averaging model for cuttings transport in horizontal drilling. *Transactions Geothermal Resources Council, Vol 30. 2006 Annual Meeting*, September 11-13. San Diego, USA. (CD).

Spielman, P., R. Hernandez, and H. Nguyen (2006) Reverse circulation of foamed cement in geothermal wells. *Transactions Geothermal Resources Council, Vol 30. 2006 Annual Meeting*, September 11-13. San Diego, USA. (CD).

Speilman, P., W. Rickard, and W. Teplow (2006) Puna geothermal venture, Hawaii – 2005 drilling program. *Transactions Geothermal Resources Council, Vol 30. 2006 Annual Meeting*, September 11-13. San Diego, USA. (CD).

Tuttle, J.D. (2006) Recent developments: drilling fluids and cement additives. *Transactions Geothermal Resources Council, Vol 30. 2006 Annual Meeting*, September 11-13. San Diego, USA. (CD).

5.6 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 6

Annex VIII- Direct Use of Geothermal Energy

The Pearl in Reykjavik. Hot water storage tanks with a restaurant on the top (courtesy Einar Gunnlaugsson).

6.0 Introduction

The Direct Use of Geothermal Energy Annex was initiated on 19 September 2003, when the agreement entered into force.

Geothermal energy can be used directly as heat for many applications such as building and district heating, industrial process heating, commercial uses such as greenhouse heating and temperature control of water for fish farming, bathing and swimming, and many other purposes. Many applications are well developed and are economically viable, while others are challenged by implementation difficulties and unfavourable economics. The Direct Use Annex will address all aspects of the technology with emphasis on improving implementation, reducing costs and enhancing use.

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

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.

6.1 Tasks of Annex VII

There are five tasks defined for this Annex. Work has started for four of these tasks.

6.1.1 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.

6.1.2 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.

6.1.3 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.

6.1.4 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.

6.1.5 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.

6.1.6 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

6.2 Work Performed in 2006

An Annex VIII meeting was held on 6 September 2006, at Town and Country Resort & Convention Center, San Diego, in association with the 16th GIA ExCo Meeting. Participants from all the countries except USA attended the meeting. The work conducted is reported by Task.

6.2.1 Task A- Resource Characterization (Temperature and Chemistry)

Data on temperature of the geothermal manifestations and chemistry from Korea, Iceland, Japan and New Zealand had been collected and a first evaluation made. The results show that differences in chemistry are related to the different rock types and geological environments.

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

A questionnaire was prepared and distributed to participating Members. The data was evaluated and results presented at the meeting.

6.2.3 Task E- Design Configuration (Engineering Standards)

The collection of available information has begun.

6.3 Work Planned for 2007

6.3.1 Task A- Resource Characterization (Temperature and Chemistry)

More data will be made available from New Zealand, Switzerland and the USA. The data evaluation will continue.

6.3.2 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 (possibly Australia, France and Poland) join, they will complete the questionnaire and this new data will be compiled.

6.3.3 Task E- Design Configuration (Engineering Standards)

Collection of available descriptions will continue and be listed, regardless of language.

6.3.4 Expected Outputs for 2007

A simple standardized database will be identified that can be used to show the direct use applications by each of the participating countries.

An Annex VIII meeting is scheduled in association with the 17th ExCo Meeting to be held in March 2007.

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NATIONAL & INDUSTRY ACTIVITIES

Chapter 7

A Synopsis of National and Industry Activities

6th power plant unit (30 MW_e) at Svartsengi, Iceland (photograph by Oddgeir Karlsson, permission of Albert Albertsson, Hitaveita Suðurnesja)

7.0 Introduction

This chapter is based on the EC, national and industry reports presented in Chapters 8-18 and 19-21, respectively. It provides a synopsis of the geothermal state of affairs in the Member Countries and the EC, and introduces the three new Sponsor Members who joined in 2006. 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 status of geothermal installed capacity and electricity generated in the Member Countries and the EC in 2006 are provided in Table 7.1, and the geothermal direct use installed capacity and energy used are presented in Table 7.2. Estimates of equivalent fuel oil savings and avoided CO_2 emissions are presented in Table 7.3.

7.1 The Context

Geothermal energy is used for the generation of electricity and for direct heat applications such as district and space heating, agricultural drying, industrial processes, green house and aquaculture pond heating, bathing and swimming, and snow melting. In 2005, electricity was being generated from geothermal resources in 24 countries, with a total installed capacity in excess of 8,900 MW_e

generating about 54,330 GWh/y (generation data from Bertani (2005), revised using 2005 GIA data for Iceland and USA). Geothermal energy provided an average of about 8.9% of national capacity and 11.0 % of national generation in those 18 countries with non-negligible development, or approximately 0.3% of the 18,235 TWh of electricity generated worldwide in 2005 (IEA, 2007a). Though worldwide geothermal capacity grew relatively steadily, at about 200 MW_e/y (Figure ES1) for the 25-year period 1980-2005; growth has begun to accelerate in the past few years.

In 2006, GIA country members had over 6,000 MW_e of installed capacity and generated about 37,205 GWh/y (Table 7.1), or about 67% and 68% of total global geothermal capacity and generation relative to 2005 values, respectively. Geothermal contributed an average of about 5.7% of Member's national capacity and 6.6% of their generation.

Table 7.1 Geothermal power installed capacity and electricity generation in GIA Member Countries and EC for 2006.

Country	Installed Capacity [MW_e]	Annual Electricity Generated [GWh/y]	% of National Capacity	% of National Energy
Australia	0.12	0.7	Negligible	Negligible
EC[a]	855	5,693[b]	-	-
Germany	0.15	0.2	Negligible	Negligible
Iceland	422	2,631	24.9	26.5
Italy	810	5,200	1.0	1.9
Japan[¶]	534.24	3,228	0.2	0.3
Mexico	953	6,685	2.2	3
New Zealand*	450	3,210	5.5	7.6
USA	2,831	16,250	0.3	0.4
Total[d]	**6,000**	**37,205**	**5.7[c]**	**6.6[c]**

[a] Does not include Iceland; [b] Estimate using Italy Country Report and Bertani (2005); [c] Average % of 6 GIA Member Countries with non-negligible generation; [d] Totals exclude EC values; [¶] Year to March 2006; * 2005 data

There is considerable potential for growth in geothermal electricity generation using both conventional and EGS techniques. Considering the mounting interest in geothermal as a renewable energy resource and the recent acceleration in its development, it is possible that several percent of the total global electricity could be provided with geothermal energy by 2020.

As stated above, geothermal energy is used in a wide variety of direct heat applications. This diversity and especially the very large individual use in the lower temperature range (heat pumps, space heating, hot pools, *etc*.) make it very difficult to obtain complete/accurate estimates of installed capacity and utilization on an annual basis. The most accurate data are especially collected and published for the World Geothermal Congresses which are held every 5 years, with the most recent held in 2005. In 2005, the installed thermal power was estimated to be about 28,269 MW_{th}, with 72 countries reporting the use of 273,372 TJ/y, or 75,940 GWh/y (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). This significant growth is expected to continue well into the future, especially with the rapid worldwide expansion in the use of geothermal heat pumps.

Data for 2006 are reported for GIA members in Table 7.2. In a few cases the data presented are for 2005 (Lund, *et al*., 2005) or has been estimated based on indicative rates of growth. The total installed capacity was about 16,317 MW_{th} with approximately 137,745 TJ/y of energy used.

Comparison with GIA Members' 2005 data: installed capacity > 4,090 MW_{th} and > 69,000 TJ/y, shows extremely large increases in 2006. These increases are predominantly contributed by Japan and the USA, and are due to more comprehensive data collection as well as real growth.

Table 7.2 Geothermal direct use in GIA Member Countries in 2006 (data in parenthesis is for 2005).

Country	Installed Thermal Power (MW_{th})	Annual Energy Used (TJ/y)
Australia	(110)	(2,968)
EC[1]	2,491	16,590[§]
EC[2]	7,329	na
Germany	(505)	6,865
Iceland	(1,844)	25,080
Italy	(607)	8,000
Japan*	3,526	43,232
Mexico	164	(1,932)
New Zealand**	(308)	9,670
Republic of Korea**	32	271
Switzerland	781	5,987
USA***	8,440	33,740
Total for GIA[3]	**16,317**	**137,745**

( ) = from Lund, *et al.* (2005); § Using IEA conversion factor: 1 TJ (heat) = 47.8 toe;
* Year to March 2006; ** 2005; *** Estimated using 8% increase on 2005 values;
1 Excludes Switzerland and Iceland and does not include heat pumps; na = not available
2 Heat pumps only, excludes Switzerland and Iceland; 3 Total excludes the EC.

Table 7.3 Equivalent fuel oil savings and avoided CO_2 emissions in 2006.

Country	Equivalent Fuel Oil Savings (Mtoe)[§, #]			Avoided CO_2 Emissions (Mt)[†, β]		
	Electricity Generation	Direct Use	Total	Electricity Generation	Direct Use	Total
Australia	negligible	0.14	0.14	negligible	0.34	0.34
EC	4.90	0.79[1]	5.69	4.65	1.87[1]	6.52[1]
Germany	negligible	0.33	0.33	negligible	0.78	0.78
Iceland	2.26	1.20	3.46	2.15	2.86	5.01
Italy	4.47	0.38	4.85	4.25	0.91	5.16
Japan*	2.78	2.07	4.85	2.64	4.93	7.57
Mexico	5.75	0.09	5.88	5.46	0.22	5.68
New Zealand	2.76	0.46	3.22	2.62	1.10	3.72
Republic of Korea	0	0.01	0.01	0	0.03	0.03
Switzerland	0	0.29	0.29	0	0.68	0.68
USA	14.0	1.61	15.6	13.3	3.85	17.2
Total for GIA[2]	**32.0**	**6.58**	**38.6**	**30.4**	**15.7**	**46.2**

* Year to March 2006; 1 Excluding geothermal heat pumps; 2 Total excludes the EC
§ IEA conversion for electricity generation: 1 GWh = 0.00086 Mtoe (IEA, 2007b)
# IEA conversion for direct use: 1 TJ = 47.8 toe (*ibid.*)
† GIA conversion for electricity assuming oil thermal power plants: 1 GWh = 817,000 kg CO_2 (Mongillo, 2005)
β GIA conversion for direct use assuming oil thermal power plants: 1 TJ = 113,610 kg CO_2 (*ibid.*)

In 2006, the GIA Member Countries are estimated to have saved the equivalent of approximately 39 Mtoe and avoided about 46 Mt of CO_2 emissions, assuming total fuel oil replacement (Table 7.3). Note that the values provided in Table 7.3 were calculated from the data in Tables 7.1 and 7.2 using the IEA conversion factors for equivalent fuel oil savings and the GIA conversions for avoided CO_2 emissions (Mongillo, 2005) for the sake of uniformity.

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

To maximize these benefits, barriers to the development of geothermal energy must be overcome. This requires an improvement in the understanding of the environmental benefits and how to avoid or minimize the drawbacks; the ability to better characterize geothermal resources; the improvement of technologies for the use of geothermal energy; and the distribution of information about geothermal energy and its benefits to governments, industry, the utilities and financial communities; and the general public. Success in these endeavours will make geothermal development more cost-effective, help it acquire a larger part of the marketplace and increase its use.

7.2 Review and Highlights of National Activities

7.2.1 Australia

Australia's geothermal generation in 2006 amounted to 0.7 GWh/y from a 120 kW_e binary generator utilizing 98 °C water. However, supportive federal and state government geothermal legislation and funding continue to foster major growing interest in the geothermal sector. At the end of 2006, 16 companies were involved in geothermal investigations in 110 geothermal license areas (a 57% increase since 2005) covering about 62,000 km^2, 90% of which are located in South Australia. The principal geothermal research is aimed at EGS, since current exploration results indicate the necessity for fracture stimulation to create producing geothermal reservoirs. More than US$ 448 M in work programme investment has been committed for 2002-2012, and at the end of 2006, five geothermal exploration companies were listed on the Australian Stock Exchange with a total market capitalization of about US$ 129 M. Federal and state grants amounting to about US$ 3.1 M were awarded to five geothermal companies to progress geothermal exploration and demonstration projects in 2006; and in the term 2000-December 2006, the federal government has awarded US$ 17.6 M to promote progress for commercializing geothermal and associated technologies. Three companies undertook drilling in 2006, with two more planning to drill in 2007. Results are extremely encouraging, ranging from the discovery of anomalous temperature gradients of 50-81 °C/km, to the production of 210 °C water. In 2006, the Australian Geothermal Energy Group (AGEG) was formed with a membership of 29 government agencies, industry and university members that support commercializing Australia's geothermal resources. They also provide financial and intellectual support for Australia's GIA membership.

7.2.2 European Community

The European Union has set legislation for promotion of renewable electricity generation with the objective of producing 21% of the EU15's electricity with renewables by 2010. In 2006, the EC also recognized the importance of heating and cooling with renewable energy, and began an impact assessment. There are few countries within the EU with the high temperature geothermal resources required to generate geothermal power using conventional means. In 2006, the EU had an electrical installed capacity of about 855 MW_e, generating a total of about 5,693 GWh/y. Italy was the major contributor, with 810 MW_e (95%) and the remainder from Portugal (the Azores), France (Guadeloupe), Germany and Austria (note that Iceland is not an EU member). The installed thermal capacity for the 25 EU countries was about 9,820 MW_{th}, of which 7,329 MW_{th} was from geothermal heat pumps. The EU is one of the major groups of countries to have developed heat pump technology, with the EU25 estimated to have about 600,000 units installed, equivalent to about 7,328 MW_{th}. In 2006, one new geothermal project was selected for EC support: HITI, or High Temperature Tools and Instruments, aims to develop geophysical and geochemical sensors and methods to operate at up to critical temperature (> 380 °C). The EGS pilot plant at Soultz-sous-Forêts is proceeding, with the goal of bringing a 1 MW_e scientific pilot plant on line by the end of 2007; then increasing production to 4-5 MW_e within the following year.

7.2.3 Germany

The German Federal Government has set the goal of renewable energies contributing 12.5% of the gross electricity consumption by 2010 as part of their strategy for sustainable development. The use of geothermal energy for power generation began in Germany at the end of 2003, and about 0.2 GWh/y was generated in 2006. The relatively favourable geothermal conditions found in the Upper Rhine Valley and the Fore Alp Region (Munich) make these areas of interest for future geothermal development. The project at Unterhaching is proceeding well; with temperatures of about 120 °C and flow rates of 100-150 l/s obtained, the plant is expected to produce up to 3.35 MW_e and 28 MW_{th} of heat. Projects like that at Landau also look very positive, and with their success demonstrating the feasibility of exploiting deep geothermal in Germany, about 80 projects with a total investment of 80 billion € could proceed in Bavaria. The use of geothermal heat pumps is also growing very rapidly in Germany, and in 2006 more than 24,000 were installed, bringing the total to about 100,000 units for private and commercial use. Government funding for geothermal projects has continued to increase, with about 14.0 M€ provided in 2006.

7.2.4 Iceland

Iceland’s location on the mid-Atlantic Ridge endows it with abundant geothermal resources, and over 50% of the primary energy supply in the country is provided by them. In 2006, geothermal energy provided about 25,080 TJ/y for direct use applications, including space heating to almost 90% of all of Iceland’s homes. There has been an expansion in energy intensive industry that has increased electricity demand, and led to the construction of two new geothermal power stations (total capacity of 180 MW_e), both of which began production in mid-2006. These developments are cost competitive with hydro. In 2006, the total installed capacity in Iceland was 422 MW_e and 2,631 GWh/y was generated. There has also been a government supported effort to investigate geothermal potential in areas previously identified as “cold regions”, with success leading to the implementation of a geothermal heating system in a small town in west Iceland. Geothermal research is focussing on categorizing known high temperature geothermal areas for future electricity development and exploration is being conducted to locate geothermal resources near districts without space heating. A consortium of Icelandic companies has begun the Iceland Deep Drilling Project (IDDP), a research project aimed at drilling to depths of 4-5 km to investigate the economic feasibility of extracting energy and chemicals from supercritical hydrous fluids (temperatures of 400-600 ºC). Iceland’s United Nations University geothermal school continued with high demand, and a new international student program (in English) in sustainable energy will begin at the University of Akureyri in 2007.

7.2.5 Italy

Italy has the longest history of geothermal power generation in the world, beginning at Larderello in 1913. In 2006, Italy had an installed capacity of 810 MW_e and generated almost 5,200 GWh/y. All geothermal development is located in Tuscany, where it meets 25% of the demand, or 1.9% for the entire country. Italy also uses geothermal for providing direct heat for spas, space and district heating, greenhouses and fish farming, and in 2006 it supplied about 8,000 TJ/y. About 36,000 t/y of CO_2 were also produced from a geothermal well for use in the food industry. Two of Enel's innovative AMIS H_2S and Hg abatement plants were installed in 2006 in the Larderello area. In agreement with the European Directive for promoting the use of renewable resources for electricity generation, Italy provided 2.7% of its electricity using renewables in 2006. A system of Green Certificates also encourages renewable energy generation by making the value of the kWh generated equal to the sum of the base price of the energy (around 5 €-cent/kWh) plus the market value of the Green Certificate, which was 12.5 €-cent/kWh in 2006. These Green Certificates make it feasible to continue geothermal development in Italy. Geothermal research is focused on developing advanced methods for reducing drilling risk and on mitigating corrosion problems in wells and surface plant equipment caused by chlorine present in the steam produced from deep wells. Italy is involved in several geothermal exploration and development programs in Central and South America and in the USA.

7.2.6 Japan

Japan has major geothermal resources; though their development has experienced difficulties over the past several years. Power development has been slowed because of resource location within or near national parks and because of concern about possible effects on the many developed hot spring resort areas. In addition, geothermal energy was removed from the category of "new energy" in 1997, so lost a variety of incentives available for other renewables. Finally, in 2003, the government terminated all R&D projects. Consequently, Japan's geothermal power generation has been steady, with an installed capacity of 534 MW_e and generation of 3,228 GWh/y in 2006. However, the Agency for Natural Resources and Energy (ANRE) and the Ministry of Economy, Trade and Industry (METI) approved the addition of geothermal energy back into the category of "New Energy" in 2006. It is expected that when this becomes legally enacted in 2007, the Japanese geothermal power market will revive. NEDO has adopted two new fields for geothermal investigations as part of its Geothermal Development Promotion Surveys programme that aims to reduce survey risk and thus encourage power generation by the private sector. In addition, a famous hot spring resort area at Kusatsu Town, Gunma Prefecture, won the METI and MOE subsidy for a 1 MW_e hot spring power development project. Japan is continuing its active international geothermal development program with the 2006 commencement of a Master Plan Study for Geothermal Power Development in Indonesia.

7.2.7 Republic of Korea

The geothermal resources identified in Korea to date have been the lower temperature variety, mostly hot springs associated with localized, deeply connected fracture systems. However, recent studies have identified a high heat flow anomaly in the southeast of the country where the Pohang geothermal programme is being conducted. A production well drilled here in 2006 reached a depth of 2,383 m and had a bottom hole temperature > 90 °C. In addition, a proof-of-concept study involving the use a groundwater source heat pump connected to a river bank infiltration municipal water supply pipeline is currently proceeding. Though low temperature geothermal utilization has only recently started in Korea, government and industry efforts for R&D and encouragement of geothermal use are increasing. The government expenditure on geothermal R&D in 2006 reached about US$ 7 M, with industry spending an additional US$ 1.15 M. There is also a strong government subsidy programme for renewable energy, which provided US$ 11.8 M for heat pump installations in 2006, twice that for 2005. This support has greatly assisted the rapid growth in the use of geothermal heat pumps, with the number of installations and energy used doubling every year.

7.2.8 Mexico

Geothermal development for electricity production began at the Pathé field in 1959. In 2006, Mexico had the world's third largest geothermal installed capacity, 953 MW_e; and generated 6,685 GWh/y, or about 3% of the nation's total electricity. Currently, several feasibility studies are examining the possibilities for extending Mexico's geothermal production by both replacing some older power plants and adding some new ones, viz: replacing 90 MW_e installed capacity of older units with 125 MW_e of new units at two fields, utilizing the same quantity of steam; and by adding 150 MW_e of new capacity at three existing fields. The government considers geothermal to be a mature technology, so there are no Government support incentives for geothermal development. R&D is mainly focussed on development and exploitation, e.g. an investigation of a hot brine injection system at Cerro Prieto is being pursued.

7.2.9 New Zealand

The geothermal energy scene in New Zealand has become very active recently, with about 1,000 MW_e of additional capacity development looking feasible. Direct heat use has been relatively static, though geothermal heat pumps could undergo considerable growth. In 2006, the installed capacity was about 450 MW_e, or about 5.5% of New Zealand's total capacity. Geothermal generation was about 3,210 GWh/y and provided about 7.6% of total generation. However, there has been a significant increase in industry expenditure on exploration, drilling and development; and New Zealand's two major geothermal operators announced plans to spend about US$ 1.5 billion on near term power projects, of which about US$ 1.5 M/y will be spent on commissioned research. Geothermal direct use has remained relatively steady for the past decade, and amounted to about 9.7 PJ/y in 2005. However, in 2006, a large single direct use installation of 20 MW_{th} was installed for timber drying. Government policies currently encourage increased development of renewable resources, including geothermal energy. Government funded research has remained relatively stable at about US$ 1.5 M/y.

7.2.10 Switzerland

The national *SwissEnergy* programme, which supports renewable energies, provides the supportive framework for geothermal R&D in Switzerland. The Swiss Geothermal Association (SVG), the key player and coordinator for geothermal energy development and use, completed its reorganization in 2006 and now acts as the Swiss Geothermal Competence Center under the label GEOTERMIE CH. Though there is no power generation in Switzerland from geothermal resources, there is significant direct use, which had a total installed capacity of 781 MW_{th} and heat production of 5,987 TJ/y in 2006. Geothermal heat pumps, which contributed 650 MW_{th} and 4,272 TJ/y, continue to grow at about 10%/y. This growth is stimulated by financial support or tax credits. Switzerland is presently developing heat pump quality labels and engineering standards. The DHM (Deep Heat Mining) project in Basel suffered a major setback when it was suspended in December 2006 due to microseismic activity caused as the result of reservoir stimulation by hydraulic fracturing. A seismic risk study must now be conducted before the government can decide whether to continue or to abandon the project. Government funding for geothermal R&D was about 1.0 M CHF (US$ 400,000) in 2006, with industry contributing > US$ 10 M for the DHM Basel project. There were significant efforts in geothermal education and information dissemination through university and technical school courses, special courses, workshops and fieldtrips, with well over 950 participants in total. Switzerland was also very active in international cooperative activities, including several EU R&D programmes.

7.2.11 United States of America

There was a major resurgence in the United States geothermal power industry in 2006. The Geothermal Energy Association reported that over 1,920 MW_e of new capacity was under development in 2006, including projects in their initial development phase. Actual construction on 8 projects in five states amounted to 131 MW_e. This expansion was driven by the federal Production Tax Credits and state Renewable Portfolio Standards. In addition, Alaska's first geothermal power plant went on-line with an installed capacity of 0.4 MW_e. There was further good news with the modification of the Energy Policy Act of 2005, which extended the production tax credit for geothermal to 31 December 2008. A new and more comprehensive survey of US geothermal resources that includes low-temperature resources and technological advances that have occurred in the past 25 years is being conducted by the USGS. A major study of EGS by MIT concluded that with reasonable investment, 100,000 MW_e, or more, of cost-competitive capacity could be provided in the next 50 years. The United States remains the major geothermal developer worldwide, with an operating capacity of 2,831 MW_e and generation of 16,250 GWh/y (0.4% of US total) in 2006. Direct use continues to grow, with estimates for 2006, including geothermal heat pumps, indicating an installed capacity of > 8,440 MW_{th} and use in excess of about 33,740 TJ/y. Geothermal heat pumps dominate geothermal direct use, contributing about 73% of the energy used in 2006. The US Department of Energy (DOE) Geothermal Technology Program (GTP) works in partnership with industry, universities and other Federal entities to conduct geothermal research to: 1) understand the potential of the geothermal resource, 2) develop the technology to access and capture geothermal energy, 3) cost-effectively convert geothermal energy to electricity and 4) facilitate implementation and deployment of technology by the private sector. The GTP provides most of the research funding, which amounted to about US$ 23.3 M in 2006. The US has a wide ranging outreach and education programme aimed at providing accurate information on and promoting geothermal energy, and interpreting geothermal research and developing educational products, mainly implemented through the *Geopowering the West* programme.

7.3 Review and Highlights of Industry Activities

7.3.1 Geodynamics

Geodynamics is a Brisbane, Australia, based corporation pioneering EGS development in Australia. Geodynamics' goal is to produce 1,000 MW_e of zero-emission, baseload electricity from the large known hot fractured rock (HFR) geothermal resource at Cooper Basin, South Australia. To strengthen its aim, the company has acquired the global rights to the Kalina binary cycle technology which it plans to use in the geothermal and industrial waste heat industry. Geodynamics was listed on the Australian Stock Exchange in September 2002 and has had significant financial support from the federal government through grants amounting to AUS$ 11.5 M (~US$ 9 M). Geodynamics has geothermal exploration licenses in the Cooper Basin (South Australia) and Hunter Valley (New South Wales). In 2006, a reservoir enhancement programme at the Habanero test site (Cooper Basin) increased the main reservoir by 52% and established a second parallel reservoir. An improved numerical reservoir model using Habanero data suggests that a planned multi-well HFR system with a 280 MW_e station would have an economic lifetime of > 50 years; and an application for a federal government grant amounting to AUS$ 75.4 M was submitted for the first 40 MW_e stage of this project. The HFR testing program was delayed due to drilling problems with Habanero 2. Consequently, a new well, Habanero 3, will be drilled as soon as practicable and its success should lead to the declaration of a proven geothermal reserve and commencement of commercial development of the first 40 MW_e stage. Geodynamics research projects include development of thermal and fracture modelling programs. Geodynamics raised AUS$ 17 M from a share placement in April 2006. Geodynamics was awarded the Sustainable Small Company of the Year 2005 Award. Geodynamics' future activities include the purchase of a new drill rig for about AUS$ 32 M, which is expected to begin operations drilling Habanero 3 in mid-2007.

7.3.2 Green Rock Energy

Green Rock Energy Limited (Green Rock) is a public company listed on the Australian Stock Exchange, with funds mainly obtained from shareholders. The company is focussed on development of renewable, clean, conventional and EGS geothermal energy projects with a strong commercial objective. Green Rock is currently involved in two projects. One is a joint venture project with the Hungarian Oil and Gas Company (MOL) and Enex (an Icelandic geothermal company) to develop geothermal energy (electricity and direct heat) in Hungary using refurbished oil wells. The first project, in Ortaháza, Hungary (32% interest), succeeded in producing enough heat for direct heat applications, but was insufficient to produce commercial power; hence it was abandoned. The join venture is now evaluating its next project in Hungary. The second project (100% Green Rock) aims to supply the electricity needs of BHP Billiton's copper operation at Olympic Dam, South Australia. A fully cored well was drilled to 1,935 m about 8 km from the mining facilities. Results indicated a compressional stress regime possibly useful for facilitating horizontal fracturing at the greater depths where temperatures are high enough to generate power. Green Rock now plans to conduct a stimulation programme in the exploration well using hydraulic fracturing techniques, then drill new deeper wells for EGS power development.

7.3.3 Ormat Technologies, Inc.

Ormat Technologies, Inc. is a leading company involved in the geothermal and recovered energy (i.e. electricity generation from "waste heat") business. Ormat designs, develops, builds, owns and operates clean, environmentally friendly geothermal and recovered energy based power plants using equipment they design and manufacture. Ormat's business activities consist of two parts: the "electricity segment" develops, builds, owns and operates geothermal and recovered energy power plants in the USA and geothermal plants in other countries, and sells the electricity generated. The "products segment" designs, manufactures and sells equipment (e.g. Ormat Energy Converters, OECs) for geothermal and recovered energy electricity generation and provides services related to engineering, procurement, construction, operation and maintenance of geothermal and recovered energy power plants. In 2006, Ormat had revenues of US$ 195.5 M from the electricity segment and US$ 73.4 M from the product segment; and net ownership interest in generating capacity increased by 51 MW_e. Ormat currently has 9 projects under construction in the USA, Guatemala and Kenya; four under development in the USA; and is conducting geothermal exploration in Nevada and Idaho. R&D activities include: collaboration in the use of geothermal fluids produced in oil and gas wells, and shared programmes with the DOE in EGS at Desert Peak (USA). Ormat has designed and supplied about 900 MW_e of geothermal power plant in the past 25 year, most of which is still in operation.

7.4 References

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NATIONAL ACTIVITIES
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Australia

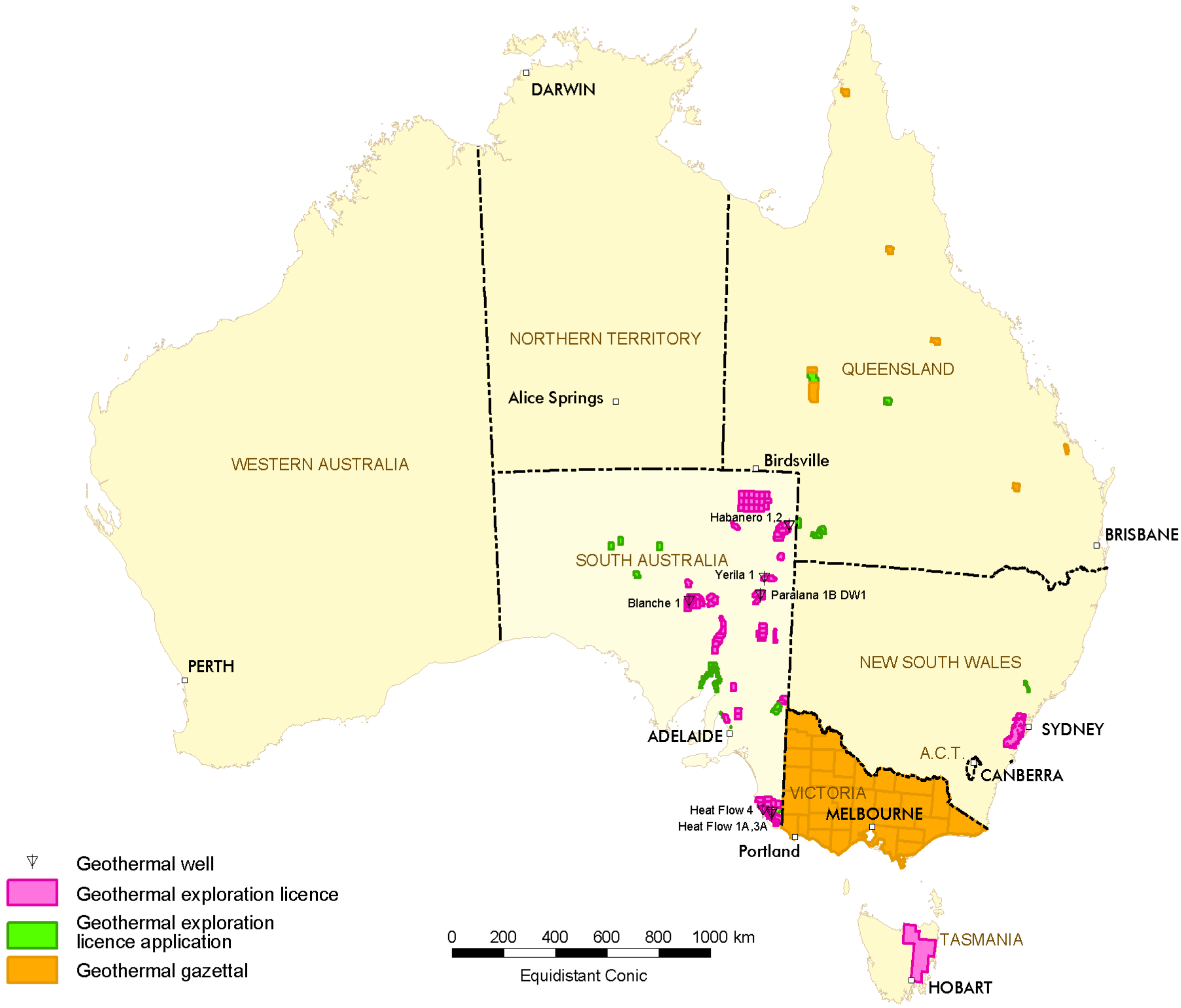

Figure 8.1 Geothermal licences in Australia for 2001-2006.

8.0 Introduction

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.

Since the grant of the first geothermal exploration licence (GEL) in Australia in 2001 through year-end 2006, 16 companies have joined the hunt for renewable and emissions-free geothermal energy resources in 110 licence application areas covering ~62,000 km^2 in Australia (Figure 8.1, above). This represents a 57% increase in applications in the last year. The associated work programs correspond to an estimated investment of AUS$ 569 million (39% increase since year end 2005) over the period 2002-2012, 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 2004-2006, 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 fall into two categories: hydrothermal (from relatively hot groundwater) and hot fractured rock i.e. Enhanced Geothermal Systems (EGS).

Currently, the only geothermal energy being used in Australia is generated by a 120 kW geothermal plant located in Birdsville, Queensland. It sources hot hydrothermal waters at relatively shallow depths from the Great Artesian (Eromanga) Basin.

Current and forecast investment to explore for, and demonstrate the potential of geothermal energy in Australia is predominantly for EGS.

In 2006, government grants from the Australian Federal and South Australian governments for geothermal energy projects totalled AUS$ 3.92 million (US$ 3.1 million). In the term 2000-2006, the Australian Federal Government has awarded AUS$ 22.3 million to foster progress towards commercialising geothermal energy resources and related technologies. In the 21 month period through December 2006, the South Australian Government has awarded AUS$ 759,000 for geothermal drilling projects. Details of these awards are provided in Table 8.1.

Additionally, the Australian Federal Government's five year funding (AUS$ 58.9 million) for an *Onshore Energy Security Program* will enable the national geoscience and geospatial information agency (Geoscience Australia) to acquire pre-competitive 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 summary of the activities of the sixteen Australian geothermal explorers at year-end 2006 is provided as Attachment 8.1.

A summary of exploration and proof-of-concept projects that have reached the drilling phase by year-end 2006 is summarised below. The five projects operated by four companies that have already entered the drilling phase are all located in South Australia and include: Geodynamics Limited's Habanero project; Petratherm's Paralana and Callabonna projects; Green Rock Energy's Blanche Project; and Scopenergy's project in the southeast of South Australia.

This report documents progress in 2006, and key achievements since 2000, when licences to explore-for geothermal resources were first introduced in Australia.

8.1 Exploration and Proof-of-Concept Projects

8.1.1 Geodynamics

The most significant advancement in terms of demonstrating the potential of hot fractured rock energy is Geodynamics' drilling, fracture stimulation and flow testing of two wells that are 500 m apart near Innamincka in the Cooper Basin, in northeast South Australia: Habanero 1 (total depth: 4,421 m) and Habanero 2 (total depth: 4,357 m). The Habanero Project was the first, and remains the most advanced Hot Rock "proof of concept" project in Australia. Flow of geothermally heated formation waters (20,000 ppm total dissolved solids) at a maximum rate of 25 l/s to surface at (up to) 210 ºC was achieved in 2005. The geothermal reservoir is a water-saturated, naturally fractured basement granite, with a temperature of 250 ºC at 4,300 m (reported by the operator), and permeability that was effectively enhanced with fracture stimulation.

Two fractured reservoir zones are present in the Habanero wells: an upper less permeable zone at 4,200 m, and a lower more permeable zone below 4,300 m. An obstruction in Habanero 2 (the intended production well) interfered with a planned flow test of the main fractured reservoir below 4,300 m while the less-productive upper fractured reservoir zone at 4,200 m remains accessible. To conclude a circulation test of the main fracture zone, Geodynamics drilled a sidetrack borehole around the blockage in Habanero 2. The sidetrack progressed to a depth 100 m above the target reservoir when the drill bit became stuck. Attempts to conclude drilling operations in the Habanero 2 sidetrack were abandoned in June 2006. Geodynamics now plans to drill Habanero 3 in 2007. Habanero 3 will have an 8 ½ inch open hole section over target reservoirs (compared to 6 inch for Habanero 2). Following the drilling of Habanero 3, a flow test with tracer injection between Habanero 1 (the intended injection well) and Habanero 3 (the intended production well) is planned as a further step towards demonstrating commercial viability.

The horizontal extension of stimulated reservoirs at the Cooper Basin site lends itself to multi-well developments. Geodynamics' HOTROCK 40 project entails a 7-well, 40 MW_e power station. The 7 wells include 3 injection wells and 4 production wells up to 1 km apart. This will be an important milestone for the demonstration of EGS from hot fractured rock in Australia and a stepping stone towards commercialising vast renewable and emissions-free baseload geothermal energy supplies to meet Australia's future energy requirements. Geodynamics believes that a successful test between Habanero 1 and 3 will lead to large-scale development of an area of more than 1,000 km^2 where rock temperatures, stress conditions and rock properties are extensive and favourable for geothermal energy production.

8.1.2 Petratherm

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 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 metres. Temperature logging of the well suggests a world class thermal resource is located at Paralana, with extrapolations indicating 200 ^oC can be expected at a depth of 3.6 km above basement granites, within insulating strata susceptible to fracture stimulation. Petratherm refers to this play concept as *heat exchange within insulator* (HEWI).

Petratherm next plans to drill and fracture stimulate its first injection well at Paralana to approximately 3.6 km depth and then drill and fracture stimulate a second well. The company then plans to create an underground HEWI system with the circulation of water between the two Paralana project wells to demonstrate hot rock energy production from an initial small scale power plant to 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.

8.1.3 Green Rock Energy

Green Rock drilled Blanche No. 1 to 1,935 m (718 m of sediments 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. Owing to lack of availability of a suitable drilling rig, Green Rock deferred the drilling of at least one deep well to establish the basis for flow tests in 2006. The company now hopes to secure a rig in late 2007.

8.1.4 Scopenergy

In the first quarter of 2006, Scopenergy drilled 3 slim-hole wells near Millicent and Beachport in southeast South Australia to determine geothermal gradients and confirm several large scale heat

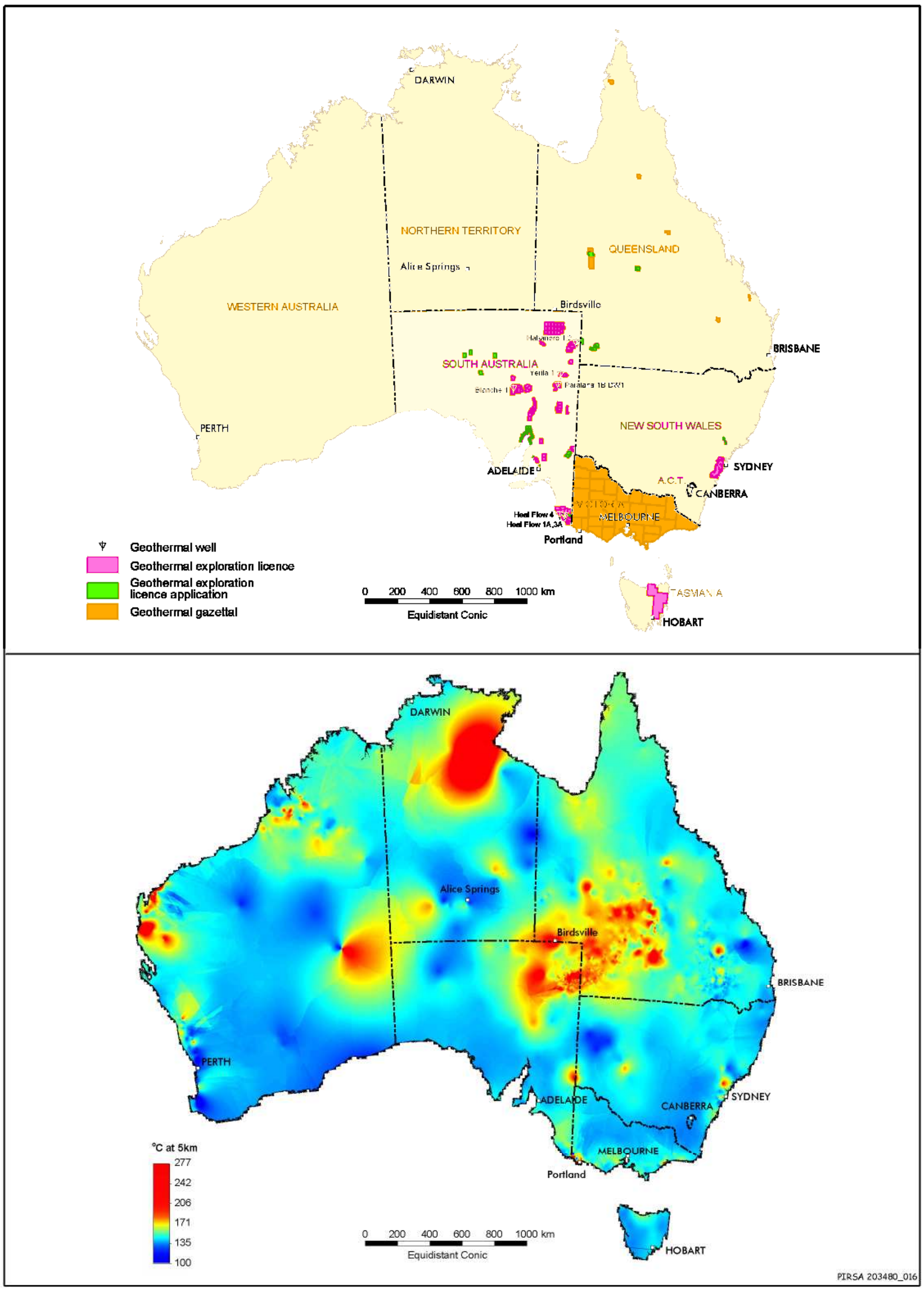

Figure 8.2 (a) Geothermal licences, applications and gazettal areas as at December 2006.
Figure 8.2 (b) Map of extrapolated temperature at 5 km depth interpolated across Australia. The map is based on available (in places sparse) data that may not be a true reflection of geothermal gradients on a regional basis. (Figure courtesy of Prame Chopra, ANU).

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. Scopenergy is now considering whether to undertake a 3-D seismic program to better define drilling targets prior to drilling its first production scale hole to reservoir depth.

8.1.5 Highlights and Achievements

Highlights and achievements to the end of 2006 are summarized as follows:

- Strong interest expressed by yet more new entrants into the geothermal sector bodes well for continued growth and competition.

- Expected passage of legislation in other Australian jurisdictions (Western Australia and Northern Territory) will also stoke the sectors' growth.

- At year-end 2006, 16 companies have joined the hunt for renewable and emissions-free geothermal energy resources in 110 geothermal licence areas covering ~62,000 km^2 in Australia. This represents a 57% increase in geothermal licences in the last year. Most (90%) of the areas applied for are located in South Australia. The balance include: 5 geothermal licence area applications in New South Wales; 5 in Queensland; and 1 in Tasmania.

- To year-end 2006: 76 geothermal exploration licenses (GELs) have been granted in South Australia; 4 exploration licences (ELs) for geothermal exploration have been granted in New South Wales; and a single, large exploration licence (EL) has been granted in Tasmania.

- Over AUS$ 569 million (US$ 448 million) in work program investment is forecast for the period 2002 – 2012. Approximately AUS$ 90 million (US$ 70 million) of this forecast was invested in the term 2002-06; 99% of which was spent in South Australia. This current forecast (for the term 2002 – 2012) represents an increase of AUS$ 159 million (US$ 125 million) over the forecast stated for year-end 2005. These forecasts exclude capital expenditure associated with demonstration power plants.

- 10 tenements were released for tender in the state of Queensland in December 2006 with a closing date in early April 2007.

- 31 gazettal areas were released for tender over the entire state of Victoria in April 2006. At the close of tender in October 2006, 20 applications had been lodged which are now in the process of being assessed. Licence offers are expected to be announced in April 2007.

- Strong public interest and investment was sustained in geothermal companies listed on the Australian Stock Exchange (ASX), with the majority of geothermal capital raisings oversubscribed. At year-end 2006, 5 geothermal explorers were listed on the Australian Stock Exchange (ASX) – Geodynamics, Petratherm, Green Rock Energy, Geothermal Resources and Eden Energy. The ASX market capitalisation for these 5 geothermal explorers at year-end 2006 was about AUS$ 172 million (US$ 129 million). The contribution of geothermal projects to the ASX market capitalisation of Pacific Hydro's diverse portfolio of energy is not estimated.

- To year-end 2006, two upstream petroleum companies held significant *cornerstone* equity in Geodynamics Ltd (Woodside Ltd and Origin Energy Ltd). These upstream petroleum companies bring considerable commercial and operational (especially drilling) experience to the geothermal sector.

- As noted above, Geodynamics, Petratherm, Scopenergy undertook drilling operations in 2006:
  - Geodynamics continued its Habanero well operations in 2006.
  - Petratherm established prospective geothermal gradients at its Callabonna (68° C/km) and Paralana (81 °C/km) sites, and deepened its Paralana well to 1,807 m and confirmed a gradient suggesting that 200 °C can be expected at a depth of about 3.6 km.
  - Scopenergy drilled 3 slim-hole wells and conducted temperature surveys in those wells near Millicent and Beachport in southeast South Australia. The next phase of work in this area is expected to be either a 3-D seismic survey (to optimise the location of deeper drilling targets) or the first production scale hole to reservoir depth.
  - Pacific Hydro confirmed anomalously high temperature gradients of 50ºC per km with temperature logging of abandoned petroleum wells near the Birdsville Track Ridge (SA) in 2006.
  - Geothermal Resources set plans in 2006 to start drilling shallow wells in its Frome Project area (Arrowie Basin, SA) in March 2007.

- Eden Energy set plans in 2006 to start drilling shallow wells in the Renmark area in the second half of 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).

- The Australian Government has provided AUS$ 58.9M over five years in the Onshore Energy Security Program to Geoscience Australia for pre-competitive data acquisition, which specifically includes geothermal energy. A geothermal energy project plan has been developed after consultation with industry, State Government and academia stakeholders.

- In 2006, Australian Federal and State grants totalling ~AUS$ 3.9 million (US$ 3.1 million) were awarded to 5 geothermal companies (to progress geothermal exploration and demonstration projects).

- In the term 2000-December 2006, the Australian Federal Government has awarded AUS$ 22.3 million (US$ 17.6 million) to foster progress towards commercialising geothermal energy resources and cognate technologies. Details are provided in Table 8.1.

- In the 21 months between April 2005 and December 2006, the South Australian government has awarded AUS$ 759,000 (US$ 600,000) for geothermal drilling projects. Details are provided in Table 8.1.

- The Australian Geothermal Energy Group (AGEG) formed in 2006. The AGEG provides financial and intellectual support for Australia's membership in the IEA's GIA. The current 29 member organisations of AGEG include representatives from: 15 companies with geothermal licences and pending application for licence in Australia; Federal, State and Territory government agencies responsible for investment attraction and licence regulation for the geothermal sector; university experts conducting research with implications for the geothermal energy sector; companies providing services to the geothermal sector; and an aligned lobby group – the Renewable Energy Generators of Australia (REGA). The members of the AGEG have a common interest in commercialising Australia's geothermal resources at maximum pace and minimum cost.

The Australian Government's 2004 White Paper *Securing Australia's Energy Future* classified hot dry rocks as a technology in which Australia was a market leader and the Australian Federal 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 EGS resources are among the best in the world.

In July 2006, the Council of Australian Governments (CoAG) asked its Climate Change Group (CCCG) to provide options for the development of technology roadmaps. CCCG supported the development of five energy technology roadmaps, one of which will be for geothermal energy. It is expected that this roadmap will be developed during 2007 and presented to CoAG in early 2008. The roadmap will identify goals and milestones for the research, experimental development and demonstration of geothermal technologies. Furthermore, it will support the development of a broader roadmap for the geothermal energy industry in Australia.

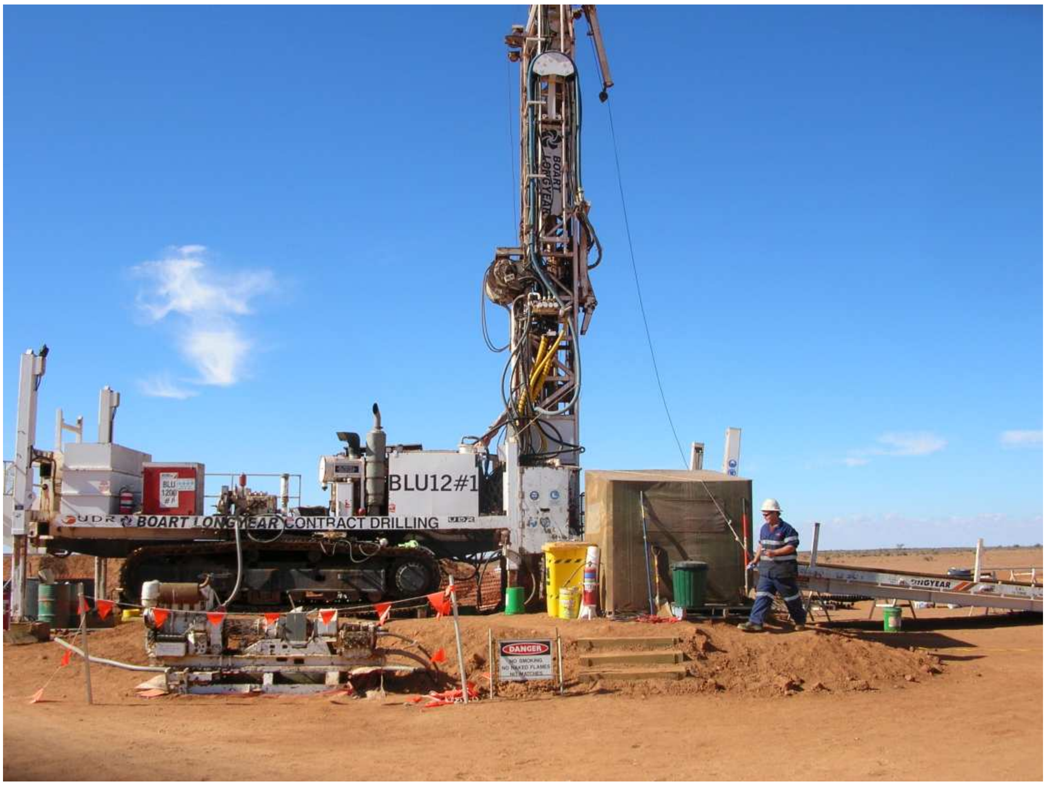

Figure 8.3 Drilling of Paralana 1B DW1 geothermal well in June 2006, Paralana, South Australia. Well recorded bottom hole temperature of 109 ^{o}C at a depth of 1,807 m (photograph courtesy of Petratherm Ltd.).

8.2 National Policy

8.2.1 Strategy

There has been a steady increase in all forms of renewable energy supplies in Australia over the period 2000-2006, fostered by government initiatives. In 2000, the Australian Federal Parliament passed the Renewable Energy (Electricity) Act. This Act saw the introduction of the Mandatory Renewable Energy Target (MRET) Scheme that requires an additional 9,500 GWh of renewable electricity by the year 2010, enough power to meet the residential needs of 4 million people. The MRET Scheme operates through a system of tradable Renewable Energy Certificates (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. The Federal Government is currently reviewing the MRET Scheme with the view to increasing the target.

In 2004, the Australian Federal government released a new energy policy White Paper, “Securing Australia’s Energy Future”. Included in this policy was the introduction of the “Low Emissions Technology Development Fund” (LETDF) that will provide AUS$ 500 million (US$ 395 million) to companies that can demonstrate new technologies that will significantly reduce long term green house gases. A number of additional renewable energy programs are outlined in Section 8.4. The energy white paper classified hot dry rocks technology as a "market leader" (highest category) technology for Australia. Market leader technologies are technologies where Australia has a strategic interest.

See: www.pmc.gov.au/energy_future

8.2.2 Legislation and Regulation (including acreage releases)

Five states (South Australia, New South Wales, Queensland, Tasmania and Victoria) have legislation in place to regulate geothermal exploration and development. Geothermal energy exploration in South Australia falls under the *Petroleum Act, 2000* whilst in New South Wales and Tasmania it is governed by the *Mining Act, 1992* and *Mineral Resources Development Act, 1995* respectively.

8.2.2.1 South Australia

A paper outlining proposed amendments to the *Petroleum Act 2000* is now open for public scrutiny and comments on a number of issues. It is proposed that the size of a geothermal licence granted is at the Minister's discretion, based on the proponent's demonstrated project plan. This proposal will include maximum licence areas of 10,000 km^2 for a GEL and 1000 km^2 for a Geothermal Retention Licence (GRL) or a Geothermal Production Licence (GPL). The closing date for comments is 29 June 2007. To download the proposed amendments visit: http://www.pir.sa.gov.au/byteserve/petrol/environmental_reg/documents/green_paper_petact2000_dec06.pdf

8.2.2.2 Victoria

Building on the *Energy Resources Act, 2005* which was passed in Victoria in April 2005, the *Regulatory Impact Statement and Geothermal Energy Resources Regulations* 2006 (GE Regulations) came into effect during 2006.

The geothermal legislation and regulations are intended to apply to high-end (scale) geothermal operations. Under the new GE Regulations, exploration permits are not required where the geothermal resource is less than 70º C or less than 1000 metres depth. Low-end operations operate under existing environmental, water and planning laws.

The primary objectives of the GE Regulations are to provide commercial certainty and a workable framework to facilitate large-scale, commercial exploration and development of Victoria's geothermal resources. The GE Regulations also seek to ensure that risks to health and safety and the environment are eliminated or minimised so far as practicable. Secondary objectives of the GE Regulations are to support the Government's aim of expanding the State's renewable energy sector and to support alternative power generation sources, thereby reducing Victoria's greenhouse gas emissions.

The entire State of Victoria was gazetted on April 11th 2006, totalling some 31 geothermal exploration areas. The bidding process was open for six months, with the closing date being 11th October 2006. The 20 received bids were assessed against several criteria, including the proposed work program and associated expenditure. Successful applicants are expected to be announced in April 2007. If no bids are successful for a given area, then this acreage will be able to be applied for on a "first-come, first-served" basis.

8.2.2.3 Queensland

Legislation for the production of geothermal energy in Queensland was progressed in 2006 but has yet to be finalised.

Ten areas were gazetted for geothermal exploration in December 2006 with a closing date in April 2007.

8.2.2.4 Western Australia

The Western Australian Government has recently approved the drafting of a Bill to amend the *Petroleum Act 1967* (WA) to accommodate the exploration and production of geothermal energy so that the Act would become the Western Australian *Petroleum and Geothermal Resources Act*. The Cabinet decision followed from an earlier announcement by Premier Alan Carpenter that the State Government would legislate in 2007 to provide a clear legal framework for companies to pursue large-scale geothermal energy projects in Western Australia.

Studies to pinpoint high potential HDR resources are underway and these areas will be released for competitive bid as soon as the amended legislation and regulations are in place

8.2.2.5 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.

A public discussion paper was released late in 2006 seeking comments on the proposal. A number of submissions were received which were all positive towards Geothermal exploration and development. Some legal issues dealing with Native Title were raised. The Northern Territory is currently obtaining legal opinion on these.

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 2007.

8.2.3 Progress Towards National Targets for Renewable Energy and Emissions

The Federal Government's Mandatory Renewable Energy Target (MRET) is 9,500 GWh of new renewable electricity by the year 2010. Current analysis projects Australia's greenhouse gas emissions at 109% of 1990 emissions levels over the period 2008-2012, which is slightly above the 108% Kyoto target. However, Australia remains committed to meet its Kyoto protocol target (see http://www.greenhouse.gov.au/projections). The combined effect of current Australian Federal, State, Territory and local governments policies and programs is expected to cut annual emissions by 87 Mt CO_2 by 2010, and further measures will help meet the target.

The Victorian Government implemented the Victorian Renewable Energy Target [VRET] scheme in late 2006, whereby energy retailers are required to purchase a minimum of 10% renewable energy by 2016. This equates to a cut in greenhouse gas emissions of 27 million tonnes and it is estimated this will lead to AUS$2 billion in new investments and 2,200 jobs.

8.2.4 Government Expenditure on Geothermal Research (Exploration), Proof- of-Concept (Appraisal), Demonstration and Development Initiatives

Australian Federal and South Australian State government expenditure on geothermal research (exploration), proof-of-concept (appraisal), demonstration and development initiatives, including grants to industry, totalled just over AUS$ 3.92 million (US$ 3.1 million) in 2006. Detailed descriptions of these grant programs are outlined in Section 8.4.1 under Support Initiatives and

Market Stimulation Incentives. There has been a total of just more than AUS$ 23 million in Australian Federal and South Australian State grants for the period 2000 to end December 2006 (Table 8.1).

8.2.4.1 Federal Government Grants

Since 2000 the Federal government has provided over $ 27 million in grants under a range of energy technology support programs. The various grants are listed in Table 8.1, which also includes grants provided by the South Australian government.

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 8.7.2.1. As the program only started in late 2006, there was minimal financial outlay during this reporting period.

Table 8.1 Federal and State grants awarded for geothermal R, D & D in Australia 2000-December 2006.

Grant	Date	Recipient	Project	Amount ($AUS)
RECP	2000	Pacific Power/ANU	Hunter Valley Geothermal Project	$ 790,000
START	2002	Geodynamics Ltd	Habanero Project	$ 5,000,000
REEF	2002	Geodynamics Ltd	Habanero Project	$ 1,800,000
GGAP	Mar 2005	Geodynamics Ltd	Kalina Cycle to produce 13 MW from waste heat at the Mt Keith Nickel Mine in WA	$ 2,080,000
REDI	Dec 2005	Geodynamics Ltd	Habanero Project, Cooper Basin, SA	$ 5,000,000
REDI	Dec 2005	Scopenergy Ltd	Limestone Coast Geothermal Project, SA	$ 3,982,855
PACE 2	Apr 2005	Petratherm Ltd	Paralana Geothermal Project, SA	$ 140,000
PACE 2	Apr 2005	Scopenergy Ltd	Limestone Coast Geothermal Project, SA	$ 130,000
PACE 2	Apr 2005	Eden Energy Ltd	Witchellina Project, SA	$ 21,000
SA Grant	Jun 2005	University of Adelaide	Induced seismicity Cooper Basin, SA	$ 50,000
SA Grant	Dec 2005	Geodynamics Ltd	Evaluation of Australian Hot Fractured Rock geothermal energy industry	$ 40,000
PACE 3	Dec 2005	Geothermal Resources Ltd	Curnamona Geothermal Project, SA	$ 100,000
PACE 3	Dec 2005	Green Rock Energy Ltd	Olympic Dam Geothermal Project, SA	$ 68,000
REDI	July 2006	Geothermal Resources Ltd	Frome Geothermal Project	$ 2,400,000
REDI	Dec 2006	Proactive Energy Developments Ltd	Novel regenerator for adapting supercritical cycles to geothermal power application	$ 1,224,250
PACE 4	Dec 2006	Torrens Energy Ltd	Heatflow Exploration in Adelaide Geosyncline	$ 100,000
PACE 4	Dec 2006	Eden Energy Ltd	Renmark (Chowilla) Geothermal Project, SA	$ 100,000
PACE 4	Dec 2006	Geodynamics Ltd	High Temperature Borehole Image logging of Habanero 3, Cooper Basin, SA	$ 100,000
			Total	**$23,126,105**

8.2.4.2 State Government Grants

South Australia

A total of AUS$ 759,000 in South Australian PACE drilling grants has been provided to seven companies exploring for geothermal energy (Table 8.1) since the PACE initiative commenced in July 2004. In December 2006, three PACE Round 4 grants totalling AUS$ 300,000 were granted to Geodynamics Ltd, Eden Energy Ltd and Torrens Energy Ltd. 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 Department of Primary Industries and Resources (PIRSA) also allocated AUS$ 40,000 (US$ 28,000) for the Centre for Independent Economics cost benefit analysis on Australia's Hot Fractured Rock (HFR) industry (see References) and another AUS$ 50,000 (US$ 39,500) for the Australian School of Petroleum at University of Adelaide research of potential hazards associated with the fracture stimulation of EGS reservoirs in Australia's Cooper Basin (Section 8.7.2.4).

Western Australia

The Department of Industry and Resources, Geological Survey has undertaken a study project on "Geothermal Energy Potential in Selected Areas of Western Australia" through consultant Earthinsite Pty Ltd. The aim of this project is to map and identify the most suitable areas within the Canning, Carnarvon and Perth Basins that may have potential for Hot Dry Rock ("HDR") geothermal energy development as well as to develop a reliable dataset for further detail studies. The study has evaluated the quality and quantity of available subsurface temperature data for the purpose of evaluating the potential for HDR geothermal energy in portions of the Perth, Carnarvon and Canning Basins. Calculations have been made of the true formation temperature where sufficient suitable temperature data exist. By combining these results with estimates of mean annual surface temperature at each well location, estimates of the equilibrium geothermal gradient at each location have been derived.

The estimates of equilibrium geothermal gradient have then been used, together with Geological Survey of Western Australia (GSWA)-furnished estimates of depth to basement, to predict the temperature at the top of the basement and the depth at each well location to the 200 °C isotherm. A compilation of published in-situ stress data for the relevant parts of the Perth, Carnarvon and Canning Basins has also been made and the relevance of these results have been assessed in terms of possible HDR developments. Calculations have also been made of the heat generation capacity for a range pf geochemistries likely to characterise basement rocks in the study areas. The study has been completed and awaits publication.

8.2.5 Industry Expenditure on Geothermal Research (Exploration), Proof-of-Concept (Appraisal), and Demonstration (Pre-competitive Development) Projects

All Australian geothermal industry field expenditure to date is classed as research and is estimated at AUS$ 29.1 million (US$ 23 million) for the calendar year 2006. This represents an 11% increase of AUS$3 million (US$2.4 million) from the previous year. A 97% increase (to AUS$ 45.4 million or US$ 35.9 million) is forecast to be expended in 2007. Historical, current and projected expenditure for 2007 are highlighted in Figure 8.4.

8.3 Current Status of Geothermal Energy Use in 2006

8.3.1 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 °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 (Figure 8.5) 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 and has 40 kW parasitic losses, which equates to a net output of 80 kW. The plant was shutdown from December 2004 to December 2005 for upgrading to meet compliance of Australian Standards regarding handling of isopentane and is now operating. Total power generation in 2006 was 2,034,615 kWh, of which 715,182 kWh was provided by the geothermal power plant. This equates to 35% of total power output.

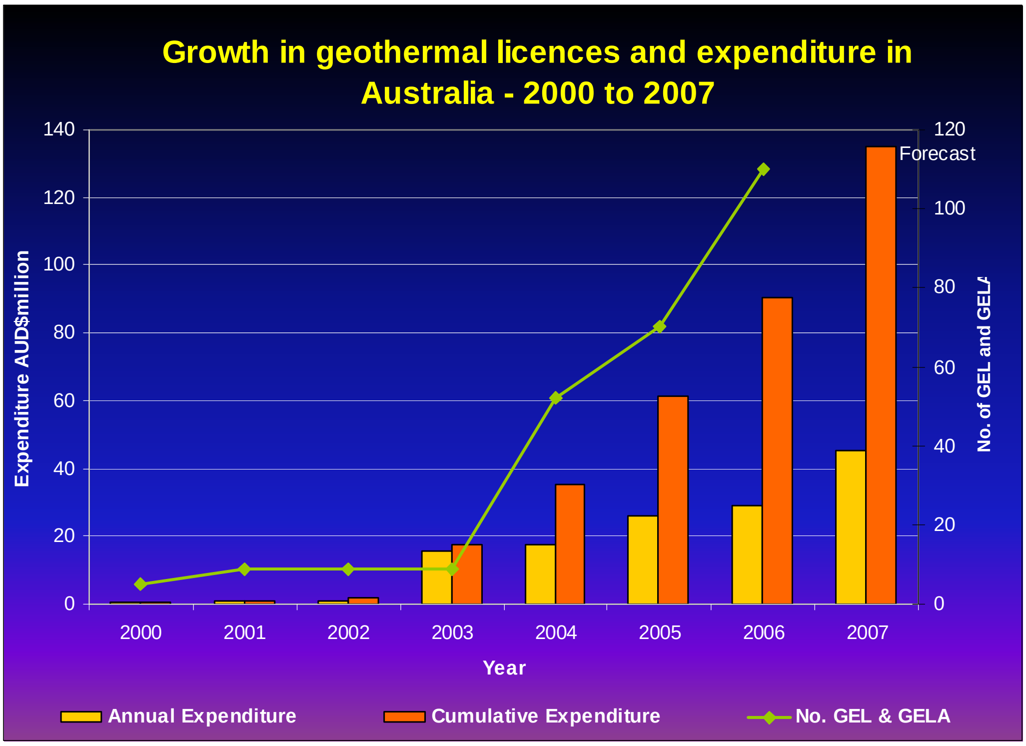

Figure 8.4 Geothermal Licence applications and exploration expenditure for 2000 to 2007, with a forecast for 2007 (source PIRSA).

In November 2006 Ergon Energy commenced 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 feasibility report is due by the end of March 2007.

8.3.2 Direct Use

Direct use of geothermal waters has been an important source of energy in the city of Portland in western Victoria. Water pumped from a 1,400 m deep bore at a temperature of 58 °C at rates of approximately 60 l/s with a nominal capacity of 3,600 kW and is used to heat many of the municipal buildings and public facilities. Direct use of this resource has been temporarily suspended pending the outcome of restorative operations on the bore which are in the planning phase. Geothermal waters are also used for spas at Moree near Barradine, at Lightning Ridge in New South Wales and at Hastings in south east Tasmania. There are also two developments in Victoria on the Mornington Peninsula (south of Melbourne) and another spa resort in Gippsland, Victoria. There are no available estimates of the amount of energy being produced at these locations. Ground source heat pumps are also finding increased use in Australia in both commercial and residential applications.

Figure 8.5 Organic Rankine Cycle Turbine and Oil Separator, Birdsville, Queensland. Courtesy of Ergon Energy

8.4 Market Development and Stimulation

8.4.1 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:

- **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.

- **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 awaits the instigation of related work by the operator (BHPB) of the Mt Keith Mine.

- **Renewable Energy Commercialisation 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.

- **Renewable Energy Certificates (RECs)–** 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.

- **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 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.

- **Greenhouse 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 carbon dioxide emissions by at least 2%. The Fund was announced by the Federal government in June 2004 and will leverage at least AUS$1 billion in additional private investment in new low emission technologies. The Fund will operate over the period 2005-06 to 2019-20.

- **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.

- **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). See: http://www.pir.sa.gov.au/sector5.shtml.

- **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/1155-home-page.asp.

8.4.2 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 EGS well drilled in Australia, knowledge gained 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 EGS 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.

8.5 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.

8.6 Economics

8.6.1 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 8.6 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 energy in Australia has been estimated at $49-$60 per MWh (ESIPC, 2006). 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 2006, with Geodynamics, Petratherm, Green Rock Energy, Eden Energy and Geothermal Resources raising AUS$ 20.78 million from public share subscriptions during the year. As at 31 December 2006, the market capitalisation of these five companies amounted to about AUS$ 172 million (US$ 129 million). There are strong indications that investors remain willing to back geothermal energy projects.

8.6.2 Trends in the Cost of Energy

Estimated costs to generate electricity from various fuels and plant-types are indicated on Figure 8.5. 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.

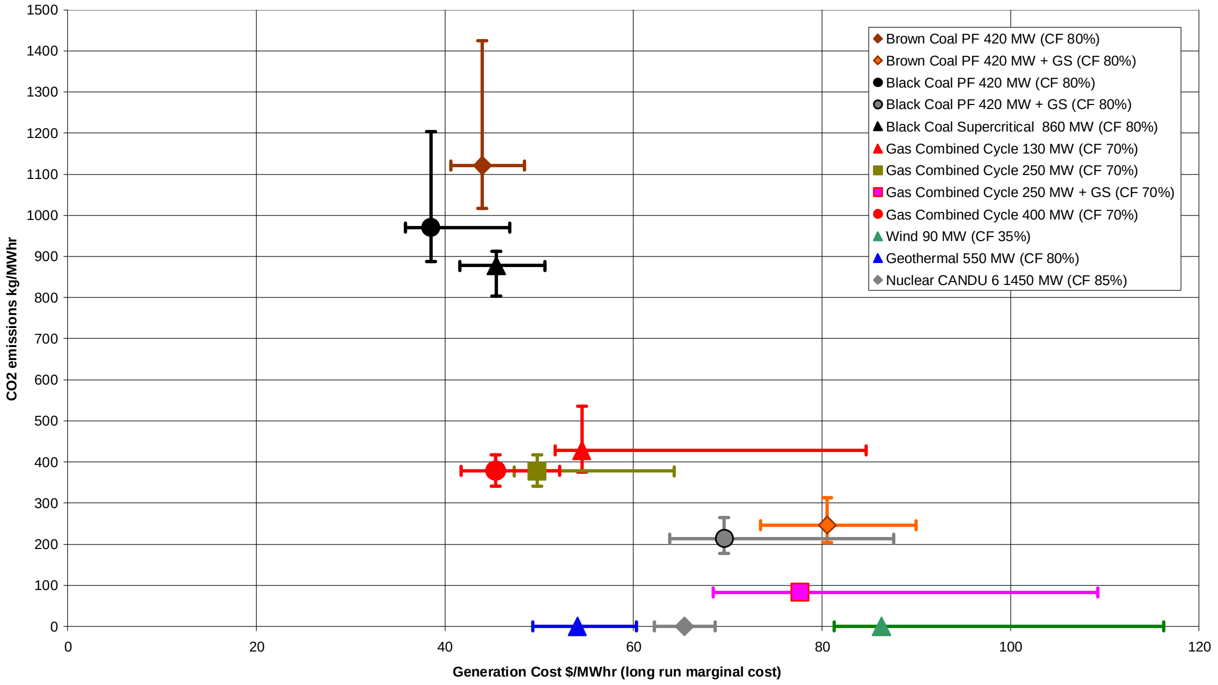

Figure 8.6 CO_2 emissions (kg/MWh) on the vertical axis versus costs to generate electricity (AUS$/MWh) on the horizontal axis to indicate relative costs and CO_2 emissions from various fuels, with and without carbon capture and geosequestration (GS). Capacity factors (CF) are the proportion of annual hours online generating electricity. Source: Electricity Supply Industry Planning Council 2006 Annual Planning Report, *http://www.esipc.sa.gov.au/webdata/resources/files/APR_Final_for_Website.pdf*

8.7 Research Activities

8.7.1 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 (Here *highgrading* refers to the use of interpretive maps to delineate where three key independent geologic factors: reservoir permeability, heat source and heat trap, are all likely to occur as a means to rank the relative certainty of the extent of EGS play-trends)

- 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.

8.7.2 Government Funded Research

8.7.2.1 Geoscience Australia

Geoscience Australia conducted considerable stakeholder consultation to develop a plan to enhance understanding of Australia's geothermal energy resources under the auspices of the Federal Government's five year (2006-2011) Onshore Energy Security Program. Key activities will include: the consolidation of existing geothermal data; the acquisition of additional, infill (pre-competitive) geothermal and cognate data (including new thermal conductivity and heat flow measurements); assessments leading to a new detailed hot fractured rock model (map) with refined gridding techniques, and constructing an information system for the dissemination of geothermal and associated data.

8.7.2.2 Australian National University – Australian Capital Territory

Research has focused on development of a new database of temperature measurements made in 5722 wells across Australia that has been used to construct improved maps of the spatial distribution of temperature in the Australian crust. This work was undertaken by Dr Prame Chopra and Fiona Holgate. The new database, Austherm04, builds upon the earlier work of Somerville *et al*. (1994) by greatly improving data quality control and by including temperature data from a further 1430 wells. Whilst there has been some enhancement of the overall spatial coverage, the bulk of the new data are still largely clustered within the same provinces that dominate the dataset published by Somerville *et al.* (1994). As a result, data distribution across the continent still tends to be rather patchy and irregular with some regions well represented and others not (see Figure 8.1b). Furthermore, these data are yet to be integrated with a predictive model that may define potential "sweet-spots" and accordingly do not yet represent all prospective trends. An Arc/Info GIS coverage has been built from the Austherm04 database (Chopra and Holgate, 2005).

The crustal temperature maps produced in this study reveal large spatial variations in temperature across continental Australia. Lowest temperatures occur where basement is exposed at the surface such as in the Yilgarn Block, Gawler Craton and Lachlan Fold Belt. High temperatures are associated with thick sedimentary basin cover and the inferred presence of high heat production granites under the sedimentary sequences. Particular examples include the Cooper-Eromanga, Macarthur and Canning Basin regions.

Other smaller areas of relatively elevated crustal temperature that may represent future HDR targets include parts of the Sydney, Perth and Murray Basins. Whilst representing significant improvements over the previous Somerville *et al*. (1994) map, the new crustal temperature maps continue to be influenced by artifacts caused by the strongly heterogeneous spatial distribution of the subsurface temperature data across continental Australia. More sophisticated geostatistical methods and analysis on a province by province basis may offer some improvements but further temperature exploration data will probably be required to significantly improve the resource analysis.

This geothermal work at the ANU has now been completed with the departures from the university of Drs Chopra and Holgate to Earthinsite Pty Ltd and Geoscience Australia respectively.

8.7.2.3 University of New South Wales

The School of Petroleum Engineering at the University of New South Wales (UNSW) has made a strong commitment to the development of renewable energy and has been actively participating in developing technology for the exploitation of geothermal energy in Australia since the first HDR Conference held in Canberra in 1992. Together with Geoscience Australia, it actively participated in collecting geophysical and temperature data from different parts of Australia and prepared a heat map of Australia in 1994.

Following this it carried out a major study to characterise temperature, stress and natural fracture systems of the basement in the Cooper Basin. As part of this study the School also developed an innovative fracturing technology for the development of geothermal reservoir. This study was primarily funded by ERDC and industry. To commercialise the technology it formed a geothermal company, Scopenergy Ltd, in January 2001 (currently owned by Eureka Capital Partners) to hold the major geothermal licences in Mount Gambier region of South Australia. The UNSW School of Petroleum Engineering has worked with Scopenergy on a number of issues, including: (1) characterisation of geothermal reservoirs in particular in sedimentary rocks; (2) geothermal reservoir development by hydraulic fracturing; and (3) fluid flow and production estimation in fractured sedimentary reservoirs. The program is being funded by the UNSW, Australian Greenhouse Office (AGO) and industry.

In 2005, the School developed a numerical simulation technique for characterisation of fracture systems in geothermal reservoirs adopting a geostatistical approach that incorporates field data. Initial results are very encouraging and the School is currently working to advance this work. The School has also developed a numerical geothermal reservoir simulator to estimate hot water recovery. An important feature of this model is that it simulates fracture system with spatial distribution and considers fluid flow between fracture and matrix.

8.7.2.4 Australian School of Petroleum, Adelaide University – South Australia

The South Australian Department of Primary Industries and Resources (PIRSA) allocated AUS $50,000 in June 2005 to 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 and then undertake similar studies in other prospective EGS provinces. The Cooper Basin study, led by Dr Suzanne Hunt, used predictive modelling of local stress change to forecast probable impacts from the fracture stimulation of naturally fractured granites in the vicinity of the Habanero wells drilled by Geodynamics. This study (Hunt and Morelli, 2006) is fully aligned with the aims of the GIA for its members to pursue collaborative efforts that address issues of "*significant concern to the acceptance of geothermal energy in general but Enhanced Geothermal Systems (EGS) in particular. The issue is the occurrence of significant seismic events in conjunction with EGS reservoir development or subsequent heat extraction.*"

Outputs from the project included numerical models that assess potential impacts (on the local in-situ stress field) from the development of EGS reservoirs and also the development of finite difference models to assess the likelihood of damage to petroleum wellbores and completions that might possibly be caused by a seismic wave hitting a wellbore at various depths. The one year study was completed in June 2006 and is currently undergoing peer review on the GIA website: http://www.iea-gia.org/documents/InducedSeismicityReportSHuntDraftOctober2006Malvazos4Jan07.pdf

Key conclusions from Hunt and Morelli (2006) are:

- The Cooper Basin in South Australia is ideally suited to 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.
- Induced seismic events at the Habanero well site in the Cooper Basin fall below the background coefficient of ground acceleration (0.5 g) thereby not exceeding the government's current building design standards for peak ground acceleration.
- 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 EGS activity (Figure 8.7).

The results and conclusions from this study were presented by Michael Malavazos, Chief Petroleum Engineer, PIRSA at the GRC Conference in San Diego in September 2006.

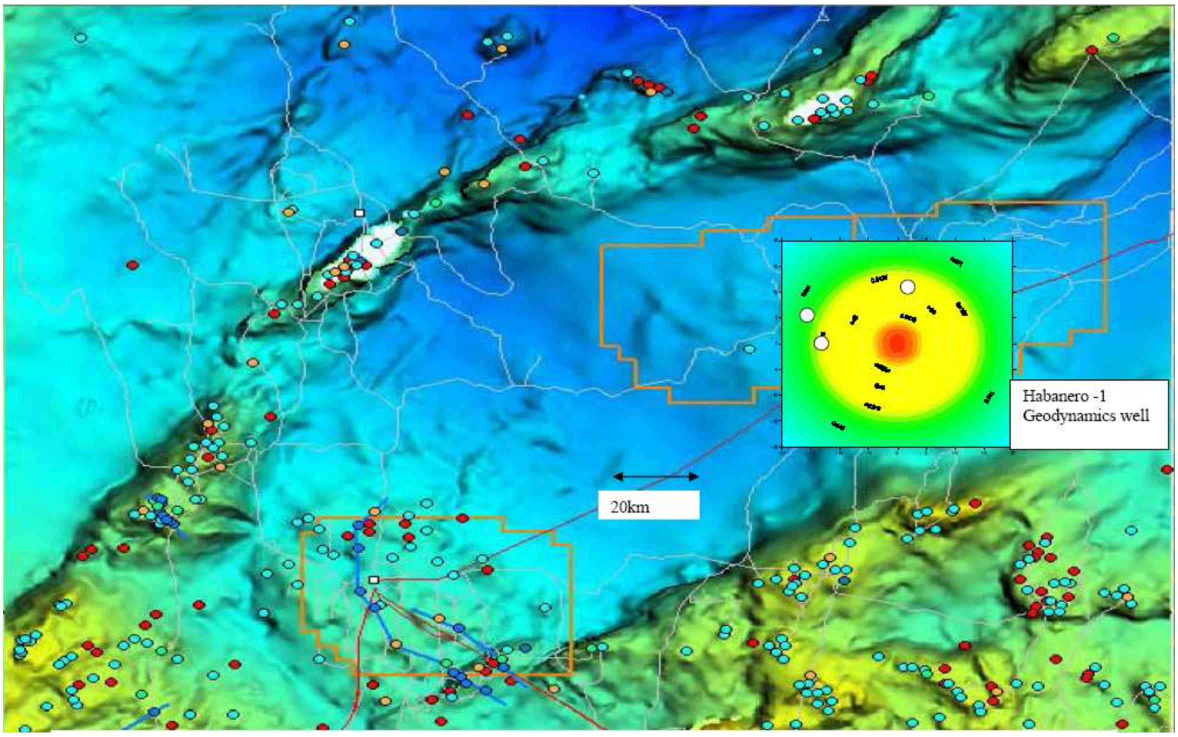

Figure 8.7 Map of basement in the Cooper Basin showing well locations. The inset bullet shows the attenuation radiation distance from Geodynamics' Habanero 1 well site. (After Hunt *et al.*, 2006)

8.7.2.5 Monash University –Victoria

Geothermal research has focussed on measuring and mapping heat flow and temperature distribution in the crust across SE Australia during 2006.

8.7.2.6 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 Northern Territory (NT) power transmission grid looks quite exciting. Hot Springs in the Daly region 100km north west Katherine and at Mataranka 120 km 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 result of this study will be presented at Annual Geoscience Exploration Seminar (AGES) at Alice Springs in March 2007. It will also be 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.

8.8 Geothermal Education & Conferences

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. In 2007 the geothermal web page will be developed and linked to Geoscience Australia's portal. The current site is located at: http://www.pir.sa.gov.au/geothermal.

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, such as:

- On 15-16 February 2006, the 2nd Hot Rock Energy Conference in Adelaide, South Australia was attended by 70 professionals from the geothermal sector, business and government. Twenty four papers were presented over the 2 day conference.

- The Business Council for Sustainable Energy Conference from 3-4 May 2006, in Brisbane, included a paper on HFR.

- The Australian Earth Sciences Convention in Melbourne, Victoria from 2nd - 6th July 2006 included geothermal energy as a major theme. Sixteen papers on geothermal topics were presented. For more information on abstracts and extended papers go to: http://www.earth2006.org.au.

- The AAPG International Conference in Perth, Western Australia from 5th - 8th November 2006 (attended by more than 2600 delegates) included an alternative energy session in which 3 papers on geothermal energy were presented.

Dr Graeme Beardsmore (Monash University, Victoria) ran a 5-day "Introduction to Geothermal Energy" course in 2006 through the VIEPS coursework program in June 2006.

8.9 International Cooperative Activities

Australia is a member of the IEA Geothermal Implementing Agreement. Geodynamics and Green Rock Energy are corporate members of the IEA Geothermal Implementing Agreement.

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

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 3D geological modelling with geothermal temperature and thermal capacity latent in radiogenic granites.

8.10 References

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Somerville, M, Wyborn, D, Chopra, P.N., Rahmann, S.S., Estrella, D. and van der Muellen, T., 1994. "Hot Dry Rocks Feasibility Study", Australian Energy Research and Development Corporation Report 94/243, pp 133.The 2nd Hot Rock Energy Conference, 16-17th February 2006, Adelaide. To order conference proceedings contact: http://www.theajmonline.com

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Attachment 1 – Australian Geothermal Licence Holders (Alphabetical Order)

Clean Energy Australasia is a privately owned company which identifies, evaluates and seeks to invest in geothermal and geosequestration exploration and production properties and facilities. The company has lodged 11 geothermal exploration licence applications (GELs) comprising an area of 5500 square kilometres surrounding existing GELs in the highly prospective Cooper Basin geothermal province in South Australia. For more information visit: http://www.cleanenergy.net.au

Eden Energy Ltd is a new diversified clean energy company that listed on the Australian Stock Exchange in May 2006. Eden has interests in hydrogen storage and transport fuel systems, including: the low emission Hythane® hydrogen-methane blend; a revolutionary cryogenic storage and superconducting magnetic electrical storage device; coal seam and abandoned mine methane; conventional gas; low temperature pyrolysis research into hydrogen production; and geothermal energy production. All these aspects of Eden's business are part of an integrated strategy to become a major global participant in the alternate energy market, particularly focussing on the clean energy transport market, producing hydrogen without any carbon emissions, transporting the hydrogen to markets and providing the engines to power hydrogen-based transport and energy solutions. Eden is exploring for geothermal resources in a number of target areas in South Australia:

1. At Witchellina, northwest of Leigh Creek
2. North of Renmark, on the Murray River
3. Around Moomba in the Cooper Basin, adjacent to Geodynamics' GELs and at Bollards Lagoon
4. At Mungeranie, in the southwest Eromanga Basin region on the Birdsville Track

The company is taking a portfolio approach, aiming to test a number of different geothermal target types, ranging from: the deep hot fractured granite model near Moomba and at Mungeranie; relatively shallow (2-3km) heat sources associated with buried radiogenic iron oxide and granite at Witchellina; and enhanced permeability zones with elevated heat flows in the Renmark Trough associated. If successful, Eden will target electricity markets and clean hydrogen production. Eden Energy was the recipient of a $100,000 PACE 4 grant in December 2006 to assist with drilling a heatflow measurement hole near Renmark in 2007. For more information, visit http://www.edenenergy.com.au

Geodynamics Ltd has first mover advantage in Australia with its Habanero project in the Cooper Basin in NE South Australia and is the only proponent with a proven resource in its tenements. Geodynamics proof-of-concept Habanero project is located where rocks are claimed to be the hottest in the world in a non-volcanic environment (up to 280ºC at 5 km depth). The company has created the world's largest underground heat exchanger by high pressure water injection in two stages in 2003 and 2005. High rates of injectivity into the heat exchanger indicate the presence of large areas of low impedance reservoir where the rock temperature is 250ºC (4.3 km). After completion of the Habanero 2 well, flows of up to 25L/sec and output temperatures of 210ºC (at surface) were measured in 2005. Since encountering problems with the Habanero 2 production wellbore, Geodynamics has set plans to drill Habanero 3 in 2007, and then carrying out a 6 week circulation test to complete the proof-of-concept for EGS in the Cooper Basin. Geodynamics' geothermal tenements in the Cooper Basin cover 986 km^2. In addition it has applied for exploration licenses in Queensland and has two geothermal exploration licenses in NSW. An external consultants report indicate transmission costs from Habanero to electricity markets within the national grid to be less than 0.8 cents per kilowatt hour. Geodynamics was the recipient of a $6.5 million START grant in 2003-4 and a $5 million REDI grant in 2005. The company aims to initially build a 40 MW_e power station connected to the national grid based on 7 wells, and then scale up to at least 280 MW_e. For more information visit http://www.geodynamics.com.au

Geothermal Resources Ltd holds two hot dry rock geothermal exploration projects located within high heat flow areas of South Australia. In both cases the model is based on "hot" radiogenic granites that are buried by a sufficient thickness of insulating sediments. The Frome project lies within the Mesoproterozoic Curnamona Craton, which is characterized by some of the most radiogenic granites in Australia, associated with numerous historic uranium occurrences. In the project area a large body of granite, evidenced by a regional gravity low and non-reflective seismic responses, is interpreted to lie beneath 2-4 kilometres thickness of younger sedimentary cover rocks. Geothermal Resources has been awarded a $ 100,000 PACE 3 grant by the South Australian government to assist with deep drilling for the purposes of obtaining reliable heat flow measurements over the interpreted buried granite complex. The Crower project situated in the SE of South Australia lies along the northern onshore margin of the Otway Basin where early Palaeozoic granites of the Padthaway Ridge dip beneath onlapping Jurassic to Cretaceous sediments. Rapid changes in thickness of the sediments caused by basement faulting and rifting at the time of continental break up provide the opportunity for locally elevated geothermal gradients and optimal depths of burial. Both projects are well located with respect to existing power grids. Geothermal Resources raised $3million in an IPO in February 2006 and has subsequently been awarded a REDI grant of $2.4 million to assist with the drill testing of its Frome Project. The Company plans to commence an eight hole drilling program on its Frome Project in early March 2007 to establish geothermal gradients and heatflow. For more information please visit: http://www.havilah-resources.com.au/geothermal_energy.html and http://www.geothermal-resources.com.au

Granite Power Ltd (previously Proactive Energy Development Ltd) is a privately held company that plans to explore for hot rocks at intermediate depths in proximity to the existing high voltage grid to connection to Olympic Dam. Granite Power has commenced geotechnical model building in GEL207 Roxby Downs in SA, and field inspection work is planned, with an ex- WMC project manager to guide on past exploration drilling activity. The Company has also commenced geotechnical model research for the Felton EPM in SE Qld. Granite Power has completed a geotechnical model on the Bulli EL6360 in NSW, and is currently seeking funding to drill a 3,000+m well there later this year. The Company has received research grants for new heat exchanger technology and new desalination technology, both of which bear beneficially on the economics of potential hot rock resources. The Company was recently granted an EL for geothermal energy near Ulan, NSW. The Company plans to list on AIM and/or the ASX in the first half of 2007 and was the recipient of a $ 1.22 million REDI grant in December 2006.

Green Rock Energy Ltd is a public company listed on the Australian Stock Exchange which is undertaking the evaluation and development of a hot dry rock ("HDR") geothermal power plant on its geothermal exploration licences in central South Australia in preparation for the construction of power plants with a base load electricity capacity of no less than 400 MW. Green Rock Energy holds a 100% interest in an area of around 3,000 km² next to BHP Billiton's world class Olympic Dam mine in South Australia. In 2005, Green Rock drilled Blanche No 1, its first exploratory diamond geothermal well, to a depth of nearly 2 kilometres and located only 5 kms from a high voltage power transmission line connected to the national power grid which supplies electricity to eastern Australia's major cities. The Company plans to carry out a "mini-frac" program in the granites in its Blanche No 1 well in 2007. The data gathered from this program will provide the Company with information to assist the design of the first of two deep wells to be drilled nearby and the fracture stimulation program to set up a water circulation system between those wells. The Company also has a 32% interest in a project in Hungary which plans to produce geothermal water for electricity generation and direct heat for industrial and agricultural uses. Production testing of water flow rates from existing wells has commenced at the Hungarian Project. Success with this testing could lead to the first geothermal power plant in Central Europe. For more information, visit http://www.greenrock.com.au.

Hot Rock Energy Pty Ltd is operator of Exploration Licence (EL) 6212 in the Sydney Basin, New South Wales. This licence area covers approximately 5,500 sq. kms and was granted in 2004 to Longreach Oil Ltd (50%) and Hot Rock Energy Pty Ltd (50%). It is currently undertaking a technical review of the Sydney Basin, incorporating petroleum, coal and water well data with the aim of identifying areas of high heatflow. The outcome of the study will lead to the isolation of certain areas of abnormally high geothermal gradients to provide the focus for shallow drilling in 2006.

KUTh Exploration Pty Ltd is a privately owned company that was granted Special Exploration Licence (SEL) 26/2005 by the Tasmanian Department of Mines, Energy & Resources in August 2006 to explore for geothermal resources. The SEL, which covers an area of 12,360 sq km, has been granted for 5 years and covers a large area of Tasmania known to contain high heat flux granites (with widespread extensions of granite under cover mapped by gravity), a cover sequence including coal measures and is on the Tasmanian power grid, which is connected to the National grid via Basslink. A variant geothermal target within the SEL is the Tamar (electrical) Conductivity Zone, a large scale and deep conductive anomaly which, if caused by the suspected deep, brine filled fracture zone, could provide a ready-made geothermal target where it intersects thermally anomalous granite. The company is undertaking an active field program in 2007 including heat flow measurements of a large number of existing drill holes and corresponding rock thermal conductivity measurements, plus magneto-tellurics and perhaps seismic in order to refine the geothermal map of Tasmania and the topography of the granites under cover. Slim hole drilling to ~1,000m on targets generated will follow. The company is planning a float on the ASX either late 2007 or in early 2008. For more information visit: http://www.kuthenergy.com.

Osiris Energy Pty Ltd is a privately held Australian company that aims to locate, define and exploit geothermal resources suitable for power generation and other ancillary uses requiring energy in the form of heat. Osiris has received two geothermal exploration licences in South Australia (GEL 220 and 221) in the Cooper Basin in the northeast of the State and will be offered the Otway Basin GELA 223 in 2007. Osiris Energy Pty Ltd is currently an unlisted company, but plans to list on the Australian Stock Exchange.. http://www.osirisenergy.com.au.

Pacific Hydro Ltd is exploring for sediment-hosted geothermal resources in the South Australian extent of the Great Artesian Basin to support a 400MW conventional geothermal project. Pacific Hydro holds 18 Geothermal Exploration Licenses covering 9,000km^2 in South Australia and has successfully completed Year 1 of its GEL work program to delineate the resource and define exploration targets. In Year 2 (2006), downhole temperature logging in existing water bores confirmed thermal gradients of 50ºC/km, which are some of the highest thermal gradients recorded in Australia, with an indicative resource temperature of about 133ºC at 2km depth. Further temperature upside is expected from exploration wells targeting the Hutton/Poolowanna reservoir package in the area of a pronounced gravity low, inferred to reflect underlying high heat production granite basement rocks. Re-interpretation of petroleum exploration seismic data has identified potential low frequency zones interpreted as channel systems and faults which may provide further temperature and permeability enhancement.

Petratherm Ltd listed on the ASX in July 2004 and in May 2006 appointed Terry Kallis as Managing Director. Mr Kallis has considerable experience in the power industry and renewable energy project development to complement the skills and capabilities of Petratherm's board and current operations management. In June 2006, successful phase-2 drilling program was completed at Paralana with the geothermal test well being extended from 485 metres to 1807 metres. Temperature logging of the well confirmed a world class thermal resource at Paralana with temperatures of approximately 200 ^{o}C expected at a depth of 3.6 kilometres. Petratherm successfully secured a PACE 2 grant of $ 140,000 to partially fund its Paralana Project drilling programme.

The company plans to drill Paralana 2 in either late 2007 or early 2008 to a depth of 3.6 kilometres and conduct fracture stimulation and flow testing.

Petratherm's flagship Paralana Project aims to initially provide electricity to the local market – the growing needs of the neighbouring Beverley Uranium Mine, from around 7.5 MW building to 30

MW, and then to expand to around 520 MW and supplying the National Electrcity Market, via two entry points, namely, Port Augusta and Olympic Dam.

For further information, visit: http://www.petratherm.com.au.

Red Hot Rocks Pty Ltd (RHR) is the geothermal subsidiary of Mobius Resources Australia Pty Ltd. RHR was formed in 2006 to examine potential commercial geothermal projects. The company participated in the 2006 applications for Geothermal Tenements in Queensland and was offered three of the available areas. Finalisation of these offers is pending resolution of Native Title issues. RHR policy is to seek involvement in the industry either as operator of specific projects or in joint venture with partners. Further information is available from Domain Capital at Level 16, 379 Collins Street, Melbourne, Vic 3000.

Scopenergy Ltd is focused on searching for hot water in hot sedimentary rocks in proximity to recent volcanic activity in the South East of South Australia, around Millicent. The company holds contiguous Geothermal Exploration Licences totalling 2,634 km^2 covering substantially all of Australia's most recently active volcanic province (5,000 yrs BP). Scopenergy commenced a slim hole (100 mm) drilling program in January 2006, seeking to confirm several large scale heat flow anomalies previously measured in 19 petroleum exploration wells and 26 water wells in the vicinity of its tenements. This program found that poor core recovery from unconsolidated sediments impeded reliable heat flow estimation. The company is now considering a production scale hole to reservoir depth and/or a 3D seismic program to better define drilling targets. Scopenergy's areas are well served by 275 kV and 132 kV transmission lines. Scopenergy's business model seeks to generate hydrothermal power from water at or above 170°C hosted in a known deep aquifer of the Otway Basin, in proximity to recent volcanic activity and the existing electricity grid. The company is the recipient of a $ 4 million Australian Government REDI grant to fund an extensive drilling and 3D seismic program and also successfully secured a PACE 2 grant of $ 130,000 to partially fund its South East drilling program that commenced in January 2006. Scopenergy is a privately owned company. For further information, telephone +61 2 9250 0133 (international) or 02 9250 0133 (in Australia).

Torrens Energy Ltd plans to explore for HFR/EGS Resources in the highly prospective South Australian Heat Flow Anomaly (SAHFA). The Company has been granted 14 GELs covering over 6,700 km^2. The existing power grid runs through, or is adjacent to, all of Torrens' Project areas, and major roads, towns and the city of Adelaide are located nearby. There are three project areas, named the Torrens, Barossa-Clare and Adelaide Projects. The GELs of the Adelaide Project are located a few kilometres north of the city, in its northern suburbs. Torrens will explore for high temperature resources, which will include activities such as 3D modelling, seismic work and a comprehensive shallow drilling program to identify suitable targets for deep drilling. Exploration success for the Company will come in the form of the identification from shallow drilling of areas of high heat flow. Torrens Energy Ltd has been awarded a $100,000 PACE 4 grant by the South Australian government to assist with its drilling for high heat flow in the Barossa-Clare Project. The Torrens and Adelaide Projects lie in the Torrens Hinge Zone where thick sedimentary cover overlies the world famous Olympic Domain where uranium rich rocks occur. The Company has undertaken independent thermal conductivity measurements on rocks and heat flow estimation on existing drillholes in the areas. The results of this work confirm both the insulating properties of the sediments as well as the presence of high heat flow. Torrens has engaged the services of Hot Dry Rocks Pty Ltd and GeothermEx Inc, Australia's and the USA's leading geothermal consultants, respectively.

Tri-Star Energy Company has made application for GELAs 264 and 265 in the western Great Artesian Basin of South Australia. The two GELAs comprise approximately 1,000 km^2 and are located west of Marree in central South Australia. Upon grant, the work programme for each area will include the investigation and review all relevant existing data to determine the geothermal potential of the areas prior to completing a feasibility and market study. Favourable results will support the drilling of an injection well and a production well during the term to underpin the future development of an electrical generation plant.

For further information, please contact Tri-Star Energy Company, which is one of the Tri-Star Group of companies that has offices in Australia in Brisbane, Queensland, telephone +61 7 3236 9800; and in the USA in Houston, Texas, telephone +1 713 222 0011.

Waterflea Pty Ltd is a Newcastle based geothermal exploration company that applied for ELA 2809 about 12 km southeast of the township of Awaba, near Lake Macquarie in New South Wales. Postal address: PO Box 683, Newcastle, NSW 2300.

Attachment 2. AGEG Membership

Company/Organisation	Name	Title	Address	E-mail	Telephone
Australian Greenhouse Office	Craig Midson	Geothermal Resource Assessment Project	GPO Box 787, Canberra ACT 2601	craig.midson@ago.gov.au	02 6274 1717
Clean Energy Australasia Ltd	Joe Reichman	CEO	PO Box 63, Sherwood QLD 4075	joe.reichman@bigpond.com	07 3379 7540
Department of Industry, Tourism and Resources	John Söderbaum	Science & Technology Advisor - Energy & Environment Division	GPO Box 9839, Canberra ACT 2601	john.soderbaum@industry.gov.au	02 6213 7865
Department of Industry, Tourism and Resources	Ralf Ernst	Assistant Manager – Energy technology and Research	GPO Box 9839, Canberra ACT 2601	ralf.ernst@industry.gov.au	02 6213 7302
Earthinsite.com Pty Ltd	Prame Chopra	Director	PO Box 3972, Weston ACT 2611	prame.chopra@earthinsite.com	02 6162 0005
Eden Energy Ltd	Graham Jeffress	Senior Geologist	PO Box Z5360 St Georges Tce Perth WA 6831	gjeffress@edenenergy.com.au	08 9221 5323
Geodynamics Ltd	Adrian Williams	CEO	Suite 6, Level 1, 19 Lang Parade, Milton QLD 4064	awilliams@geodynamics.com,au	07 3721 7500
Geodynamics Ltd	Doone Wyborn	Chief Scientific Officer	Suite 6, Level 1, 19 Lang Parade, Milton QLD 4064	dwyborn@geodynamics.com.au	07 3721 7506
Geoscience Australia	Anthony Budd	Geothermal Project Leader	GPO Box 378, Canberra ACT 2601	anthony.budd@ga.gov.au	02 6249 9574
Greenrock Energy Ltd	Adrian Larking	Managing Director	PO Box 1177, West Perth WA 6872	alarking@greenrock.com.au	08 9482 0482
Greenrock Energy Ltd	Alan Knights	Executive Director	PO Box 1177, West Perth WA 6872	aknights@greenrock.com.au	08 9482 0482
Havilah/Geothermal Resources Ltd	Bob Johnson	Chairman	63 Conyngham Street, Glenside SA 5065	geo@havilah-resources.com.au	08 8338 9292
Intrepid Geophysical	Des Fitzgerald	Managing Director	2/1 Male Street, Brighton, VIC 3186	des@dfa.com.au	03 9593 1077
KUTh Energy Pty Ltd	Malcolm Ward	Operations Manager	35 Smith Street, North Hobart, TAS 7000	mward@kuthenergy.com	0411 267 453
NT Department of Primary Industry, Fisheries & Mines	Tony Waite	Principal Geologist	GPO Box 3000, Darwin NT 0801	tony.waite@nt.gov.au	08 8999 5428

Company/Organisation	Name	Title	Address	E-mail	Telephone
Monash University - School of Geoscience	Graeme Beardsmore	Senior Research Fellow	Monash University, VIC 3800	graeme.beardsmore@sci.monash.edu.au	03 9905 1169
NSW DPI	Brad Mullard	Director Coal & Petroleum Development	PO Box 344, Hunter Region Mail Centre NSW 2310	brad.mullard@dpi.nsw.gov.au	02 4931 6404
Osiris Energy Pty Ltd	Ian Reid	Director	PO Box 871, South Yarra VIC 3141	ian.reid@osirisenergy.com.au	0417 391 789
Pacific Hydro Pty Ltd	Terry Teoh	Development Manager - SA	30 Kensington Road, Rose Park SA 5067	tteoh@pacifichydro.com.au	08 8333 2833
Panax Geothermal Pty Ltd	Bertus de Graaf	Managing Director	27 Hazelmere Pde, Sherwood QLD 4075	ldegraaf@bigpond.com	07 3278 1205
Petratherm Ltd	Terry Kallis	Managing Director	105-106 Greenhill Rd, Unley SA 5061	tkallis@petratherm.com.au	08 8274 5000
PIRSA	Barry Goldstein	Director – Petroleum & Geothermal	Level 6, 101 Grenfell Street, Adelaide SA 5000	goldstein.barry@saugov.sa.gov.au	08 8463 3200
PIRSA	Tony Hill	Principal Geologist	Level 6, 101 Grenfell Street, Adelaide SA 5000	hill.tonyj@saugov.sa.gov.au	08 8463 3225
Proactive Energy Developments	Stephen de Belle	CEO	Level 21, 201 Miller Street, North Sydney NSW 2060	sdb@mantlemining.com	02 9959 2348
Qld Department of Mines & Energy	Russell D'Arcy	Manager – Strategic Initiatives & Partnerships	GPO Box 2454, Brisbane Qld 4001	russell.darcy@nrm.qld.gov.au	07 3237 1475
Red Hot Rocks Pty Ltd	John Shirley	Director	56 Motherwell Street, South Yarra VIC 3141	jjshirley@bigpond.com	03 9827 3952
Renewable Energy Generators of Australia Ltd	Susan Jeanes	CEO	PO Box 1048, Flagstaff Hill, SA 5159	ceo@rega.com.au	08 8270 7227
Scopenergy Ltd	Roger Massy-Greene	Managing Director	Level 9, 1 York Street, Sydney NSW 2000	RogerMG@scopenergy.com.au	02 9250 0121
Tas Department of Infrastructure, Energy & Resources	Carol Bacon	Managing Geologist	GPO Box 936, Hobart Tasmania 7001	carol.bacon@dier.tas.gov.au	03 6233 8326
Torrens Energy Ltd	Chris Matthews	CEO	6 Hollywood Way, Glenalta SA 5052	chris.matthews@torrensenergy.com	08 8178 0636
Tri-Star Energy	Vic Suchocki	Land Manager	PO Box 7128 Riverside Centre, Brisbane QLD 4001	Brisbane@tri-starpetroleum.com	07 3236 9800
University of Adelaide	Richard Hillis	SA Chair and Associate Dean Research Science	The University of Adelaide SA 5005	Richard.hillis@adelaide.edu.au	08 8303 3080

Company/Organisation	Name	Title	Address	E-mail	Telephone
UNSW - School of Petroleum Engineering	Sheik Rahman	Associate Professor	University of NSW, NSW 2052	sheik.rahman@unsw.edu.au	02 9385 5659
VIC DPI	Kathy Hill	Director Geoscience Victoria	GPO Box 4440, Melbourne VIC 3001	kathy.hill@dpi.vic.gov.au	03 9658 4562
VIC DPI	Jim Driscoll	Senior Geologist	GPO Box 4440, Melbourne VIC 3001	jim.driscoll@dpi.vic.gov.au	03 9658 4535
WA DOIR	Bill Tinapple	Director Petroleum & Royalties	Level 11, 100 Plain Street, East Perth WA 6004	bill.tinapple@doir.wa.gov.au	08 9222 3291
WA DOIR	Maryie Platt	Manager Native Title & Heritage	100 Plain Street, East Perth WA	maryie.platt@dor.wa.gov.au	08 9222 3813

Attachment 3. The Australian Geothermal Energy Group (AGEG)

Preface

The Australian Geothermal Energy Group (AGEG) provides financial and intellectual support for Australia's membership in the International Energy Agency's Geothermal Implementing Agreement. Members of AGEG include representatives from:

- Companies with entitlements to undertake geothermal exploration (research), appraisal (proof-of-concept), demonstration and development projects in Australia
- Companies and organisations providing services to the geothermal sector
- Government agencies responsible for investment attraction and licence regulation for the geothermal sector
- University experts conducting relevant research

The members of the AGEG have a common interest in sharing information to commercialise Australia's geothermal resources at maximum pace and minimum cost in Australia's competitive energy markets.

An articulation of AGEG's vision and terms of reference follows.

AGEG's Vision

Profitable renewable and emissions-free geothermal energy is at least 15% of installed base-load power generation capacity and meets more than 10% of Australia's power demand by 2050.

AGEG's Terms of Reference

Reduce critical shared uncertainties at minimum cost and maximum pace to foster the commercialisation of Australia's geothermal energy resources. Collectively:

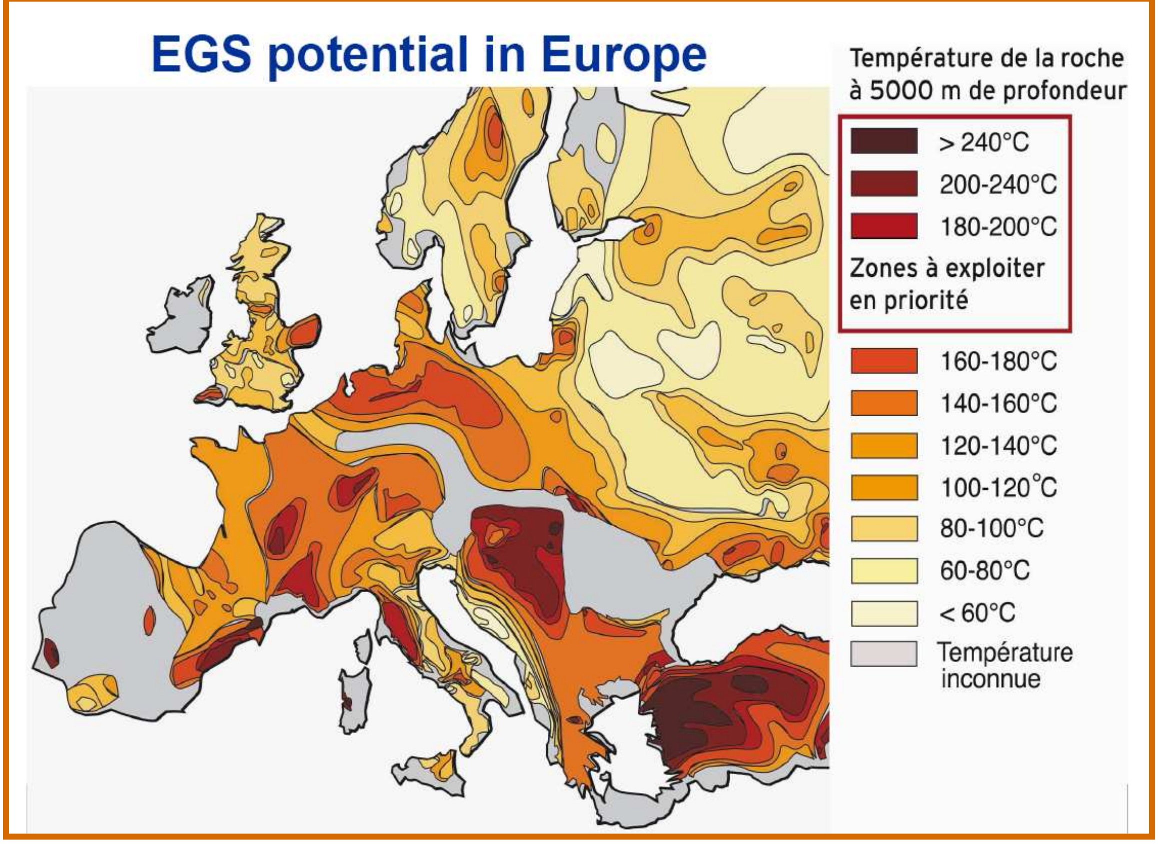
- Promote effective cooperation on geothermal Research, Demonstration &Development (RD&D) through collaborative work programs, workshops and seminars
- Collect, improve, develop and disseminate geothermal RD&D policy information
- Identify geothermal RD&D issues and opportunities to commercialise geothermal energy projects at maximum pace and minimum cost by: improving current geothermal technologies and methods; and developing new geothermal technologies and methods
- Broaden and increase the dissemination of information on geothermal energy and outputs to decision makers, financiers, researchers and the general public

Member Organisations	Representatives
Australia's Contracting Party for the IEA's GIA **and** **South Australian Government**	**Barry Goldstein -** GIA ExCom Member, Chair - Australian Geothermal Energy Group and Director **-** Petroleum & Geothermal Group, Primary Industries & Resources SA
	Tony Hill – GIA ExCom Alternate, Secretariat - Australian Geothermal Energy Group, and Principal Geologist, Petroleum & Geothermal Group, Primary Industries & Resources – SA
Australian Federal Government	**John Söderbaum**, Science & Technology Advisor - Energy & Environment Division, Dept. of Industry, Tourism &Resources
	Anthony Budd, Geothermal Project Leader, Geoscience Australia
	Ralf Ernst, Geothermal Roadmap Project, Dept. of Industry, Tourism &Resources
	Craig Midson, Resource Assessment Project, Australian Greenhouse Office
Clean Energy Australasia Pty Ltd	**Joe Reichman**, CEO
Earthinsite Pty Ltd	**Prame Chopra**, Director
Eden Energy	**Graham Jeffress**, Senior Geologist
Geodynamics Ltd	**Adrian Williams**, CEO
Granite Power Ltd (formerly named **Proactive Energy Development**)	**Stephen de Belle**, CEO
Greenrock Energy Ltd	**Adrian Larking**, Managing Director
Geothermal Resources Ltd	**Bob Johnson**, Chairman
Intrepid Geophysical	**Des Fitzgerald**, Managing Director
KUTh Energy	**Malcolm Ward**, Operations Manager
Monash University	**Graeme Beardsmore**, Senior Research Fellow, School of Geoscience
New South Wales State Government	**Brad Mullard**, Director Sustainable Development, Department of Primary Industries
Northern Territory Government	**Tony Waite**, Principal Geologist, Department of Primary Industry, Fisheries & Mines
Osiris Energy Pty Ltd	**Ian Reid**, Director,
Pacific Hydro Ltd	**Terry Teoh**, Development Manager – South Australia,
Panax Pty Ltd	**Bertus de Graaf**, CEO
Petratherm Ltd	**Terry Kallis**, Managing Director
Queensland State Government	**Russell D'Arcy**, Manager Strategic Initiatives & Partnerships, Department of Natural Resources & Mines
Red Hot Rocks Pty Ltd	**John Shirley**, Director
Renewable Energy Generators Australia Ltd	**Susan Jeanes**, CEO
Scopenergy Ltd	**Roger Massy-Greene**, Director
Tasmanian State Government	**Carol Bacon**, Managing Geologist, Department of Infrastructure, Energy & Resources
Torrens Energy Ltd	**Chris Matthews**, CEO
Tri-Star Energy	**Vic Suchocki** , Land Manager
University of Adelaide	**Dr Martin Hand**, Dept. of Geology & Geophysics **Professor Richard Hillis**, Dept of Geology & Geophysics & Australian School of Petroleum
University of New South Wales	**Sheik Rahman**, Associate Professor, School of Petroleum Engineering
Victorian State Government	**Kathy Hill**, Director Geoscience, Department of Primary Industries
West Australian State Government	**Bill Tinapple**, Director Petroleum & Royalties, Department of Industry and Resources

NATIONAL ACTIVITIES

Chapter 9

European Commission



EGS potential in Europe (from Jeroen Schuppers EC report, 17th Executive Committee Meeting, Nice, France, 22-23 March 2007).

9.0 European Union Policy

While the EU has set legislation on the promotion of electricity generation from renewable energy sources (with an objective of the share of electricity produced by renewable energy of 21% by 2010) and for the promotion of biofuels (with an objective of 5.75% by 2010), the production of heating and cooling from renewable energy has so far not been the subject of specific EU legislation.

On 14 February 2006, the EU Parliament adopted a report with recommendations for the Commission to work on heating and cooling from renewable sources of energy. The Commission is presently working on a possible initiative to promote heating and cooling from renewable energy sources. An Impact Assessment study was started in 2006.

The Commission launched a public consultation with the objective to contribute to the above mentioned Impact Assessment by providing a range of opinions and new and innovative ideas regarding the implementation and the impacts of different types of policies and measures that could be considered to promote heating and cooling from renewable energy sources. This information will be taken into account in the further preparatory work on this dossier.

This public consultation addresses all renewable energies used to produce heating and cooling: solar thermal, geothermal and heat pumps, and biomass; as well as all types of measures/policies in order to evaluate their potential. Furthermore, all sectors of activity (the public sector, industry, energy services and district heating, tertiary and domestic) are addressed.

9.1 Current Status of Geothermal Energy Use in 2006

9.1.1 Electricity Generation

Few European countries have the natural resources necessary for electrical generation of geothermal energy. Total installed capacity in the European Union in 2006 amounted to 855 MW_e, with a total generation of about 5,693 GWh/y. Italy has the major high temperature geothermal resources in the EU, (810 MW_e), and alone represents nearly 95% of total European capacity. The other countries are Portugal, which is developing installations on the volcanic archipelago of the Azores; France, which is exploiting the Bouillante site in Guadeloupe; as well as Germany and Austria, which have been developing this sector for a short period of time.

9.1.2 Direct Use

In the 25 member European Union at the end of 2006, medium and low temperature geothermal energy represented a capacity of 2,491 MW_{th} (for geothermal use of about 16,590 TJ/y), excluding geothermal heat pumps. Hungary is the biggest user of medium and low temperature geothermal energy with, according to the Hungarian Association for Geothermal Energy, installed capacity of 725 MW_{th}. Italy is the second ranked European Union country for low temperature applications with, according to the UGI (Italian Geothermal Union) and the Enel, a capacity of 500 MW_{th}. France, ranked third in the EU with 307 MW_{th} installed at the end of 2006, has developed urban heating networks more (GEB, 2007).

The European Union is one of the main regions to have developed heat pump technology. It is estimated that in 2006 there were about 600,000 geothermal heat pump units, equivalent to 7,329 MW_{th}. Geothermal energy use corresponding to this capacity is of the order of 0.78 Mtoe. Sweden has the largest number of heat pumps with more than 270,100 units, i.e. a cumulated capacity of 2,431 MW_{th}. It is ahead of Germany (90,520 units, i.e. 996 MW_{th}), France (83,860 units, i.e. 922 MW_{th}), Denmark (43,250 units, i.e. 820 MW_{th}, Austria (40,150 units, i.e. 665 MW_{th}) and Finland (33,610 units, i.e. 720 MW_{th}) (*ibid.*).

9.2 Research Activities in the European Union in 2006

9.2.1 New Activities

In 2006, one new geothermal research project has been selected for Commission support: HITI (High Temperature Tools and Instruments). The project started officially on 1 January 2007, but it is financed from the budget of the 6th Framework Programme (2002-2006).

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 is currently being drilled for this purpose into the Iceland volcanic zone, with Iceland a major participant in the Iceland Deep Drilling Project (IDDP), which receives 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 downhole tools and approaches for deep high-temperature boreholes. The 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 thermomechanical 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) and reservoir storativity and equilibrium (from geothermometers and organic tracers). 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.

9.2.2 EGS Pilot Plant

The aim of this project, located at Soultz-sous-Forêts, Alsace, France, is to establish the world's largest and most efficient EGS system at a depth of about 5,000 m. The system will consist of one central injection borehole and two symmetrically deviated production boreholes, each separated by about 500 m from the injection hole at depth (Figure 9.1). The surface circulation loop has been designed in order to enable permanent production from side wells GPK2 and GPK4 with re-injection via the central well, GPK3. A total flow rate of 80 l/s was initially envisaged, equivalent to a total thermal power of 50 MW_{th} and an electric power of 6 MW_e. The aim is to bring a 1.0 MW_e scientific pilot plant on line by the second half of 2007, and to increase this to some 4-5 MW_e within the following year.

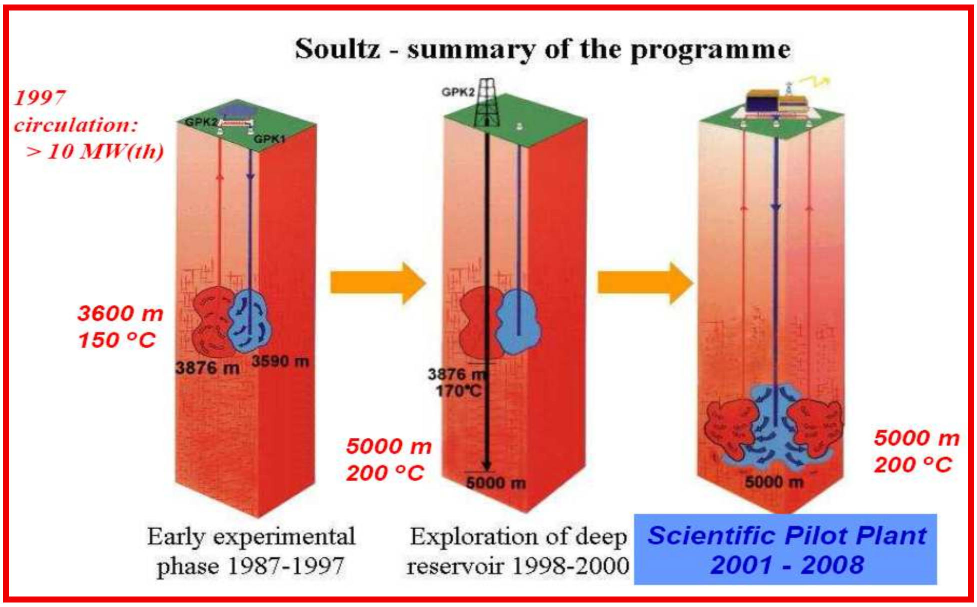


Figure 9.1 The Soultz-sous-Forêts EGS project in Alsace, France, is expected to have the scientific pilot plant on-line in the second half of 2007.

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NATIONAL ACTIVITIES

Chapter 10

Germany

Drill rig at Landau geothermal site (courtesy of Lothar Wissing)

10.0 Introduction

The goal the Federal Government set itself is a renewables share in gross electricity consumption of at least 12.5% in 2010. The medium term objective for the Federal Government is to increase the share of renewable energies in the electricity supply to at least 20%, and in primary energy consumption to at least 10%, by 2020. In the long run, i.e. by around 2050, about half of the energy supply is to be met by renewable energies.

The Act on granting priority to renewable energy sources (Erneuerbare-Energien-Gesetz, EEG) of 21 July 2004 makes it compulsory for operators of power grids to give priority to feeding electricity from renewable energies into the grid and to pay fixed prices for this. The adoption of the precursor to the Renewable Energy Sources Act in 1990 triggered a major increase in wind power generation. The entry into force of the Renewable Energy Sources Act in the year 2000 has led to a similar boom in biomass and photovoltaics. The use of geothermal energy for electricity generation has also developed considerably. The Renewable Energy Sources Act has thus proved to be an exemplary and successful tool of energy policy.

In 2006, the use of renewable energies continued to develop very positively. Their share in primary energy consumption increased from around 4.7% in 2005 to around 5.3% in 2006 (calculated according to the so-called physical energy content method). In comparison with 2000 (2.6%), this is more than double. The contribution to total final energy supply (electricity, heating, fuel) increased to 7.4% in 2006 (2005: 6.6%). The importance of renewable energies for climate protection remains high: For 2006, their total CO_2 reduction was calculated at around 97 Mt (through substitution of other energy forms in the electricity, heating and fuel sectors), of which around 44 Mt CO_2 saving resulted from the Renewable Energy Sources Act (EEG) alone. In 2006 alone, an additional CO_2 saving of around 11 Mt was achieved through the expansion of renewable energies.

10.1 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 CO2 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

Geothermal energy use in Germany is still in its initial stage. The installed capacity amounted to 230 kW_e for power production.

Due to the relatively favorable temperature characteristics, the geological situation and also the economic structure, for the foreseeable future the Upper Rhine rift valley and the Fore Alp Region near Munich is of interest for commercial geothermal power plants. In the North German basin and also in regions of crystalline rock, research mainly aims at establishing an economic operation of geothermal heating plants even at low flow rates and/or low temperatures.

Beside the use of deep geothermal resources the use of ground heat by ground coupled heat pumps in of increasing interest in Germany. In 2006, more than 24,000 heat pump systems were installed, making the estimated total number of systems more than 100,000 for the private and commercial sectors as well as for public buildings. In consequence, the awareness of the possibilities of geothermal power is increasing enormously in Germany. Every month about 2,000 systems are going into operation.

Important for the further development of geothermal applications are successful stories like the project in Unterhaching near Munich, which completed the second borehole at January 2007.

Now two wells are available with a temperature about 120 ^{o}C and a flow rate of 100-150 l/s for the generation of electricity and the supply to a district heating system. The plant is expected to produce up to 3.36 MW_e and 28 MW_{th} of heat.

Besides the Renewable Energy Sources Act (EEG), the Federal Ministry for Environment, Nature Conservation and Nuclear Safety supports R&D in geothermal energy with the 5th Energy Research Programme of the Federal Government.

Research funding can make an important contribution to bringing geothermal electricity generation closer to market maturity, by helping reduce the costs and risks involved in exploiting geothermal energy must be further reduced. The decisive group of costs for geothermal electricity generation is represented by drilling operations. Until boreholes reliably demonstrate the extent to which thermal energy and later electricity can be obtained, up to 80 % of the overall capital cost may have been expended. Drilling work therefore represents a great investment risk.

During the last three years, the funding of geothermal projects increased steadily: 2004, 5.9 M€; 2005,10.7 M€ and 2006, 14.0 M€.

In 2006, the geothermal part of funding was about 18 % of the total research budget for renewable energies.

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 (150 kW_e) and about 0.2 GWh/y was generated in 2006. This remains the only geothermal power plant in Germany.

10.2.1.1 Rates and Trends in Development

The geothermal project in Unterhaching has completed the second borehole successfully. Consequently, the installation of a Kalina-Plant started in spring 2006, and is planned to go into operation in autumn 2007, with 3.36 MW_e installed capacity and 28 MW_{th} heat production.

The community of Bruchsal announced in July 2006 that it would install a geothermal power plant, with construction to begin at the end of the year.

In Landau, the second well was completed to a depth of about 3,100 m, with the temperature of the produced brine of about 140-150 °C. An ORC-turbine having a capacity of 2.5 MW_e has been ordered. The plant will go into operation in 2007.

With the success of these projects, which proved the feasibility of exploiting deep geothermal resources in Germany, many new projects are planned, particularly around the Munich /Unterhaching area. It is estimated that about 80 projects in Bavaria are planned, with a total investment of about 3.2 billion €.

10.2.2 Direct Use

10.2.2.1 Installed Thermal Power

In 2006, the total direct use of geothermal energy was about 6,865 TJ/y. The installation of heat pumps was a booming business, with installations of 2,000 units per month. It is estimated that around 100,000 earth coupled heat pumps are now installed with a total capacity of nearly 1 GW_{th}.

Large installations in a range between 2 and 11 MW_{th} exist in Neustadt-Glewe, Unterschleißheim, Erding, Straubing, Waren (Müritz) and Wiesbaden.

10.2.3 Energy Savings

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

10.3 Market Development and Stimulation

The turnover in 2006 resulting from the construction of plants for the use of geothermal energy is about 580 M€. Figures are not currently available for single technologies like heating pumps, district heating or deep geothermal energy.

Financial sources for promoting the use of geothermal energy are given by soft loan programmes of the KfW Promotional Bank and single programmes of the Federal States mainly designed for private applications, e.g. heat pumps systems. In the heating sector, almost 140,000 plants were supported through the German government's market incentive programme, thus triggering investment of 1.5 billion €.

Due to the current 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.

For the deep drilling sector, some projects will postponed due to high prices and shortage of drilling rigs.

10.4 Development Constraints

The average geothermal gradient in Germany is 30 °C/km, so quiet low for deep geothermal applications. Only in certain regions like the upper Rhine rift valley and the German mollasse basin do higher geothermal gradients occur. Therefore deep drilling down to 3000-4000 m is necessary to reach temperatures above 100 °C required 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 of the regions of interest. In the northern basin of Germany the geothermal sources also have a high salinity.

Currently, the availability of drilling rigs is poor due to the huge demand by oil industry. The prices are consequently high for drilling, so some projects are being postponed.

10.5 Economics

The production price of conventional generated electricity is about 4-7 ct€/kWh and the consumer prices are between 15 and 20 ct€. Prices for energy from oil, gas, coal, and electricity are dependent upon world market prices.

Electricity generation by geothermal techniques is not yet competitive without governmental funding. Consequently, the simultaneous use of the heat for district heating is essential for the economic success of a project. For this reason the tendency can be recognized to design projects more for district heating than for electricity generation.

The figures for future investments are quiet variable, with some sources mentioning an investment volume about 5.5-6.5 billion €.

Geothermal electricity generation is being funded by 0.15 €/kWh for plants up to 5 MW_e installed capacity.

In 2006, 4,100 people were employed in the geothermal sector.

10.6 Research Activities

10.6.1 Focus Areas

With the calls for proposals published in the Federal Gazette No. 179 on 21 September 2006, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety was setting new priorities for research support in the renewables sector. Relating to geothermal energy, heat generation will gain importance. It is also planned to provide some support to new and promising technologies with a high potential for innovation. Support is also intended for international projects and technologies for export. Hence, within the calls for proposal, there is slight shift in priorities from more basic research towards practical application:

- Development of methods to minimize the finding risks for wells
- Development of measurement methods and of devices for geothermal wells with high pressure, temperature and corrosion
- Improvement of drilling technology particularly for geothermal applications
- Improvement of energy conversion processes like ORC, Kalina-cycle
- Integration of geothermal energy into local heat and electricity grids
- Development and improvement of methods and processes influencing the management of the resources and productivity like stimulation processes, frac–processes and monitoring

10.6.2 Government Funded R&D Projects

10.6.2.1 Neustadt-Glewe

Neustadt-Glewe is the first geothermal plant generating electricity in Germany. The heat production has been operating very successfully since 2003. In November 2003, the organic Rankine cycle was installed for electricity production. After 5 years of operation and electricity generation, an evaluation of operational parameters of the geothermal heat plant will be carried out and funded by 2 M€.

10.6.2.2 Groß Schönebeck

A hot water rock storage reservoir was prepared in the sedimentary North-German Basin for the use of geothermal heat. In 2006, the second borehole was completed to 4,400 m depth. The project was funded by 14.3 M€.

10.6.2.3 Hannover (Horstberg II)

A study concerning the one-probe-two-layer-method was carried out by two institutes. The goal is to examine methods for extraction of geothermal heat from sedimentary rocks. During hydraulic tests, temperature and pressure logs will run as well as seismic detection. The results are interpreted by analytical and numerical models to get information on the thermal capacity and the physical and economic life of the one-probe-two-layer-system. The project was funded by 3.1 M€.

10.6.2.4 Landau

The second borehole was completed in 2006 (Figure 10.1). Stimulation tests between the two boreholes were successful. An ORC-plant is now ordered and shall be installed in 2007. The project costs of 15 M€ was financed by private investors with 3.8 M€ provided by government.

Figure 10.1 Drillrig at the Landau geothermal project site (photograph courtesy of Lothar Wissing).

10.6.2.5 Bruchsal

This project is currently stopped.

10.6.2.6 Soultz-sous-Forêts (France)

This project is a European project on HDR and is funded by the EC, France and Germany and a part by the industry. In the first phase, 3 boreholes were drilled to up to 5,000 m deep. Stimulation tests were done with very good success. It was possible to generate two heat exchangers at two horizons. The upper reservoir is located at 3,000-3,600 m depth and delivers temperatures of 165 °C. The lower reservoir, with depths of 5,000 m, showed temperatures of 200 °C. The new reservoir at 5,000 m shows closer boundaries compared to the upper reservoir. No leak-off to the upper reservoir has been detected. The last planned borehole, GPK 4, was drilled without problems to 5,200 m depth.

The cost accumulated by all parties has amounted to 30 M€, with funding by the German Government being 6.4 M€.

10.6.3 Industry Funded R&D Projects

10.6.3.1 Unterhaching

The second borehole has been completed at Unterhaching and a Siemens Kalina-plant is to be installed in 2007 for heat and electricity generation. The project costs are estimated to be about 30 M€, financed by risk capital, governmental funding and soft loans. The water temperatures are around 120 °C at 3,500 m and the production rate is between 120 and 150 l/s.

10.6.3.2 Speyer

The Speyer project was unsuccessful and has finished.

10.7 Geothermal Education

Education with the focus on geothermal issues is offered by universities like University of Bochum, RWTH Aachen, Technical University Berlin and 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 participates in the IEA as member of the Geothermal Implementing Agreement.

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NATIONAL ACTIVITIES

Chapter 11

Iceland

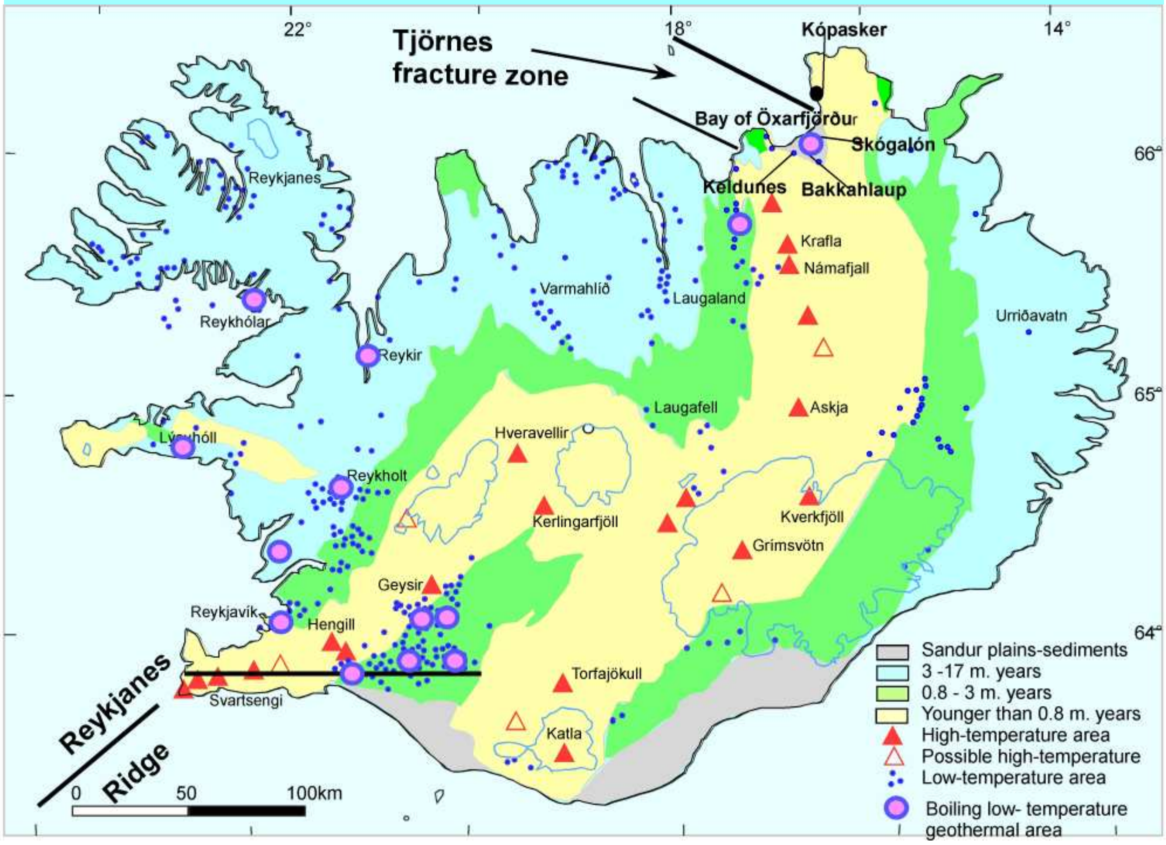

Figure 11.1 Location of Iceland's geothermal fields.(Based on Björnsson *et al.*, 1980).

11.0 Introduction

Geothermal energy provides over half of the primary energy supply in Iceland. The principal use of geothermal energy is for space heating, and almost 90% of all energy used for house heating comes from geothermal resources. Of the total electricity generation, about 26.5% comes from geothermal energy. See Figure 11.1 for locations of geothermal areas in Iceland and Figure 11.2 for the distribution of geothermal energy utilization.

11.1 Highlights for 2006

Because of the location of Iceland on the Mid-Atlantic Ridge, the geothermal resources are ample and abundant. Over half of the primary energy supply in the country comes from geothermal energy. The main use of geothermal energy is for space heating and almost 90 % of all houses are heated by this energy source. Other sectors of direct use are swimming pools, snow melting, industry, greenhouses and fish farming. An expansion in the energy intensive industry has led to a rapid increase in electricity demand in the country. This has stimulated the development of geothermal power production and resulted in the construction of new plants. Two of the largest energy companies in Iceland, Reykjavik Energy and Hitaveita Suðurnesja, both started new power plants for electricity production. The total capacity of these two plants is 180 MW_e.

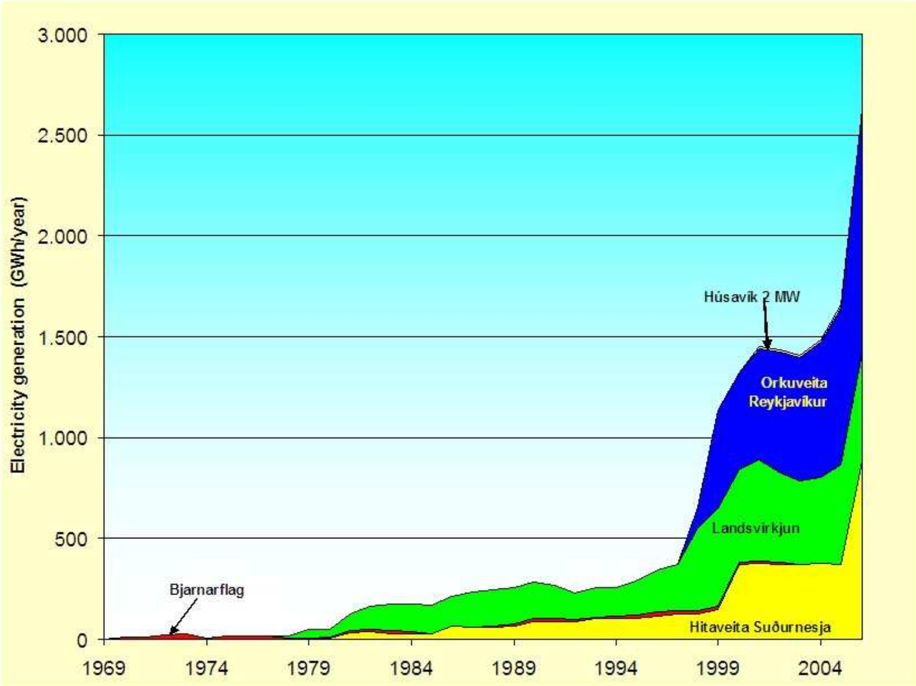

Figure 11.2 Electricity generation using geothermal energy in Iceland 1970-2006.

11.2 National Policy

The national strategy is aimed at harnessing geothermal resources whenever possible, respecting the natural and human environment.

There has been a governmental effort to explore the geothermal potential in areas previously defined as *cold regions*. This effort has been quite successful and at present a production well is being drilled for the heating of a small town in west Iceland, Grundarfjördur (about 900 inhabitants), where a geothermal area for utilization was located by gradient drilling.

In addition, foreign investment in power intensive industry is encouraged and watch is being kept on developments in the hydrogen fuel field.

Market reform in the electricity industry began on 1 July 2003, with the implementation of the EU electricity directive. Full market opening for the industry is planned for by 2007. Other laws concerning research and harnessing of geothermal energy are currently being modified.

Government expenditure on geothermal R&D was about 1M Euros in 2006. Industry expenditure amounted to 6-7 M Euros.

11.3 Current Status of Geothermal Energy Use in 2006

11.3.1 Electricity Generation

As a result of a rapid expansion in the energy intensive industry in Iceland the demand for electricity has increased considerably. This has partly been met by increased geothermal electricity production. In the past years, Reykjavik Energy has been constructing a new 80 MW_e power plant at Hellisheidi for both electricity and hot water production. This is one of the geothermal fields in the Hengill area where there are several geothermal fields, including the already harnessed Nesjevellir field. The electricity production was started in the summer of 2006.

At Reykjanes, Hitaveita Suðurnesja started power production in a new power plant of 100 MW_e in June 2006.

In Bjarnarflag an environmental impact assessment for a 90 MW_e power plant has been completed. At the Krafla power plant a third 30 MW_e unit is planned, but currently pending due to other projects.

In 2006, Iceland's geothermal installed capacity was 422 MW_e, increasing by 180 MW_e when the new power plants in Reykjanes and Hellisheidi were put into production. Total geothermal power generation in Iceland was 2,631 GWh/y in 2006.

11.3.2 Direct Use

The total direct use of geothermal energy in Iceland in 2006 was about 25,080 TJ/y, corresponding to 6,970 GWh/y. Almost 90% of all energy used for space heating is geothermal and its share is still slowly increasing mainly due to the governmental effort to explore the geothermal potential in areas previously defined as *cold regions.*

Heating of swimming pools is also one of the most important types of geothermal utilization in Iceland and the one with the longest tradition. There are today about 130 geothermally heated swimming pools (surface area of 28,000 m^2). Most of the public pools are open-air pools that are used throughout the year. There are plans for an extended balneological outbuilding in northeast Iceland in the near future.

Snow melting has been common in Iceland for the past 15-20 years and the total area covered is about 740,000 m^2.

There has been no increase in direct industrial uses of geothermal energy in Iceland during the last years and recently there has rather been a reduction, as one of the biggest industrial users of geothermal energy closed.

A seaweed processing plant at Reykhólar, W-Iceland, uses about 150 TJ/y annually for drying. A plant for the commercial production of liquid carbon dioxide (CO_2) has been in operation at Haedarendi in SW-Iceland since 1986. Geothermal water is also used on a small scale for timber drying and fish drying. The total geothermal energy used for industrial purposes is about 1,200 TJ/y.

11.3.3 Energy Savings

The use of geothermal energy in Iceland provided a fuel savings of about 700,000 tonnes of oil equivalent (toe). The reduced/avoided CO_2 emissions amounted to about 2.226 Mt.

11.4 Market Development and Stimulation

The government gives grants to small projects in the field of energy. However, for the last few years emphasis has been on finding usable geothermal water for space heating in areas where resources were previously unknown.
The high demand for electricity for intensive industry resulting from the favourable prices of electricity has resulted in large-scale geothermal power development.

Development cost trends have been stable except for increases in steel prices. Performance improvement has been dramatic and the time for drilling high temperature geothermal wells has been reduced from 55 to 40 days. This has not yet affected the cost for the energy companies as the prices are unit prices and they have not been changed.

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 constrains on drilling sites and access to them.

11.6 Economics

Recent developments of geothermal resources have demonstrated that geothermal power plants can compete with hydro power plants in the country in providing electricity for the industry of aluminium smelters.

Government investment in geothermal has increased due to the large demand for the power intensive industry.

The cost of energy has been stable.

11.7 Research Activities

11.7.1 Focus Areas

Research is focusing on known high temperature geothermal areas for the purpose of categorizing them for future electricity production. In addition, geothermal areas are being searched for near districts that do not currently have geothermal space heating.

A consortium of Icelandic energy companies has begun the project of drilling a 4-5 km deep drill hole into the Krafla high-temperature systems to reach 400-600 °C hot supercritical hydrous fluid at a rifted plate margin on a mid-ocean ridge. The main purpose of the Iceland Deep Drilling Project (IDDP) project (http://www.iddp.is/pdfs/deepdrilling_gof_05.pdf) is to find out if it is economically feasible to extract energy and chemicals out of hydrothermal systems at supercritical conditions.

11.7.2 Government Funded Research

Deep drilling: The Government of Iceland decided at its meeting on 30 August 2005, to participate significantly in funding the IDDP drilling and flow testing in 2006-2009. The total amount from the government can reach 300 Million IKR (3.3 M Euros)

During the past six 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, so-called *cold areas*. A total of US$ 1.9 M has been granted for this purpose and used mainly for drilling 50-100 m deep thermal gradient exploration wells. This method has proven to be a successful exploration technique in Iceland.

11.7.3 Industry Funded Research

The National Power Company in Iceland funds a full professor chair in geothermal research at the Natural Resources Faculty, University of Akureyri.

Individual heating companies as well as the cooperation of energy producing companies funds several geothermal research projects, the biggest one being the IDDP, which is also funded by the government. Each of the three biggest electricity companies has signed a contract to participate, each with up to 300 Million IKr to the IDDP. The drilling is foreseen to start in 2008 at Krafla.

11.8 Geothermal Education

During the 27 years the geothermal training program in Iceland operated under the supervision of the United Nations University a total of 359 fellows from 40 countries have graduated. In 2006 there were 21 fellows from 12 countries trained. In the Master of Science program in geothermal research there are currently 9 students, with 8 having finished so far. There is a great demand for the admission to the training program. The Icelandic government provides the main part of the funding of the geothermal training program.

The Natural Resources Faculty, University of Akureyri, offers BSc and MSc degrees in sustainable energy utilization of the renewable energy sources with emphasis on hydro and geothermal energy. The students attend several courses covering the harnessing of geothermal energy and are trained in different geothermal disciplines. A new MSc degree program in sustainable energy taught in English will be offered for international students from the autumn of 2007.

University of Iceland offers BSc, MSc and PhD degrees in geophysics, geology and other disciplines that form the basis for geothermal research.

11.9 International Cooperative Activities

Iceland is a member of the IEA GIA and leads the new Annex VIII- Direct Use of Geothermal Energy. In addition, it is a member of the International Geothermal Association with two Board Members, and now hosts the IGA Secretariat, having done so since September 2004.

Iceland is also a Member of the World Energy Council, cooperates within the EU and Orkustofnun hosts the UNU Geothermal Training Programme.

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NATIONAL ACTIVITIES
Chapter 12
Italy

Figure 12.1 Two 20 MW_e geothermal units operating in the Mt. Amiata area.

12.0 Introduction

This chapter outlines the development of the geothermal activities in Italy in the year 2006.

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, and where it remained for 2006 because no new plants were commissioned.

In 2006, geothermal net generation reached 5,200 GWh/y. Though this represents only 1.9% 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 2006, the supply of thermal energy totalled about 8,000 TJ/y.

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. According 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. 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 337,800 GWh/y in 2006, an increase of 2.25 % on the year 2005. The contribution of the domestic production was 86.8 %, while the remaining 13.2 % was imported.

Domestic electricity generation is provided as follows: 82.5 % comes from fossil fuels, 14.5 % from hydro and 3 % from geothermal, wind and solar.

With the same Decree Law (n° 79/99), specific policies were also adopted for supporting the development of renewable resources.

12.2 The Current Status of Geothermal Energy Use

12.2.1 Electricity Generation

All the plants in operation are located in Tuscany, in the areas of Larderello/Travale-Radicondoli and Mt. Amiata (Figure 12.1, this chapter title page).

As of 31 December 2006, 248 production wells were in operation with a steam network of about 160 km total length. In addition, 32 reinjection wells were in operation with a total water network of about 180 km.

32 units (with a capacity 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.

The net electricity generation in 2006 was 5,200 GWh/y, the highest value so far produced

12.2.1.1 Drilling Activities in 2006

- Drilling and completion of 1 new production well and of 1 shallow well for water production
- Workover and deepening activities in 6 wells
- Drilling and completion of 5 deep exploratory wells (maximum depth 4,153 m) in the frame of the “Deep Exploratory Program” launched in 2003 in the area of Larderello/Travale-Radicondoli, with the aim of verifying the possibility of further extension of the productive horizons both areally and at depth

In 2006, the total drilling activity in Italy amounted to 10,714 m.

In addition to the drilling activities in Italy, Enel had also worked in El Salvador, where 2 wells were completed for a total of 6,141 m drilled.

12.2.1.2 Power Plant Construction in 2006

There were no new power plants commissioned in Italy in 2006.

Figure 12.2 A 20 MW_e unit with the AMIS hydrogen sulphide and mercury emissions abatement system at the left.

12.2.1.3 AMIS Plant Construction in 2006

The AMIS abatement plants have been designed by Enel to remove H_2S and Hg from plant emissions. This technology makes possible a substantial reduction in the environmental impact of the generation park, with a consequent improved acceptance by the local population (Figures 12.1 and 12.2). It eliminates the bad smell of H_2S present in the geothermal areas, which presents a real nuisance to 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 2006, two additional AMIS plants were installed and operated in the Larderello area.

The total investment for the above mentioned activities was 95 million Euro.

12.2.2 Direct Uses of Geothermal Energy

In addition to the electricity generation, in Italy geothermal fluids are also used as thermal sources. In 2006, the total heat supplied was equivalent to about 8,000 TJ/y.

Most of the applications (60% of the supply) are devoted to bathing (temperatures < 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 uses, supplying the equivalent of about 1,100 TJ/y of geothermal heat. Enel also sells about 36,000 t/y of nearly pure CO_2, produced from a deep well located in the Torre Alfina field (Latium), and 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 were adopted in Italy. This provision gave rise to the "Green Certificate" market.

As from the year 2001, 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 within the following year. The quota was initially, *i.e.* from the year 2002, set at 2% of the total energy produced or imported, and 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 the 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 and of the market value of the Green Certificates (the latter is limited to the first eight years of plant operation). In the year 2006, this mechanism lead to an average market price of 12.5 €-cent/kWh of the Green Certificates, to be added to the average price for the sale of electricity, which was around 5 €-cent/kWh.

The presence of the above mentioned Green Certificates makes it's possible in Italy to proceed with the exploration, development and utilization of deep geothermal resources, with the drilling of very expensive wells up to 3,500-4,000 m depth.

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 developers for new supplies or for increase of 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 placed a serious hindrance to developing new projects.

Aiming at the retrieval of a constructive and mutually beneficial relation with the territory, Enel has begun a number of initiatives with the intent of achieving a reduction in environmental drawbacks and an increase in acceptability.

New design solutions have been developed 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 in 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 1 January 2003, Enel paid:

- 0.1148 €-cent/kWh to the affected municipalities
- 0.0574 €-cent/kWh to the Tuscany District Authority

12.5 Economics

In Italy, the geothermal projects developed in recent years are relevant to deep resources, with resulting huge investments in drilling activities (wells up to 3,000-4,000 m deep). Because of this huge investment, the total capital cost can exceed 3 million €/MW_e installed, depending on well depths, productivity, chemical composition of the fluids. The Green Certificates make the development of new geothermal projects feasible.

12.6 Research Activities

Research activities have focused both on the implementation of advanced methodologies (3-D seismics) aimed at reducing the mining risk for the deep wells and on the methodologies aimed at the solution/mitigation of the corrosion problems in the wells, the gathering system and the 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 is engaged in several geothermal exploration and development programs in Central and South America as well as in the USA. In El Salvador, as partner of La Geo (the Salvadorian geothermal company which currently operates the geothermal fields of Ahuachapan and Berlin), Enel has completed further development of the Berlin field, with the drilling of wells and the construction and start-up of a 44 MW_e power plant.

Exploration activities have also been started in several areas of Chile and Nicaragua.

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NATIONAL ACTIVITIES

Chapter 13

Japan

Well N16-TE-2 in Tenei Village, Fukushima Prefecture. The well was drilled to a depth of 1400.8 m and reached a temperature of 112.1 °C for a small-scale power development by NEDO from late 2004 to early 2005 (Photo by Yuko Kizaki, Geothermal Engineering Co., Ltd).

13.0 Introduction

13.0.1 Historical Background

Japan's first geothermal power generation of 1.12 kW took place in Beppu, Oita Prefecture, Kyushu, in 1925. The practical use of geothermal energy commenced in 1966, with the introduction of the first full-scale geothermal power plant, the Matsukawa Geothermal Power Plant of 9.5 MW_e (23.5 MW_e at present), Iwate Prefecture, 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 pre-existing hot spring resort areas. Therefore, at the end of the 1980s, only nine plants were operating, with a total capacity of about 215 MW_e.

The risks involved in initial investment also hinder geothermal development. Thus, the government has been promoting research and development of exploration techniques in several geothermal areas. As a result, geothermal development in several areas in the Tohoku and Kyushu Districts reached the construction stage in the early 1990s, more than doubling the total capacity to about 534 MW_e.

The government has, however, withdrew a variety of incentives to geothermal energy in the late 1990s, as Japan's economy entered a deflation recession stage particularly since the Asian currency crisis in 1997. In December 1997, the government withdrew geothermal energy from the category of "New Energy" that was subsidized by several lines of incentives. Then, geothermal energy was suddenly placed into free competition of the electricity market. In June 2001, the government politically evaluated geothermal energy and decided it was not worthy to allocate budgets for its research and development. Then, all the geothermal projects for research and development were terminated in March 2003. In April 2003, the RPS (Renewable Portfolio Standard) Law was put into effect, but not applied to the conventional type geothermal power generation except for the geothermal binary cycle power generation.

The lines of less incentive policies froze the geothermal market in Japan and no new geothermal power plants have been constructed since the late 1990s, except for the installation of the Hachijojima geothermal power plant of 3.3 MW_e in 1999, the Kuju Kanko Hotel of 2 MW_e in 2000 and a demonstration binary power plant of 2 MW_e in the Hatchobaru geothermal power plant in 2004.

This pessimistic attitude was changed by the government decision, in 2006, that geothermal energy should be revived into "New Energy".

13.0.2 Highlights for 2006

- Geothermal energy was approved back into the category of "New Energy" by the Agency for Natural Resources and Energy (ANRE) of the Ministry of Economy, Trade and Industry (METI) in 2006. It will be legally enacted in 2007, and the Japanese geothermal power market will soon be revived.
- Kusatsu Town, Gunma Prefecture, one of the famous hot spring resort areas, won the METI and Ministry of the Environment (MOE) subsidy for the 1 MW_e hot spring power development project (Press release at November 7, 2006).
- The New Energy and Industrial Technology Development Organization (NEDO) adopted two new fields for the Geothermal Development Promotion Surveys: West Okushiri-cho (Hokkaido) and Hachimantai (Iwate), and succeeded in Otari (Nagano).
- The Japan International Cooperation Agency (JICA) commenced the Master Plan Study for Geothermal Power Development in Indonesia from 2006.

13.1 National Policy

13.1.1 Strategy

ANRE, METI, is in charge of Japan's energy policy. METI states that the promotion of geothermal energy development is extremely important, because it is one of the oil alternative energies, and it is a clean, stable power supply of domestic production that answers a social request for reducing global environmental problems. Therefore, an inducement to encourage private entrepreneurs at the early stage of the geothermal power development, is aimed at.

To adjust the environmental contribution statistics of the international standard for "Renewable Energy", the New Energy Committee of ANRE, METI, proposed that the small-scale hydro and geothermal energy would be better back in 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. Probably, this will be legally enacted on "the Special Measures Law for the Promotion of Utilization of the New Energy" (so-called New Energy Law), during 2007.

13.1.2 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 the definition of New Energy, which needs governmental support. Then the "Renewables Portfolio Standard Law" was enacted in 2003, and geothermal energy was included as a renewable energy in this law, but realistically restricted to 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.

13.1.3 Progress Towards National Targets

The numerical target on the geothermal electrical capacity has remained 534 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.

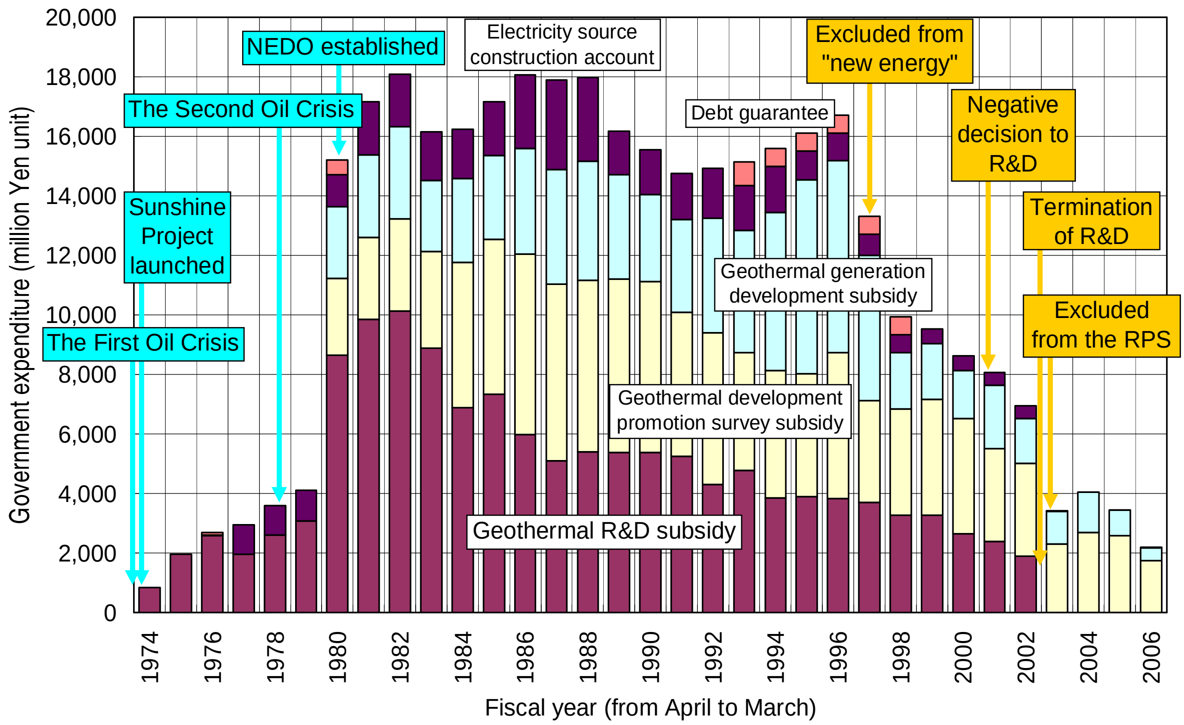

Figure 13.1 A chronological change of annual geothermal budgets in Japan.

13.1.4 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. The government expenditure has drastically been decreasing during the last several years, since geothermal energy was excluded from “New Energy” in 1997.

13.1.5 Industry Expenditure on Geothermal R&D

In the current, less incentive situation, the market for geothermal power generation development in the private sector is inactive, except for overseas investment by trading companies and that of plant facility exports by turbine and generator makers.

13.2 Current Status of Geothermal Energy Use in 2006

13.2.1 Electricity Generation

13.2.1.1 Installed Capacity and Electricity Generated

The installed capacity of geothermal electricity generation in Japan at the end of March 2006 was 534.24 MW_e, including that of the companies’ own power plants (Thermal and Nuclear Power Engineering Society, 2007; Figures 13.2 and 13.3 and Table 13.1). ANRE has reported statistics on the total installed capacity of electricity generation for FY 2006 (from April 2005 to March 2006) on its Web site (Agency for Natural Resources and Energy, 2007). The total installed capacity of electricity generation for the country at the end of March 2006 was 233,797 MW_e, where thermal power accounted for 59.0 %, hydroelectric power 19.5 %, nuclear power 21.2 % and geothermal 0.2 % (Figure 13.4)

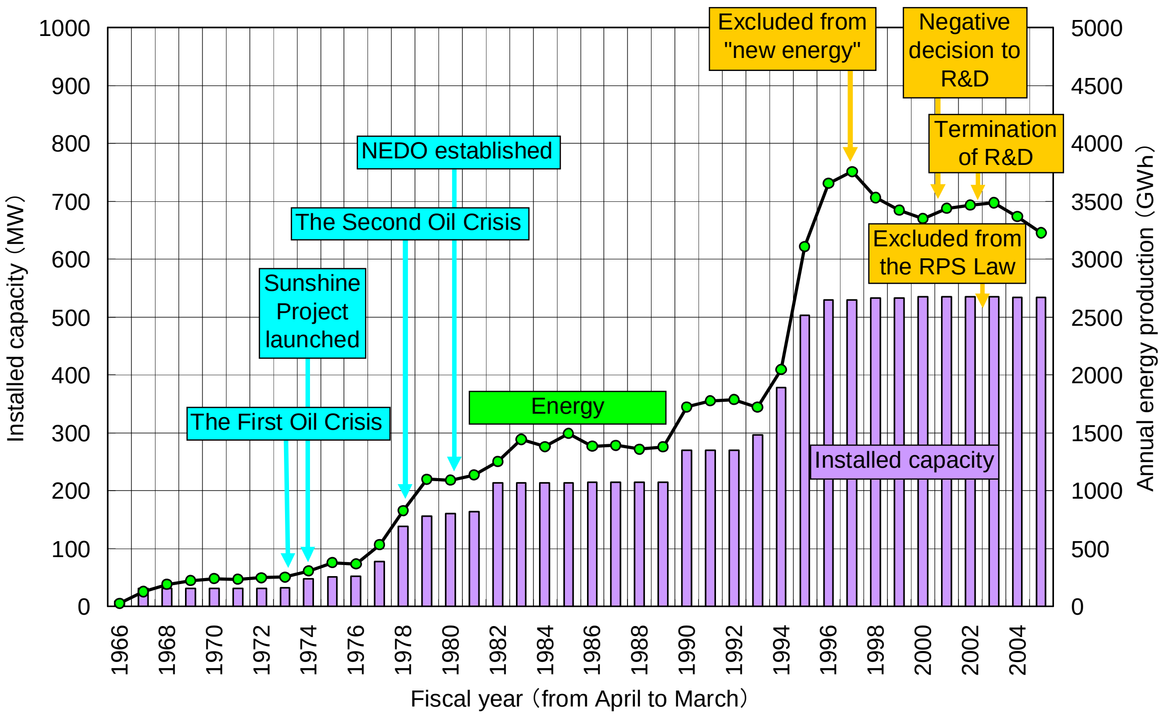

Figure 13.2 A chronological change of installed capacity and annual energy production of geothermal power plants in Japan.

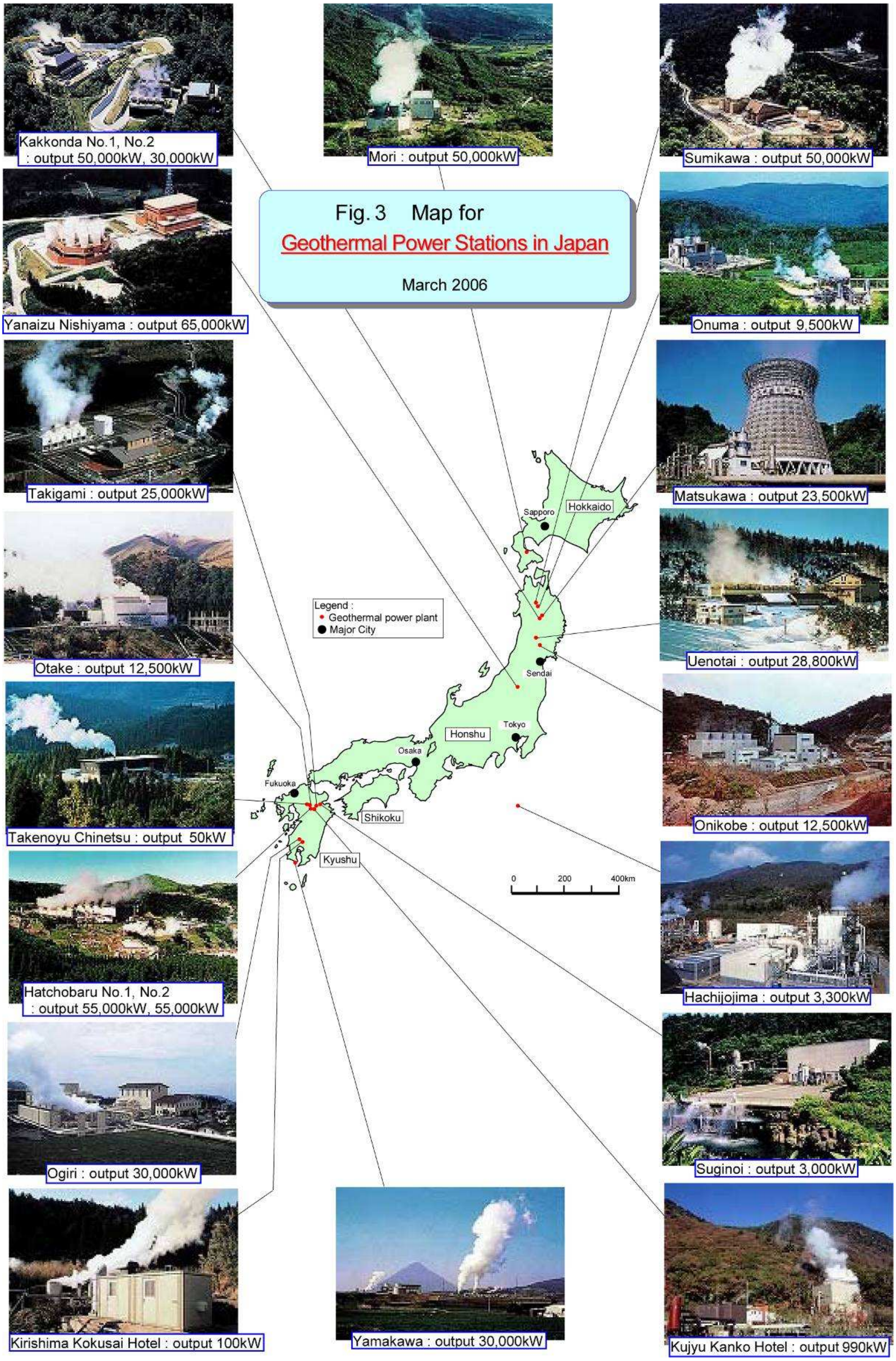

Figure 13.3 Map of geothermal power plants in Japan.

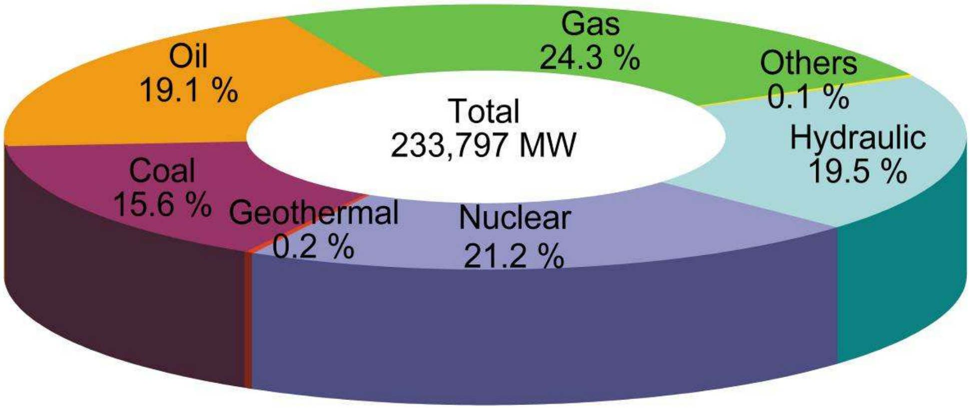

Figure 13.4 Share of installed capacity of individual generation sources in Japan from April 2005 to March 2006.

Table 13.1 Operating geothermal power plants in Japan from April 2005 to March 2006.

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	152,136	Nov. 1982
Sumikawa	Tohoku Electric Power Co., Inc.	Mitsubishi Materials Corporation	50.00	357,736	Mar. 1995
Onuma	Mitsubishi Materials Corporation	Mitsubishi Materials Corporation	9.50	60,306	Jun. 1974
Matsukawa	Tohoku Hydropower & Geothermal Energy Co., Inc.	Tohoku Hydropower & Geothermal Energy Co., Inc.	23.50	127,053	Oct. 1966
Kakkonda 1	Tohoku Electric Power Co., Inc.	Tohoku Hydropower & Geothermal Energy Co., Inc.	50.00	193,131	May 1978
Kakkonda 2	Tohoku Electric Power Co., Inc.	Tohoku Hydropower & Geothermal Energy Co., Inc.	30.00	190,541	Mar. 1996
Uenotai	Tohoku Electric Power Co., Inc.	Akita Geothermal Energy Co., Ltd.	28.80	193,268	Mar. 1994
Onikobe	Electric Power Development Co.	Electric Power Development Co.	12.50	103,876	Mar. 1975
Yanaizu - Nishiyama	Tohoku Electric Power Co., Inc.	Okuaizu Geothermal Ltd. Co.,	65.00	400,546	May 1995
Hachijojima	Tokyo Electric Power Company	Tokyo Electric Power Company	3.30	15,242	Mar. 1999
Suginoi	Suginoi Hotel	Suginoi Hotel	3.00	6,175	Mar. 1981
Kuju	Kuju Kankou Hotel	Kuju Kankou Hotel	0.99	8,414	Dec. 2000
Takigami	Kyushu Electric Power Co., Inc.	Idemitsu Oita Geothermal Co., Ltd.	25.00	213,669	Nov. 1996
Otake	Kyushu Electric Power Co., Inc.	Kyushu Electric Power Co., Inc.	12.50	72,314	Aug. 1967
Hatchobaru 1	Kyushu Electric Power Co., Inc.	Kyushu Electric Power Co., Inc.	55.00	372,835	June 1977
Hatchobaru 2	Kyushu Electric Power Co., Inc.	Kyushu Electric Power Co., Inc.	55.00	418,365	June 1990
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	238,668	Mar. 1996
Kirishima Kokusai Hotel	Daiwabo Kanko Co., Ltd.	Daiwabo Kanko Co., Ltd.	0.10	0	Feb. 1984
Yamagawa	Kyushu Electric Power Co., Inc.	Kyushu Electric Power Co., Inc.	30.00	104,187	Mar. 1995
Total			**534.24**	**3,228,462**	

Figure 13.5 A 2000 kW demonstration binary power plant in the Hatchobaru geothermal power plant. Observers are from Ten'ei-mura. (Photo taken 9 November 2004).

The total electricity generation for geothermal energy in Japan during FY2005 (from April 2005 to March 2006) was 3,228.5 GWh/y (Thermal and Nuclear Power Engineering Society, 2007; Figure 13.2 and Table 13.1).

13.2.1.2 New Developments in 2006

The installed capacity of geothermal electricity generation in Japan is 534.24 MW_e, and that has not changed since 2000. However, Kyushu Electric Power Co., Inc. has recently built a 2000 kW demonstration binary power plant in the inside of the Hatchobaru Geothermal Power Plant in 2004 (Figure 13.5), utilizing an abandoned production well in the conventional power generation due to the pressure draw down. This plant consists of the ORMAT organic binary Rankine cycle system. This is the first practical geothermal binary plant in Japan, and therefore, the demonstration operation is continued from February 2004 to March 2006, including the various demonstrations for its technical and economical feasibilities. This system was approved as a first qualified facility to take advantage of the Renewable Portfolio Standard (RPS) Law from the geothermal sector in Japan, 24 February 2005.

13.2.1.3 Rates and Trends in Development

The installed capacity for geothermal electricity generation has remained almost constant in the last several years, except for that of the Hatchobaru demonstration binary power plant. Recently, a press release stated that a 1 MW_e Kalina-cycle power generation plant is planned in Kusatsu-cho, Gunma Prefecture, central Japan, utilizing waste hot spring water of 95.4 ºC under the support of the METI and MOE subsidy (Press release at 7 November 2006). Small-scale geothermal power plants will reduce the risk and lead-time for development, and will mitigate the conflict between the hot spring unions and geothermal developers when hot spring owners themselves will develop their own plants. This will be an important approach in the near future.

13.2.1.4 Number of Wells Drilled

During 2006, 5 production wells were drilled for 5 geothermal power stations (Matsukawa, Kakkonda, Onikobe, Yanaizu-nishiyama and Hatchobaru), and 1 reinjection well was drilled at Hatchobaru geothermal power station.

Two exploratory wells were drilled at Otari and 1 exploratory well was drilled at Okushiri.

13.2.1.5 Contribution to National Demand

ANRE has reported statistics on the total electricity generation for FY 2006 (from April 2005 to March 2006) on its Web site (Agency for Natural Resources and Energy, 2007). The total electricity generation for the country at the end of March 2006 was 973.6 TWh/y, of which thermal power accounted for 59.3 %, hydroelectric power 9.1 %, nuclear power 31.2 % and geothermal 0.3 % (Figure 13.6). Thus, geothermal power has provided about 0.3 % of electricity in FY2006.

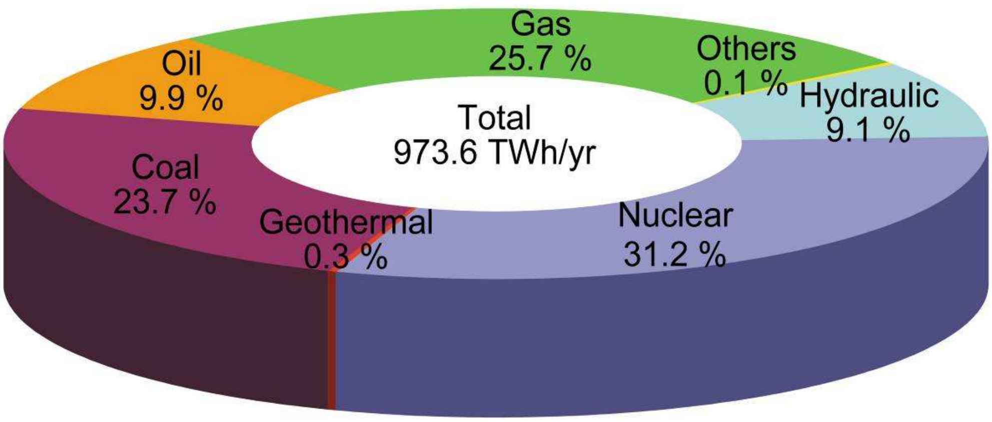

Figure 13.6 Share of electricity production of individual generation sources in Japan from April 2005 to March 2006.

13.2.2 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 saving energy 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.

13.2.2.1 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 8th) was carried out in the year 2006 (New Energy Foundation, 2007). However, the numerical values on the original tables in NEF (2007) are sometimes incorrect in a strict sense, probably due to round-off variations. Therefore, they are corrected here by the check on the spreadsheet type calculations. The difference in the numerical values in the following tables from those by the New Energy Foundation (2007) comes from these correction procedures.

Questionnaires for hot water uses were sent to 267 municipalities in Japan and answers were returned from 116 of them. The numbers of facilities for the various hot water uses in Japan as of March 2006 are shown in Table 13.2 (New Energy Foundation, 2007). The total number of facilities in Japan is 697. 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 shown in Table 13.3 (New Energy Foundation, 2007). The total installed capacity of hot water use is 400.3 MW_{th} in Japan. The largest application of hot water utilization is for road snow melting and it is followed by house heating and welfare facilities heating.

Table13.2 The numbers of facilities for the various hot water uses in Japan as of March 2006 (New Energy Foundation, 2007).

Prefecture	Horti-culture	Fish breed-ing	Cattle shed heating	Agri-culture	Industry	Food process	Hotel heating	Sight-seeing facility	House heating	Medical use	Welfare facility heating	Public facility heating	Road snow melting	Others	Total
Hokkaido	15	6		5			12	2	16	15	89	55	30		245
Aomori	6	2		1	1		1	1	4	2	38	3	15		74
Iwate	3	2		1			4		1	1	2	2	24		40
Miyagi	2												2		4
Akita	1			4		1	3				2	5	9		25
Yamagata	1	2					4				2	1	12		22
Fukushima			1					3	1	3	8	1			17
Tochigi		1							8						9
Gunma				1			1	2	2		3	1	4		14
Tokyo	1														1
Kanagawa							4		9					1	14
Niigata					1		1			1	1		3		7
Toyama							1						1		2
Ishikawa	1									1	4				6
Fukui									1			1			2
Nagano	2				1		1	1	8	2	10	2	16		43
Gifu							1	3	2			1	5		12
Shizuoka				1			3	5	7		5	5			26
Hyogo									1	1	1				3
Wakayama								1	1	1					3
Tottori									1		1				2
Okayama		1		1						1	4	1			8
Ehime										1					1
Nagasaki									1		2				3
Kumamoto											1				1
Oita	8			3			6	12	21	4	5	3			62
Miyazaki										1	3				4
Kagoshima	8	2		4			4		9	4	11	5			47
Total	48	16	1	21	3	1	46	30	93	38	192	86	121	1	697

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 is shown in Table 13.4 (New Energy Foundation, 2007). The total number of the facilities in Japan is 638, of which geo-heat pumps in a narrow sense are restricted into 116 and the others are more primitive type utilizations of 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 shown in Table 13.5 (New Energy Foundation, 2007). The total installed capacity of geo-heat uses is 13.3 MW_{th}.

Estimating the energy contribution from hot spring bath use is a long-pending project in Japan. The Ministry of the Environment 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 (Table 13.6; Ministry of the Environment, 2007). Then, we need a statistical approach 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.

As of March 2006, there are 27,866 hot spring sources in Japan (Table 13.6; Ministry of the Environment, 2007). Of these, 8,742 sources are unused, and the remaining 19,124 sources are used (Table 13.6); 31.37 % and 68.63 %, respectively.

A total discharge rate of natural springs and artesian wells is 831,640 l/min and that of pumping wells is 1,929,660 l/min as of March 2006 (Figure 13.7). If we assume that the unused hot spring sources are evenly distributed in them, the discharge rate of used natural springs and artesian wells is 570,755 l/min, i.e. 68.63 % of the total discharge. However, the unused hot springs in

Table 13.3 Installed capacity (MW_{th}) of hot water uses in Japan as of March 2006 (New Energy Foundation, 2007).

Unit: MWt

Prefecture	Horti-culture	Fish breed-ing	Cattle shed heating	Agri-culture	Industry	Food process	Hotel heating	Sight-seeing facility	House heating	Medical use	Welfare facility heating	Public facility heating	Road snow melting	Others	Total
Hokkaido	10.93	5.29		3.11			2.97	0.04	3.25	1.73	23.51	8.86	18.09		77.78
Aomori	1.36	0.23		0.01	0.38		0.03	0.10	1.63	0.21	3.66	0.57	2.38		10.56
Iwate	2.33	1.15		0.03			0.48		4.01	0.10	0.19	1.62	14.29		24.20
Miyagi	4.47												0.89		5.36
Akita	0.47			1.17		0.16	0.89				0.06	0.55	1.67		4.97
Yamagata	0.03	0.42					0.14				0.27	0.00	1.72		2.58
Fukushima			0.36					0.63	0.11	0.12	0.89	0.02			2.13
Tochigi		0.00							1.95						1.95
Gunma				0.05			0.12	0.00	16.49		7.26	13.58	2.83		40.33
Tokyo	1.74														1.74
Kanagawa							2.32		10.61					1.74	14.67
Niigata					0.17		0.12			0.09	0.00		84.60		84.98
Toyama							0.10						0.49		0.59
Ishikawa	0.08									0.03	1.86				1.97
Fukui									0.07			0.02			0.09
Nagano	0.47				0.43		0.00	6.74	8.92	1.10	1.28	0.26	16.92		36.12
Gifu							5.74	0.95	1.88			0.10	6.29		14.96
Shizuoka				0.06			0.56	0.70	2.40		0.15	0.43			4.30
Hyogo									2.65	0.03	1.00				3.68
Wakayama								0.03	0.01	0.06					0.10
Tottori									1.34		0.06				1.40
Okayama		0.00		0.00						0.02	0.09	0.04			0.15
Ehime										0.01					0.01
Nagasaki									0.38		0.06				0.44
Kumamoto											0.21				0.21
Oita	4.41			0.89			13.59	1.04	23.34	1.84	2.45	2.23			49.79
Miyazaki										0.08	0.94				1.02
Kagoshima	4.90	0.82		0.19			4.64		2.24	0.04	1.26	0.08			14.17
Total	31.19	7.91	0.36	5.51	0.98	0.16	31.70	10.23	81.28	5.46	45.20	28.36	150.17	1.74	400.25

Table 13.4 The number of geo-heat use facilities in Japan as of March 2006 (New Energy Foundation, 2007).

Prefecture	Heat exchanger + heat pump										Heat exchanger + exchanged-air circulation					Direct soil air circulation						Total
	Horticulture	Hotel	Sight-seeing facility	House	Medical use	Welfare facility	Public facility	Snow melting	Others	Sub-total	House	Public facility	Snow melting	Others	Sub-total	House	Medical use	Welfare facility	Public facility	Others	Sub-total	
Hokkaido	1			13		1	5	9	6	35	4	3	8	2	17							52
Aomori	1						2	12	1	16			1		1							17
Iwate				2			1	2	3	8										1	1	9
Miyagi					1		2	1		4												4
Akita			1	1			4	2		8			4		4							12
Yamagata							2	2		4			9		9							13
Fukushima				1	2		2			5			3		3	7				3	10	18
Ibaraki																8					8	8
Tochigi																10					10	10
Gunma																3				1	4	4
Saitama																16				2	18	18
Chiba						1	1			2						12	1			2	15	17
Tokyo				1		1			1	3						3			1		4	7
Kanagawa									1	1						3					3	4
Niigata							1	1		2			2		2	1				1	2	6
Toyama																				1	1	1
Ishikawa													1		1	3			1		4	5
Fukui							2			2			8		8	6		1		3	10	20
Nagano		1							1	2						7		1	1	1	10	12
Gifu																18	1			2	21	21
Shizuoka																10				3	13	13
Aichi				1						1						21				1	22	23
Mie				1						1						1					1	2
Shiga									1	1			1		1	2		2		1	5	7
Kyoto		1								1			1		1	2				3	5	7
Osaka																9				2	11	11
Hyogo				1			1			2			4		4	4				2	6	12
Nara																5					5	5
Tottori							1			1			6		6					1	1	8
Shimane																4			1	1	6	6
Okayama								1		1						16			1	3	20	21
Hiroshima			1	3		1	6		2	13			6		6	17					17	36
Yamaguchi																128		1	4	4	137	137
Kagawa														1	1	7			1		8	9
Ehime																				3	3	3
Kochi							1			1						3					3	4
Fukuoka							1			1						5		3	3	3	14	15
Nagasaki																7				2	9	9
Oita																3				4	7	7
Miyazaki							1			1						3				3	6	7
Kagoshima																35	1	1		1	38	38
Total	2	2	2	24	3	4	33	30	16	116	4	3	54	3	64	379	3	9	13	54	458	638

Table 13.5 Installed capacity of geo-heat uses in Japan as of March 2006 (New Energy Foundation, 2007).

Unit: kWt

Prefecture	Heat exchanger + heat pump										Heat exchanger + exchanged-air circulation					Direct soil air circulation						Total
	Hortic-ulture	Hotel	Sight-see-ing facility	House	Medi-cal use	Wel-fare facility	Public facility	Snow melt-ing	Others	Sub-total	House	Public facility	Snow melt-ing	Others	Sub-total	House	Medi-cal use	Wel-fare facility	Public facility	Others	Sub-total	
Hokkaido	23			145		47	87	116	89	507	24	64	1,026	15	1,129							1,636
Aomori	47						34	773	34	888			48		48							936
Iwate				10			76	487	42	615										2	2	617
Miyagi					49		354	11		414												414
Akita			9	3			291	111		414			267		267							681
Yamagata							1,171	146		1,317			97		97							1,414
Fukushima				7	329		98			434			299		299	11				4	15	748
Ibaraki																14					14	14
Tochigi																16					16	16
Gunma																5				2	7	7
Saitama																24				3	27	27
Chiba						241	42			283						17	2			3	22	305
Tokyo				10		65			16	91						5			2		7	98
Kanagawa									1	1						5					5	6
Niigata							9	129		138			52		52	2				2	4	194
Toyama																				2	2	2
Ishikawa													10		10	6			2		8	18
Fukui							276			276			1,351		1,351	10		2		5	17	1,644
Nagano		104							19	123						11		2	2	2	17	140
Gifu																31	1			3	35	35
Shizuoka																16				5	21	21
Aichi				4						4						33				12	45	49
Mie				17						17						1					1	18
Shiga									13	13			24		24	4		45		1	50	87
Kyoto		128								128			50		50	4				6	10	188
Osaka																17				2	19	19
Hyogo				12			157			169			274		274	8				3	11	454
Nara																9					9	9
Tottori							228			228			1,182		1,182					2	2	1,412
Shimane																8			2	2	12	12
Okayama								116		116						26			5	5	36	152
Hiroshima			130	12		0	389		23	554			568		568	26					26	1,148
Yamaguchi																191		2	2	11	206	206
Kagawa														342	342	12			1		13	355
Ehime																				4	4	4
Kochi							12			12						5					5	17
Fukuoka							7			7						7		21	61	6	95	102
Nagasaki																9				4	13	13
Oita																5				6	11	11
Miyazaki							44			44						5				5	10	54
Kagoshima																57	2	2		2	63	63
Total	70	232	139	220	378	353	3,275	1,889	237	6,793	24	64	5,248	357	5,693	600	5	74	77	104	860	13,346

Table 13.6 Annual hot spring utilization in Japan to the end of March 2006 (Ministry of the Environment, 2007).

Fiscal year	Number of jurisdiction health centers	Number of municipalities	Number of hot spring localities	Total number of hot spring source (A+B)	Number of used hot spring sources (A)		Number of unused hot spring sources (B)		Number of hot spring sources by temperature				Production rate L/min.		Number of accommodations	Number of guest capacity of accommodations	Number of annual man-day guests in accommodations	Number of public baths
					Spouting hot springs	Pumping-up hot springs	Spouting hot springs	Pumping-up hot springs	Hot springs under 25 ºC	Hot springs above 25 ºC under	Hot springs above 42 ºC	Steam and gas	Spouting hot springs	Pumping-up hot springs				
1957															7,556	302,041	40,701,812	
1958															7,738	329,699	47,519,270	
1959															7,913	358,005	49,471,913	
1960															8,276	383,608	55,251,803	
1961															8,744	456,226	77,561,499	
1962	446	916	1,518	13,079											9,244	500,445	86,743,797	
1963	447	898	1,207	10,395	5,757	4,638							930,110		10,319	562,516	85,675,621	1,588
1964	469	950	1,667	11,398	5,485	4,541			1,165	1,660	7,539		991,831		10,427	581,025	87,371,026	1,620
1965	489	980	1,331	11,913	5,953	5,875	85						1,109,633		10,904	649,439	93,311,028	1,629
1966	520	1,003	1,390	12,180	6,060	5,826	86						1,143,788		11,411	764,670	89,634,687	1,686
1967	518	1,080	1,479	13,563	5,521	6,087	1,955		1,555	2,235	8,350	738	1,207,194		12,586	751,138	96,050,339	1,594
1968	532	1,110	1,590	14,221	5,409	6,525	2,287		1,694	2,429	8,703	693	1,258,138		13,553	774,360	100,551,422	1,588
1969	535	1,162	1,609	14,827	5,427	6,844	2,566		1,765	2,411	9,044	771	1,334,612		13,252	805,118	101,261,143	1,780
1970	552	1,207	1,748	15,436	5,354	7,028	1,309	1,745	1,889	2,634	9,274	807	651,265	696,092	13,219	827,239	104,051,002	1,815
1971	552	1,236	1,802	16,002	5,474	7,288	1,308	1,932	2,007	2,801	9,442	870	624,190	659,394	13,004	856,731	109,616,365	1,746
1972	562	1,283	1,845	16,308	5,242	7,554	1,398	2,114	2,062	3,053	9,491	794	631,202	701,082	13,508	875,050	117,915,449	1,749
1973	568	1,313	1,901	16,681	5,146	7,893	1,380	2,262	2,267	3,132	9,681	813	613,776	734,778	14,006	939,972	121,463,272	1,815
1974	569	1,320	1,916	17,160	5,117	8,086	1,546	2,411	2,165	3,338	9,969	717	652,680	770,967	14,688	1,033,456	117,257,335	1,798
1975	570	1,361	1,939	17,491	5,181	8,297	1,455	2,558	2,267	3,346	10,102	752	668,199	799,772	14,598	993,994	110,228,798	1,992
1976	580	1,386	1,988	17,733	5,218	8,362	1,501	2,652	2,242	3,274	10,049	775	675,856	834,294	14,593	988,247	108,743,832	2,038
1977	585	1,423	1,990	18,183	5,102	8,552	1,673	2,856	2,273	3,437	10,264	747	688,448	838,147	14,758	1,001,543	108,582,166	2,096
1978	575	1,440	2,012	18,678	5,129	8,652	1,751	3,146	2,324	3,736	10,185	815	690,879	866,424	15,200	1,022,690	107,269,376	2,082
1979	578	1,473	2,033	19,052	4,996	8,721	1,844	3,491	2,320	3,898	10,003	845	681,099	923,859	15,619	1,056,043	111,295,210	2,065
1980	566	1,451	2,053	19,504	5,019	8,824	1,886	3,777	2,434	3,955	10,215	884	741,216	948,911	15,112	1,062,827	107,079,659	2,156
1981	564	1,470	2,106	19,470	5,001	8,854	2,001	3,614	2,513	4,002	10,235	888	757,276	984,030	15,141	1,079,357	108,757,430	2,257
1982	567	1,477	2,118	19,768	5,112	9,055	1,972	3,629	2,525	4,107	10,491	954	805,494	1,035,799	15,124	1,073,806	109,382,651	2,311
1983	572	1,497	2,116	20,103	5,069	9,217	2,047	3,770	2,566	4,272	10,437	964	790,207	1,055,883	15,014	1,074,788	107,813,584	2,358
1984	576	1,522	2,127	20,151	5,035	9,293	2,030	3,793	2,628	4,277	10,509	945	807,829	1,064,701	14,882	1,086,620	111,090,010	2,460
1985	575	1,548	2,145	20,396	5,005	9,384	2,125	3,882	2,696	4,334	10,757	941	784,585	1,089,414	15,002	1,096,035	113,898,046	2,694
1986	582	1,574	2,155	20,759	5,098	9,497	2,106	4,058	2,713	4,359	10,842	961	763,119	1,138,168	15,413	1,105,928	121,788,044	2,743
1987	584	1,593	2,189	21,095	5,095	9,597	2,210	4,193	2,815	4,544	10,940	963	816,773	1,252,447	15,383	1,120,849	125,507,775	2,884
1988	594	1,635	2,254	21,336	5,002	9,759	2,258	4,317	2,870	4,612	10,918	948	818,360	1,218,941	14,977	1,146,275	130,865,438	2,991
1989	603	1,685	2,302	21,758	5,012	9,983	2,392	4,371	2,926	4,787	11,136	893	831,159	1,256,338	15,085	1,168,167	134,870,936	3,112
1990	608	1,732	2,360	22,353	5,040	10,277	2,409	4,627	3,105	5,088	11,401	934	870,367	1,354,205	15,119	1,202,382	140,138,479	3,283
1991	630	1,798	2,382	23,097	5,091	10,639	2,463	4,904	3,092	5,244	11,485	1,006	888,410	1,427,296	15,082	1,210,747	142,853,123	3,576
1992	645	1,875	2,357	23,568	5,134	10,931	2,463	5,039	3,216	5,371	11,513	993	871,678	1,440,965	15,164	1,227,095	143,246,266	3,867
1993	637	1,918	2,383	24,061	5,084	11,291	2,534	5,152	3,274	5,451	11,752	1,041	880,058	1,495,445	15,227	1,245,672	139,728,475	4,038
1994	648	1,963	2,431	24,679	5,062	11,633	2,661	5,323	3,267	5,692	12,213	1,096	886,498	1,538,907	15,356	1,264,429	138,779,626	4,164
1995	658	2,015	2,508	25,129	5,053	11,908	2,759	5,409	3,319	5,771	12,368	1,091	876,108	1,628,592	15,714	1,288,594	140,572,876	4,375
1996	646	2,074	2,565	25,455	5,031	12,131	2,894	5,399	3,405	5,917	12,545	1,101	860,542	1,676,017	15,504	1,298,283	143,164,495	4,738
1997	606	2,132	2,615	25,822	5,048	12,342	2,814	5,618	3,466	6,049	12,677	1,097	868,832	1,735,812	15,643	1,332,588	140,301,952	5,080
1998	562	2,184	2,839	26,077	5,080	12,606	2,865	5,526	3,391	6,172	12,916	1,119	888,930	1,750,050	15,638	1,371,708	139,711,747	5,525
1999	559	2,213	2,893	26,270	5,143	12,714	2,794	5,622	3,484	6,294	12,957	1,057	894,295	1,772,844	15,548	1,357,089	135,377,318	5,836
2000	541	2,238	2,988	26,505	5,164	12,873	2,868	5,604	3,505	6,443	13,070	1,057	827,918	1,809,162	15,512	1,363,017	137,525,810	6,034
2001	525	2,280	3,023	26,796	5,186	13,063	3,000	5,552	3,590	6,486	13,226	1,077	819,328	1,791,219	16,558	1,373,318	137,097,634	6,433
2002	518	2,292	3,102	27,043	5,180	13,328	2,956	5,579	3,626	6,543	13,144	1,084	813,023	1,856,497	15,389	1,384,302	137,935,709	6,738
2003	511	2,280	3,127	27,347	5,189	13,559	2,969	5,629	3,690	6,573	13,093	1,156	800,891	1,880,287	15,390	1,387,981	136,285,534	7,006
2004	495	1,939	3,114	27,644	5,120	13,805	2,989	5,730	3,759	6,753	13,209	1,166	775,642	1,936,498	15,332	1,408,683	135,867,119	7,294
2005	511	1,492	3,162	27,866	5,149	13,975	2,966	5,776	3,841	6,857	13,294	1,162	831,640	1,929,660	15,024	1,413,088	136,613,954	7,431

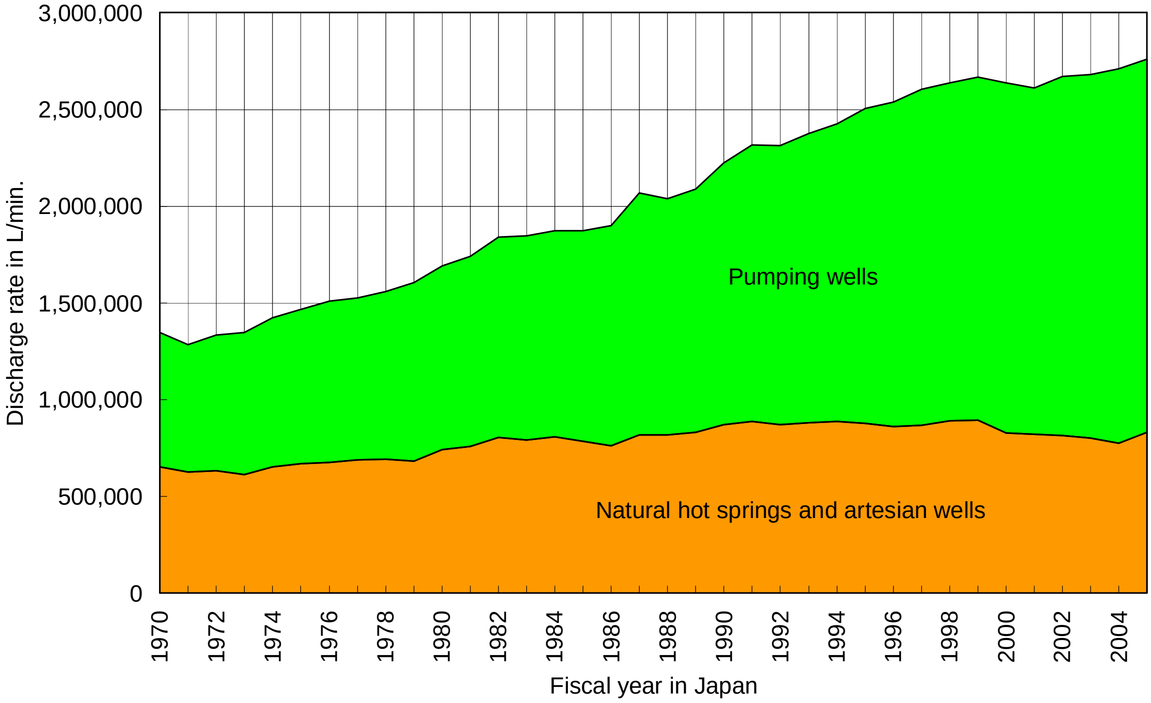

Figure 13.7 Annual discharge rate of hot springs in Japan from 1970 to 2005 (Drawn from the data by Ministry of the Environment, 2007)

pumping wells 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 here neglected and those higher than 42 ºC are only counted (Figure 13.8). As a percentage of numbers, 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, the 57.47 % of 570,755 l/min is 328,013 l/min (19,681 ton/hr) and 57.47 % of 1,929,660 l/min is 1,108,976 l/min (66,539 ton/hr). This is reasonable for the pumping wells. However, it is recently found that the discharge rate of hot springs clearly increases with the discharge temperature due to the effect of buoyancy of water for the natural springs and artesian wells (Figure 13.9; Muraoka *et al.*, 2006). When we use the fitting curve at permeability 10^{-13} m^2 (Figure 13.9; Muraoka *et al.*, 2006), the discharge rate of a hot spring source at the mean temperature 71 ºC between 42 ºC and 100 ºC is 700.7 l/min, and the rate at the mean temperature 21 ºC between 0 ºC and 42 ºC is 48.0 l/min. Therefore, weighted by this ratio, it is estimated that the percent of discharge rates of hot spring sources higher than 42 ºC is 95.18 % and the rate of those lower than 42 ºC is 4.82 %. Then, 95.18 % of 570,755 l/min is 543,245 l/min (32,595 ton/hr) for the natural springs and artesian wells, whereas 57.47 % of 1,929,660 l/min is 1,108,976 l/min (66,539 ton/hr) for the pumping wells.

A mean reference temperature at ground surface in Japan is assumed to be 15 °C. For the natural springs and artesian wells, the thermal capacity is 1,023.3 MW_{th}. For the pumping wells, the thermal capacity is 2,089.0 MW_{th}. The total thermal capacity of the hot spring bath uses is 3,112.3 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 3,112.3 MW_{th} for hot springs for bath use. The total thermal capacity of all direct use in Japan is 3,525.9 MW_{th}.

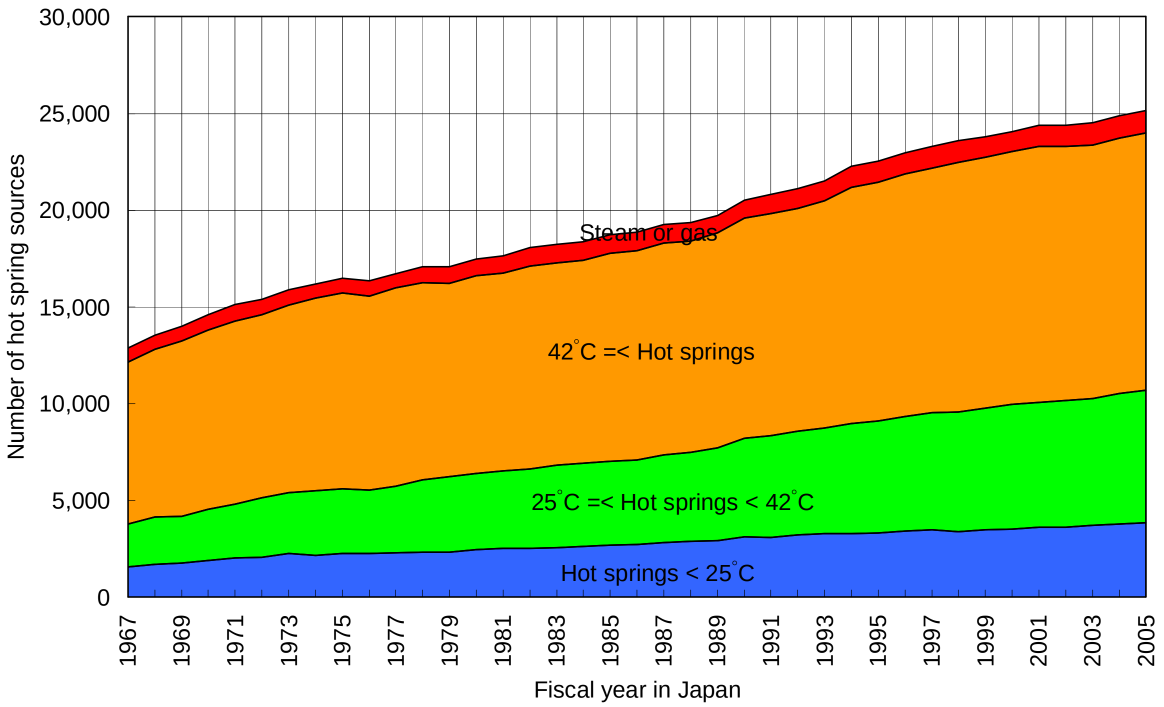

Figure 13.8 Annual number of hot springs classified by temperature in Japan from 1967 to 2005 (Drawn from the data by Ministry of the Environment, 2007).

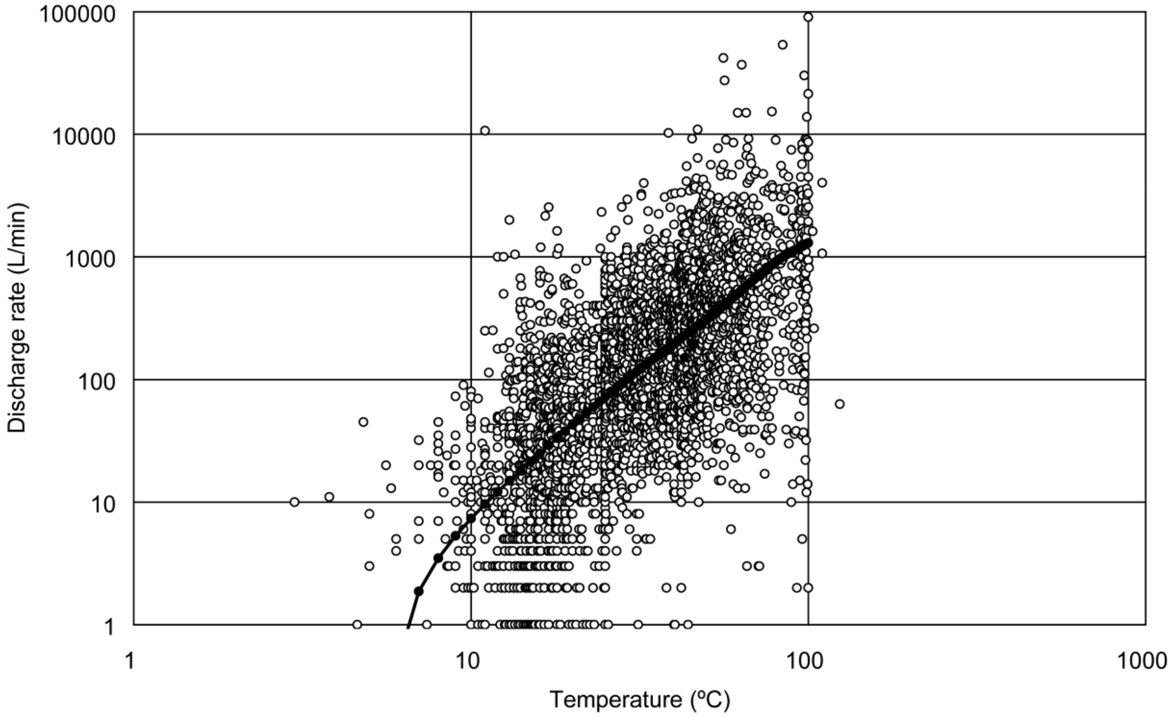

Figure 13.9 A bi-logarithmic plot of the discharge temperature and discharge rate of the 3,686 hot springs in Japan (Muraoka *et al*., 2006). The fitting curve is given by one-dimensional advection flow equation under the assumptions of the reservoir depth 1 km, discharge area 10^4 m^2 and permeability 10^{-13} m^2.

13.2.2.2 Thermal Energy Used

As of March 2006, the thermal energy used and the utilization capacity factors for thermal use, excluding bath use, are shown in Table 13.7 (New Energy Foundation, 2007). The total hot water thermal energy used was 4,887.9 TJ/y or 1357.8 GWh/y. As seen in the table, 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 average capacity factor for hot water use is 0.39.

The thermal energy used and the associated capacity factors for geo-heat uses in Japan, as of March 2006, are shown in Table 13.8 (New Energy Foundation, 2007). The total used thermal energy for geo-heat applications is 67,857 GJ/y, 67.9 TJ/y or 18.9 GWh/y. 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 in the fiscal year 2005 on Table 13.6, 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 here assumed to be 0.52. In addition, most of bath tubs are cleaned every day so that the hourly utilization factor is assumed to be 0.75. Then, 0.52 multiplied by 0.75 makes 0.39 that is a very conservative assumption for the utilization (capacity) factor. Then, we obtain the annually used thermal energy 12,585.6 TJ/y or 3,496.0 GWh/y in terms of saving fuels by natural springs and artesian wells.

For the pumping wells, we must subtract energy consumption for pumping from the thermal capacity. The thermal capacity is 2,089.0 MW_{th}. When we again assume the conservative utilization (capacity) factor to be 0.39, we find the annual thermal energy used is 25,692.7 TJ/y 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/y of electricity consumption. It is equal to 1.20 TJ/y. We must here consider of the difference in the energy quality in terms of the toe-basis (toe = tonnes 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/y from 25,692.7 TJ/y, the annually used thermal energy is estimated to be 25,690.3 TJ/y or 7,136.2 GWh/y 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 38,275.9 TJ/y or 10,632.2 GWh/y. 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 but the value is 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 43,231.7 TJ/y or 12,008.9 GWh/y.

13.2.2.3 Category of Use

We here summarize the direct use in Japan (Table 13.9). 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 the table, the hot spring bath use represents the largest contribution,

Table 13.7 Used thermal energy and capacity utilization factors of hot water uses in Japan as of March 2006 (New Energy Foundation, 2007).

Unit: TJ/year

Prefecture	Horti-culture	Fish breed -ing	Cattle shed heating	Agri-culture	Industry	Food process	Hotel heating	Sight-seeing facility	House heating	Medical use	Welfare facility heating	Public facility heating	Road snow melting	Others	Total (TJ/year)	Crude oil equivalents (kl/year)	Capacity utilization factor (%)
Hokkaido	180.50	88.57		49.88			46.10	0.83	72.76	32.82	206.98	128.74	173.13		980.31	30,191	40.0
Aomori	10.67	5.09		0.03	7.77		0.24	1.88	51.50	4.86	71.59	4.34	15.68		173.65	5,348	52.1
Iwate	14.41	18.57		0.42			4.86		5.31	0.62	2.64	26.12	56.21		129.16	3,978	16.9
Miyagi	53.42												14.19		67.61	2,082	40.0
Akita	5.99			15.86		3.59	11.13				0.46	11.21	11.28		59.52	1,833	38.0
Yamagata	0.32	5.71					2.71				3.74	0.06	6.70		19.24	593	23.6
Fukushima			3.41					11.01	3.39	0.98	14.32	0.26			33.37	1,028	49.7
Tochigi		0.02							61.49						61.51	1,894	100.0
Gunma				1.00			1.28	0.00	519.96		44.94	68.66	23.66		659.50	20,311	51.9
Tokyo	12.71														12.71	391	23.2
Kanagawa							46.46		334.64					34.19	415.29	12,790	89.8
Niigata					3.85		1.18			2.93	0.00		21.26		29.22	900	1.1
Toyama							1.25						4.53		5.78	178	31.1
Ishikawa	1.39									0.47	48.85				50.71	1,562	81.6
Fukui									0.92			0.23			1.15	35	40.5
Nagano	4.28				13.53		0.00	49.10	242.20	20.76	37.26	8.07	126.48		501.68	15,451	44.0
Gifu							126.80	16.54	20.79			1.75	35.63		201.51	6,206	42.7
Shizuoka				0.09			4.31	8.94	60.22		4.69	13.38			91.63	2,822	67.6
Hyogo									19.27	0.39	19.58				39.24	1,209	33.8
Wakayama								0.12	0.01	0.16					0.29	9	9.2
Tottori									42.17		1.81				43.98	1,354	99.6
Okayama		0.05		0.10						0.59	2.06	1.14			3.94	121	83.3
Ehime										0.09					0.09	3	28.5
Nagasaki									11.92		0.32				12.24	377	88.2
Kumamoto											1.87				1.87	58	28.2
Oita	53.35			6.20			197.57	9.70	692.89	37.09	69.36	23.28			1089.44	33,552	69.4
Miyazaki										0.25	18.04				18.29	563	56.9
Kagoshima	39.56	23.80		0.50			52.57		49.98	1.21	17.02	0.34			184.98	5,697	41.4
Total (TJ/year)	376.60	141.81	3.41	74.08	25.15	3.59	496.46	98.12	2189.42	103.22	565.53	287.58	488.75	34.19	4887.91	150,536	38.7
Crude oil equivalents (kl/year)	11,598	4,367	105	2,281	775	111	15,290	3,022	67,429	3,179	17,417	8,857	15,052	1,053	150,536		
Capacity utilization factor (%)	38.3	56.8	30.0	42.6	81.4	71.1	49.7	30.4	85.4	59.9	39.7	32.2	10.3	62.3	38.7		

Table 13. 8 Used thermal energy and utilization capacity factors for geo-heat uses in Japan as of March 2006 (New Energy Foundation, 2007).

Unit: GJ/year

Prefecture	Heat exchanger + heat pump										Heat exchanger + exchanged-air circulation					Direct soil air circulation						Total (GJ/yr)	Capacity utilization factor (%)
	Horticulture	Hotel	Sight-seeing facility	House	Medical use	Welfare facility	Public facility	Snow melting	Others	Sub-total	House	Public facility	Snow melting	Others	Sub-total	House	Medical use	Welfare facility	Public facility	Others	Sub-total		
Hokkaido	114			1,586		273	427	299	770	3,469	241	372	4,642	131	5,386							8,855	17.2
Aomori	228						345	2,375	298	3,246			217		217							3,463	11.7
Iwate				97			238	2,178	365	2,878										31	31	2,909	15.0
Miyagi					307		2,065	24		2,396												2,396	18.4
Akita			38	29			1,744	244		2,055			1,207		1,207							3,262	15.2
Yamagata							2,632	514		3,146			654		654							3,800	8.5
Fukushima				72	2,077		569			2,718			1,348		1,348	169				59	228	4,294	18.2
Ibaraki																223					223	223	50.5
Tochigi																250					250	250	49.5
Gunma																79				26	105	105	47.6
Saitama																383				42	425	425	49.9
Chiba						1,403	243			1,646						275	26			48	349	1,995	20.7
Tokyo				91		379			140	610						83			31		114	724	23.4
Kanagawa									7	7						83					83	90	47.6
Niigata							37	284		321			234		234	26				31	57	612	10.0
Toyama																				31	31	31	49.2
Ishikawa													47		47	88			26		114	161	28.4
Fukui							1,464			1,464			3,127		3,127	155		31		77	263	4,854	9.4
Nagano		753							167	920						173		31	26	31	261	1,181	26.7
Gifu																483	16			52	551	551	49.9
Shizuoka																244				73	317	317	47.9
Aichi				49						49						526				197	723	772	50.0
Mie				166						166						16					16	182	32.1
Shiga									112	112			110		110	62		713		16	791	1,013	36.9
Kyoto		930								930			235		235	57				94	151	1,316	22.2
Osaka																270				33	303	303	50.6
Hyogo				129			633			762			1,237		1,237	125				48	173	2,172	15.2
Nara																145					145	145	51.1
Tottori							1,327			1,327			5,329		5,329					26	26	6,682	15.0
Shimane																120			26	31	177	177	46.8
Okayama								546		546						417			71	73	561	1,107	23.1
Hiroshima			524	121		0	2,011		200	2,856			2,562		2,562	417					417	5,835	16.1
Yamaguchi																3,009		26	27	170	3,232	3,232	49.8
Kagawa														809	809	189			16		205	1,014	9.1
Ehime																				59	59	59	46.8
Kochi							50			50						73					73	123	22.9
Fukuoka							38			38						112		335	969	88	1,504	1,542	47.9
Nagasaki																139				63	202	202	49.3
Oita																83				90	173	173	49.9
Miyazaki							177			177						77				79	156	333	19.6
Kagoshima																894	26	26		31	977	977	49.2
Total (GJ/yr)	342	1,683	562	2,340	2,384	2,055	14,000	6,464	2,059	31,889	241	372	20,949	940	22,502	9,445	68	1,162	1,192	1,599	13,466	67,857	16.1
Capacity utilization factor (%)	15.5	23.0	12.8	33.7	20.0	18.5	13.6	10.9	27.5	14.9	31.8	18.4	12.7	8.3	12.5	49.9	43.1	49.8	49.1	48.8	49.7	16.1	

88.5 % of the direct use in Japan. Hot water use, excluding bath use, is 11.3 %, or one magnitude less than bath use; and geo-heat use including geo-heat pumps is 0.2 %, 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.

Table 13.9 Summary of geothermal direct uses in Japan as of March 2006.

Category	Capacity (MWt)	Use (TJ/year)	Use (GWh/year)	Ratio (%)	Capacity factor
Hot water use (without bath use)	400.3	4,887.9	1,357.8	11.31	0.39
Geo-heat use (including geo-heat pump)	13.3	67.9	18.9	0.16	0.16
Hot spring bath use	3,112.3	38,275.9	10,632.2	88.53	0.39
Total	3,525.9	43,231.7	12,008.9	100.00	0.39

13.2.2.4 New Developments during 2006

As has been mentioned, the New Energy Foundation (NEF) in Japan 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. 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/y in 2002 to 4,887.9 TJ/y 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/y in 2002 to 67.9 TJ/y in 2006, more than a factor of three during the four years. Hot springs for bath use are constantly developed every year (Figures 13.7 and 13.8). 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.

13.2.2.5 New Developments during 2006

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 (Table 13.6). If we simply apply a linear trend (Figure 13.8), 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 (Table 13.6). If we simply apply a linear trend here (Figure 13.7), the mean annual increment is 43,600 l/min. This must be the largest and steadiest direct use market in Japan.

13.2.3 Energy Savings

13.2.3.1 Fossil Fuel Savings/Replacement

The total geothermal electricity produced in Japan is saving 818,102 toe/y (toe = tonnes of oil equivalent) in FY2005, 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 1,521,756 toe/y in FY2005, based on the IEA-GIA conversion factor 1 TJ = 35.2 toe in produced heat (Mongillo, 2005).

In the grand total of geothermal power and direct use, Japan is saving 2,339,858 toe/y from April 2005 to March 2006.

13.2.3.2 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 a reduction of 2,637,685 tonnes of CO_2/y in FY2005, based on the IEA-GIA CO_2 saving 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 reduces CO_2 emissions by 4,911,640 tonnes/y in FY2005, based on the IEA-GIA CO_2 saving factor 409 kg/MWh in produced heat (Mongillo, 2005).

In the grand total of geothermal power and direct use, Japan reduced it CO_2 emissions by 7,549,325 tonnes/y from April 2005 to March 2006.

Figure 13.10 The production test in the Otari geothermal area, Nagano Prefecture, Japan.

13.3 Market Development and Stimulation

13.3.1 Supportive Initiatives and Market Stimulation Incentives

The New Energy and Industrial Technology Development Organization (NEDO) initiated the “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 57 areas as at the end of FY2005. Since 1999, NEDO has carried out Survey C 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 two areas selected for the surveys for FY2006 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 the West Okushiri-cho, a promising region is clarified from the result of a previous survey. In Hachimantai, a promising region is clarified from the result of a previous survey, too. At Otari, during the second year study, two production wells and one reinjection well were drilled and an ample geothermal resource was confirmed by a pumping test (Figure 13.10). A step-up to power generation development is now expected in this 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 on the ground, with a subsidy ratio of 20%. These systems started in 1983. Beginning in 2002, binary facilities in geothermal power generation systems were rewarded with a subsidy ratio of 30%.

Actual subsidy record for FY 2006:

- Production wells were drilled at: Matsukawa, 1 well; Kakkonda, 1 well; Onikobe, 1 well; Yanaizu-Nishiyama, 1 well, Hatchobaru, 1 well
- Reinjection well was drilled at: Hatchobaru, 1 well
- Facilities : renewal of geothermal turbine facility at Suginoi Hotel, new pipe laying at Kakkonda, Onikobe, Yanaizu-Nishiyama, and Takigami

13.3.2 Development Cost Trends

The last construction of a geothermal power plant in Japan was in 2000, except for the Hatchobaru demonstration binary power plant. There are no recent statistics on development cost. Therefore, it is difficult to mention to the development cost trends. The trend of geothermal power plant design is shifting to the relatively small scale which uses low enthalpy geothermal fluid and needs shallower-depth wells. Therefore, the total cost of construction tends to decrease, but the unit construction cost is increasing.

13.4 Development Constraints

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 renewable energy together with solar, wind, hydro and biomass energy. However, in Japan, only solar and wind are classified as “New Energy” that enjoys protection under the law concerning the Special Measures Law for the Promotion of Utilization of the 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 back into the category of New Energy should help reduce constraints on development.

13.5 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. The Japan's economy is gradually recovering in 2007, and the duration of economic expansion has reached the longest period of time in the post-war period. However, the policy to be a small government will still remain for the near future.

13.5.1 Trends in Geothermal Investment

Geothermal power generation is economically marginal in Japan, and therefore, investment in geothermal developments is risky in the current situation where governmental incentives are not fully available. The market for geothermal power generation development in the private sector is currently inactive except for those of overseas investment by trading companies and those of plant facility exports by turbine and generator makers.

13.5.2 Trends in the Cost of Energy

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.

13.6 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.

13.6.1 Focus Areas

Many researchers who are concerned with hot dry rock systems or enhanced geothermal systems 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 Tohoku University, the Graduate School of Engineering in Kyushu University, the Research Institute of Materials and Resources in Akita 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.

13.6.2 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, Tohoku University and Akita University are approximately 60 million Yen, 5 million Yen and 5 million Yen in 2006, respectively. The amount used in geothermal researches at AIST is dispersed in several research groups and is approximately 20 million Yen in the year 2006.

13.6.3 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. The electric companies and their institute, CERL in CRIEPI, are funding geothermal R&D, but the amounts are unknown.

13.7 Geothermal Education

Geothermal education is mainly conducted by Kyushu University, Tohoku University and Akita University at both undergraduate and graduate levels. The Geothermal Research Society of Japan holds a forum on the geothermal energy for its enlightenment and dissemination to citizens once a year.

An international group training course on geothermal energy for three months a year has been conducted by the Earth Resources Engineering Department of Kyushu University at the request from the United Nations (UNESCO) and financed by the Japan International Cooperation Agency (JICA) since 1970. This course was upgraded into an advanced course in geothermal energy for six months from 1990 to 1999, and further renewed into a course on geothermal energy and environmental sciences from 2000 to 2001. Although many countries requested that the course be continued, it was terminated in 2001 by the ODA budget decrease. In total, 393 specialists from 37 countries have participated in these group training courses during their 32 years of operation.

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) Scholarship. 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.

13.8 International Cooperative Activities

In contrast with the retreat in incentives to domestic geothermal developments, the Japanese government is enthusiastically undertaking the provision of assistance for accelerating geothermal development in Asia. This will hopefully rebound on the domestic geothermal market in the near future.

13.8.1 JICA master Plan Study in Indonesia

The Japan International Cooperation Agency (JICA) commenced the "Master Plan Study for Geothermal Power Development in the Republic of Indonesia" at the request of the Indonesian government in 2006 (Figure 13.11). Geothermal resource potentials for power generation in Indonesia are estimated to be 27,357 MW_e, undoubtedly 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. 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 13.11 The kick-off Workshop for the Master Plan Study held in Jakarta, Indonesia, on 18 May 2006.

Figure 13.12 Steaming ground in the Simbolon geothermal field, Sumatra, Indonesia, on 2 September 2006.

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 the 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 will be a database for systematic assessment of representative geothermal fields in Indonesia and a scenario for systematic geothermal developments (Figures 13.12 and 13.13). The project is scheduled in a relatively short term from March 2006 to September 2008, during 19 months.

Figure 13.13 Travertine terrace in the Sipoholon geothermal field, Sumatra, Indonesia, 1 September 2006.

13.8.2 JBIC ODA Loans Activity in Indonesia

The Japan Bank for International Cooperation (JBIC) was established in 1999 in order to undertake lending the ODA soft loans to developing countries for their economic and social developments.

Recently, JBIC has enthusiastically been providing ODA soft loans to geothermal developments in Indonesia at the request from the Indonesian government. For example, JBIC decided to lend: 5.9 billion Yen for the geothermal development in the Lahendong geothermal field, Sulawesi, in March 2004; 20.3 billion Yen for the geothermal development in the Ulubelu geothermal field, southern Sumatra in March 2005; and 1.0 billion Yen for the geothermal development in the Kamojang geothermal field, West Java, in March 2006. Likewise, JBIC seems to be going to provide ODA soft loans for geothermal developments in Indonesia almost once a year.

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NATIONAL ACTIVITIES

Chapter 14

Republic of Korea

Figure 14.2 Drill rig for the production well, BH-4, Pohang geothermal project.

14.0 Introduction

Although high-temperature geothermal resources for power generation do not exist in Korea, and even though it is only recently that the utilization of low-temperature resources was begun, there can be seen increasing efforts for R&D and fostering geothermal utilization at both government and industry levels.

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 system mainly in the granite area. Recently a geothermal anomaly was identified on the basis of high heat flow and geothermal gradient in the Tertiary sediment area of the south eastern part of the Korean Peninsula, where the Pohang low-temperature geothermal development program is now being carried out.

Geothermal heat pump installation is now booming; the number of installations and the total produced energy approximately double every year. There is a strong subsidizing program for

fostering renewable energy and the total estimated subsidy for geothermal heat pump installation in 2006 reached US$11.8 million, which is twice of the previous year.
Highlights for 2006 can be summarized as follows:

- A production well in Pohang low-temperature geothermal site reached the final depth of 2,383 m at the end of 2006 and the bottom hole temperature is expected to be higher than 90 °C
- A groundwater source heat pump connected to bank infiltration municipal water supply pipe line has been installed as proof-of-concept and its performance is now being monitored

14.1 National Policy

14.1.1 Strategy

The Korean Government does not have an independent strategy for geothermal yet, but does have 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 the Korean "new and renewable systems" began by focusing investment on the technology development in the three selected areas with big market potential: photovoltaic, wind power and fuel cells. 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.

14.1.2 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.

14.1.3 Progress Towards National Targets

The total use of new and renewable energy at the end of 2005 reached 4.88 million tons of oil equivalent (toe), accounting for only 2.1 % of the total primary energy consumption. 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 the 2006. However, considering the small amount at the end of 2005, it seems not to be easy to achieve this goal without a special activating plan.

The status and prospect of geothermal energy still does not seem significant because the government program focuses on the three major sources: photovoltaic, wind power and fuel cell. Fortunately, however, the importance of geothermal utilization is being acknowledged by the government and the public side and geothermal's share of market stimulating incentive is rapidly increasing. Therefore, we expect some remarkable progress can be made in the next five years.

Increases in geothermal heat pump installations and energy uses are presented 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 (2000-2005)*.

Year	2000	2001	2002	2003	2004	2005
Installed Capacity (RT)	10	88	207	670	1,768	2,331
Annual Energy Used (toe)			122	393	1,355	2,558

* Values reported to New & Renewable Energy Center, Korea Energy Management Corporation (KEMCO).

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

In 2006, total investments by government reached some US$ 7 million including:

- Development of deep-seated, low-temperature geothermal resources: US$ 3 million
- Information system for geothermal resources distribution and utilization: US$ 0.7 million
- Various geothermal heat pump utilization and demonstration programs: US$ 3.2 million

Government R&D expenditure is increasing at an annual rate of 10-20%, depending on the applied subjects and Table 14.2 shows the statistics for the last three years.

14.1.5 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 15% up to 50% of the total budget, depending on the size of the business. In 2006, the total amount was estimated to be some US$ 1.15 million (Table 14.2).

Table 14.2 Geothermal R&D expenditure for the period 2004-2006.

Year	2004	2005	2006
Government	5,505	5,979	6,943
Industry	758	881	1,148
Total	6,263	6,860	8,091

14.2 Current Status of Geothermal Energy Use in 2005

14.2.1 Electricity Generation

There is currently no geothermal electrical power generation in Korea.

14.2.2 Direct Use

14.2.2.1 Thermal Energy Used

In Korea, the annual statistics are to be available by the end of the first half of the next year, thus the data is from 2005 utilization.

The installed thermal power at the end of 2005 was 31.65 MW_{th}, including hot spa and geothermal heat pump usage.

Table 14.3 Geothermal direct heat uses in Korea as of 31 December 2005.

Use	Installed Capacity (MW_{th})	Annual Energy Use ($TJ/y=10^{12}$ J/y)	Capacity Factor
Bathing and Swimming	13.53	163.29	0.38
Geothermal Heat Pumps	18.12	107.44	0.19
Total	31.65	270.73	

The thermal energy used in 2005 is estimated to be about 270 TJ/y, with capacity factors of 0.38 and 0.19 for hot spas and heat pumps, respectively (Table 14.3).

Direct use in Korea currently includes only bathing (hot spas) and heat pumps (Table 14.3).

14.2.2.2 New Developments in 2006

The low-temperature geothermal development program in Pohang is still on-going. A groundwater source heat pump connected to bank infiltration municipal water supply pipe line has been installed as proof-of-concept and its performance is now being monitored.

One production well at Pohang, the low-temperature geothermal development site, reached the final depth of 2,383 m at the end of 2006.

14.2.2.3 Energy Savings

Energy saving is still a negligible amount and there are no statistics available.

14.3 Market Development and Stimulation

The Korean Government offers long-term low-interest loans, tax benefits and government/public funds for those using renewable energy. Subsidies for geothermal installation through various

Table 14.4 Subsidy for geothermal installation for the period 2004-2006.

Year	2004		2005		2006*	
	Capacity (No. of cases)	Subsidy§	Capacity (No. of cases)	Subsidy§	Capacity (No. of cases)	Subsidy§
Spreading Program	793 RT (10)	1,886	1,659 RT (17)	3,642	(41)	9,541
Rural Spreading Program	402.5 RT (5)	1,505	510 RT (3)	1,770	(9)	2,252
Total	1195.5 RT (15)	3,391	2,169 RT (20)	5,412	(50)	11,793

§ In US$ 1,000s (US$ 1 = 1,000 Won)
* Estimated values in 2006
** Note: Data correspond to starting year, so actual operations are to be one or two years later

renewable energy spreading programs amounted to US$ 11.8 million in 2006 (Table 14.4). Also from 2004, the Mandatory Public Renewable Energy Use Act came into effect and states that “in construction of all public buildings bigger than 3,000 m^2 in area, more than 5% of the total budget must be used to install renewable energy equipment." Geothermal heat pump installation is now being accelerated with this act.

14.4 Development Constraints

14.4.1 Technical and Social Barriers

A barrier to the progress of geothermal heat pump use from the technical and scientific point of view may be explained by lack of information on the thermal properties of subsurface materials and lack of scientific knowledge on hydro-geological 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 this technology is at the very beginning stage. Therefore, people tend to consider that a natural gas or an oil boiler is cheaper in initial stage, and durable.

14.4.2 Environmental Issues

The "Groundwater law" states that the depth and purpose of all boreholes must be reported on prior to drilling. Also if somebody is to use groundwater, they must undergo an environmental impact evaluation and submit its result. 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, the thermal utilization should be free from such regulation. Some arguments are still going on.

14.5 Economics

14.5.1 Trends in Geothermal Investment

Government investment in geothermal has steadily increased since 2003. Investment from industry has also increased as a matching fund to the government R&D budget. Government investigation is being made though R&D expenditure and various subsidizing programs; statistics are available in Table 14.2 and Table 14.4, respectively.

14.5.2 Trends in the Cost of Energy

Because 97% of fossil fuel is imported, energy cost in Korea reflects the recent high oil price. The price of electricity, however, does not change much, partly due to the high portion of nuclear power generation (~40%) and partly due to government policy. The average electricity price is about US 7.5 cents/kWh.

14.6 Research Activities

14.6.1 Focus Areas

R&D activities in Korea are focused on 1) low-temperature geothermal water development, and 2) geothermal heat pump applications. Almost all of the research activities are initiated by government funding.

14.6.2 Government Funded

R&D in geothermal investigations, exploration and exploitation is led by 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". RD&D programs on geothermal heat pump applications are funded by the New & Renewable Energy Center, Korea Energy Management Corporation (KEMCO). In 2006, a total of 11 RD&D projects were funded and US $3.25 million was granted, to reach 46% of the total funding, which means that government RD&D expenditure on shallow geothermal utilization is rapidly increasing.

14.6.2.1 Pohang Geothermal Project

The Pohang low-temperature geothermal development project, the first large-scale geothermal program in Korea for district heating and cascade utilization, has made remarkable progress in 2006. The production well BH-4 reached its final depth of 2,383 m at the end of the year (Figure 14.1). The original target depth was 2,000 m and the temperature at the depth of 1,980 m was 82.5 °C. Since the well did not meet the basement at the depth of 2 km, we decided to extend the well and detected the basement at a depth of 2,265 m (Figure 14.2, this chapter title page). The basement rock is a kind of grano-diorite from major element analysis, and age dating will be made (Figure 14.3). Detailed logging, pumping test and other necessary borehole surveys will follow in 2007 to characterize the geothermal water reservoir. For a detailed explanation of the Pohang site, please refer to the 2005 GIA Annual Report.

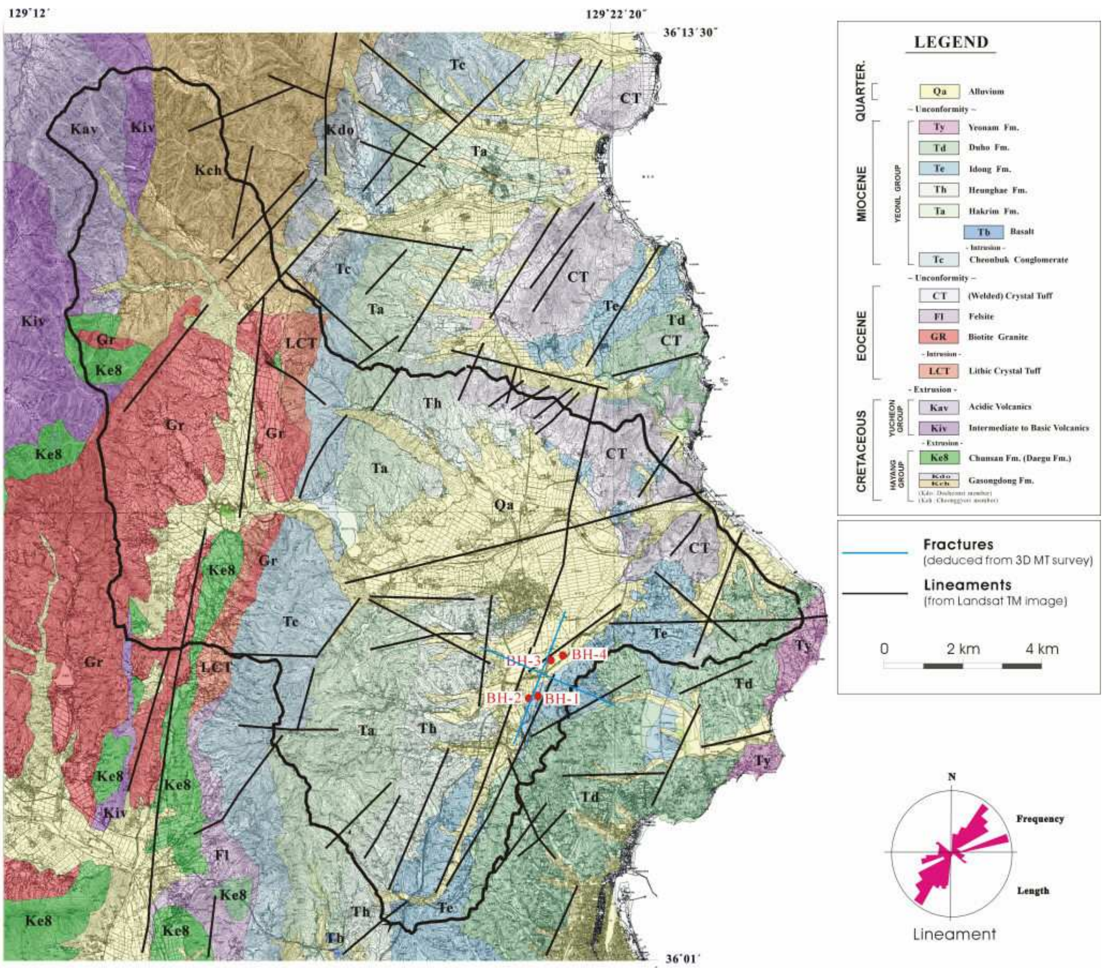

Figure 14.1 Location map for the four boreholes superimposed on the geologic map and surface lineaments. BH-1: exploration hole for coring, BH-2: pilot well, BH-3: abandoned because of failure, BH-4: production well.

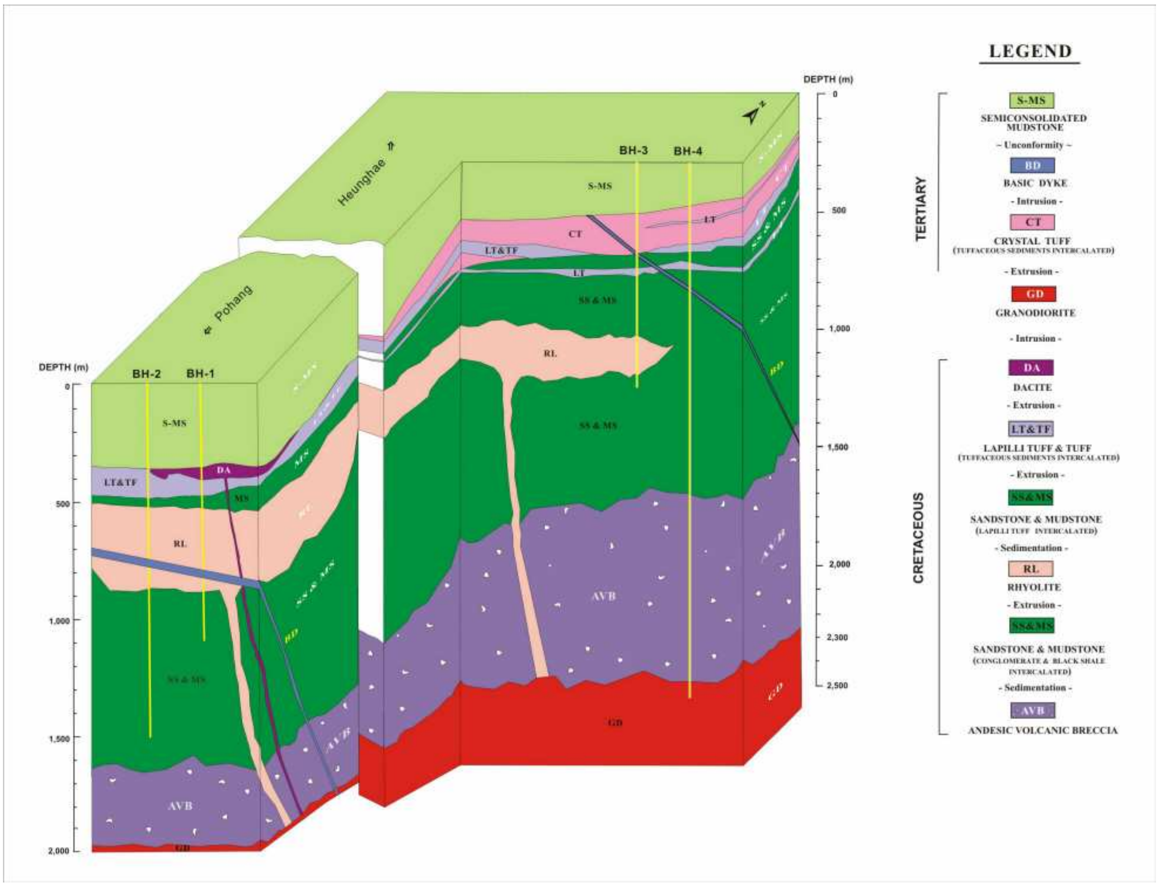

Figure 14.3 Updated sketch of geology of Pohang site out of core, drill cutting and well logs.

14.6.2.2 Groundwater Source Heat Pump Connected to Bank Infiltration

In 2005, KIGAM initiated a government funded R&D program for compiling a map of thermal properties of subsurface materials throughout its territory to provide basic design parameters to geothermal heat pump installer. Geothermal heat pump installation in Korea is rapidly expanding but quantitative information on the thermal properties of subsurface materials is not yet available. As a consequence, the installed heat pump systems are likely to be over-designed, which can make the systems less competitive in terms of initial cost. The R&D program aims at compiling 1:250,000 scale map of thermal conductivity by the end of 2007.

The R&D program also includes the demonstration of a groundwater source heat pump using alluvial and river water. In Korea, the amount of groundwater use for residence and industry reaches up to 5 million tonnes per day- this will possibly produce a huge amount of thermal energy for heating and cooling the buildings nearby. The fact that it does not incur any drilling cost when connecting heat pump to existing groundwater well head or pipe line, may offer great opportunity for expanding geothermal utilization. This project is carried out in collaboration with K-Water (new name for Korea Water Resources Corporation) and a small business company installing geothermal heat pumps.

One of the major achievements in 2006 was the installation of the heat pump as proof-of-concept; directly connected to the municipal water supply pipe line from the bank infiltration system. There are several pumping wells along the Nakdong River, in the southeastern part of Korea,

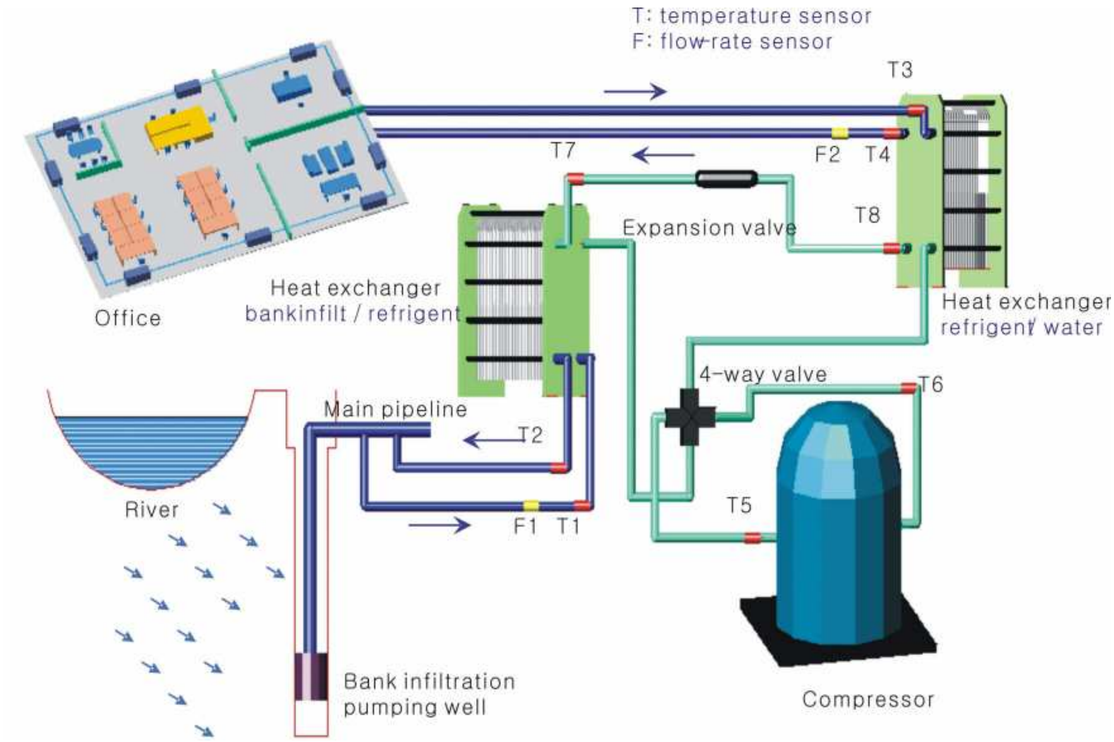

Figure 14.4 Schematic diagram of the bank infiltrated water source heat pump system.

utilizing bank infiltration system to supply potable water to a big town, Changwon City. The maximum capacity of the system is to supply total of 180,000 m^3/day with 24 pumping wells, while 60,000 m^3/day is currently pumped, processed and supplied. The purpose of the application was to demonstrate a way of utilizing the huge amount of thermal energy contained in the infiltrated groundwater. Since it is a demonstration or proof-of-concept installation, a small size heat pump with a capacity of 15 refrigerating ton (RT; about total 52.8 kW) was installed to supply heat and cooling for a room with an area of 145 m^2 in a three-story office building. We made a by-pass at the main pipe line from a well with a capacity of 2,000 m^3/day to the heat pump as shown in Figures 14.4 and 14.5. The temperature of the pumped water is 17-18 °C throughout the year and the flow rate to the heat pump is 4-5.5 m^3/hr, depending on the heating or cooling load. The performance of the system is now being monitored and we expect this to be an important corner stone for expanding geothermal heat pump installations, especially by utilizing groundwater thermal energy.


Figure 14.5 Well head for bank infiltrated water supply (left) and installed heat pump (right).

14.7 Geothermal Education

There does not exist regular curriculum for geothermal at university level in Korea 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 the recent high oil price.

14.8 International Cooperative Activities

The major international cooperative activity of KIGAM is participating IEA-GIA ExCo and Annex VIII. KIGAM also maintains research collaboration with Institute for Geo-Resources and Environment (GREEN) of AIST, Japan, in the 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).

14.9 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 II geothermal project, Mexico (courtesy of CFE, Mexico)

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 field (central Mexico). By December 2006, the geothermal-based installed net capacity for electricity generation was 953 MW_e, ranking Mexico in third place worldwide.

15.1 National Policy

About 78.8% of the installed capacity for electricity generation belongs to the two government-owned utilities, namely the Comisión Federal de Electricidad (CFE) and Luz y Fuerza del Centro (LyFC). 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 on the same basis 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 Cerro Prieto Field, using the same amount of steam. CFE is also considering increasing by 25 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). Also CFE is currently doing feasibility studies for evaluation of the following projects: 50 MW_e binary power plant in Cerro Prieto Field: replacement of three 5 MW_e units in Los Azufres Field with one 25 MW_e unit, 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

The Mexico's total installed capacity is 953 MW_e, distributed among the geothermal fields as follows: Cerro Prieto (720 MW_e), Los Azufres (188 MW_e), Los Humeros (35 MW_e) and Las Tres Vírgenes (10 MW_e).

The total electricity generation with geothermal steam in 2006 was 6,685 GWh/y. Electricity generation from geothermal sources represents around 3.0 % of total power production. The geothermal contribution to electricity generation is more than 1.5 times higher than its contribution to the installed capacity, reflecting the very high capacity factor.

There were no new geothermal developments in Mexico during 2006.

During 2006, CFE drilled 9 geothermal production wells in the Cerro Prieto field. For 2007, 9 production wells are scheduled for Cerro Prieto and no injection wells; 2 production wells are scheduled for Los Humeros and 1 exploration well in the Acoculco geothermal area.

In 2006, CFE conducted the following work over jobs: 11 in production wells in Cerro Prieto field; 3 in production wells and 1 in an injection well in the Los Azufres field; 1 in a production well in the Tres Vírgenes field. For 2007, there are work-over jobs are scheduled for 10 production wells in the Cerro Prieto field and 1 in a production well in the Tres Vírgenes field

15.2.2 Direct use

The total estimated installed thermal power in 2006 was 164 MW_{th}. The use was mainly for balneology in 160 sites distributed in 19 states.

15.3 Market Development and Stimulation

15.3.1 Support Incentives and Market Stimulation Incentives

At present there are no incentives for geothermal development in Mexico. The Comisión Federal de Electricidad, the larger of two national utilities, increased its installed capacity for power generation with geothermal sources from 853 to 953 MW_e in 2003, and this is the only substantial increase expected throughout 2007, 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 on the same basis 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 La Primavera 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 impacts.

15.5 Economics

15.5.1 Trends in Geothermal Investment

As mentioned above, although the target for geothermal development in the present federal administration has been met, studies are underway in CFE for future developments in the order of 25 MW_e in Los Humeros, 100 MW_e in Cerro Prieto that will replace 2 of the older units (75 MW_e) and 75 MW_e in Cerritos Colorados (La Primavera), 50 MW_e binary power plant in Cerro Prieto Field: replace three five MW_e unit in Los Azufres Field with 25 MW_e unit as well as the development of new fields in Acoculco, San Pedro, La Soledad and Tacaná.

15.5.2 Trends in the Cost of Energy

The average price for electricity has shown a steady increase over last several years, with a last increase of about 10.9% from 2005 to 2006.

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) offers a Geothermal Training Program (10 month program) which, in addition to the program offered by Iceland and the one previously offered by New Zealand, has been utilized by CFE to train some of their young engineers. 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.*) also 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 2006, 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.

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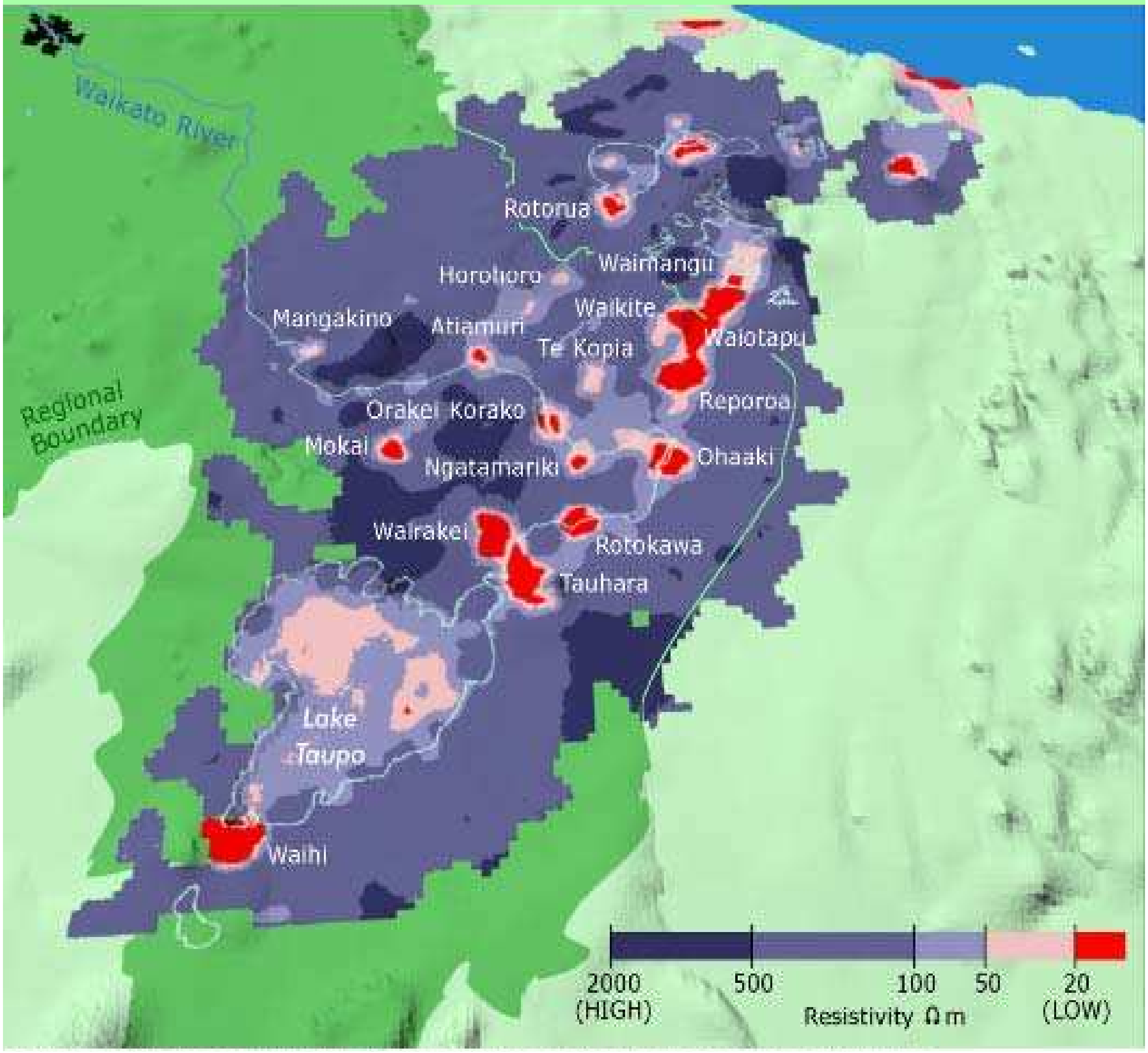
NATIONAL ACTIVITIES

Chapter 16

New Zealand



Electrical resistivity image of the Taupo Volcanic Zone (courtesy of GNS Science, New Zealand)

16.0 Introduction

The New Zealand geothermal scene is currently very active. There has been recent installation of new generation, with around 1000 MW_e of additional geothermal generation looking feasible and commercially attractive in the next few years. While direct heat use has been relatively static, some market leaders are now installing geothermal heat pumps, and this looks like an area for considerable growth. Various regional and district councils have been, or are in the process of clarifying, the rules and policies related to takes of water. Central Government remains dedicated to the greater use of renewable low-emission energy forms (including geothermal energy), but is now trying to clarify its wider energy strategies and means of encouraging further uptake of renewables.

The installed capacity of geothermal electricity generation in New Zealand is currently 450 MW_e, or about 5.5% of the total capacity. Geothermal meets 7% of peak demand, and about 6.5% of total generation. Note that in the 2006 calendar year (these are the latest official figures) geothermal electricity generation was approximately 3,210 GWh/y; while in 2005, direct heat use amounted to 9.7 PJ/y.

16.1 National Policy

16.1.1 Strategy

Energy supply has been identified by the NZ government as one of the target areas for sustainable development because of its strong correlation to economic growth, potential environmental impact, and because both consumers and industry are heavily reliant on its supply. The Government regards geothermal energy as being a resource that can play a vital role in New Zealand's future energy mix. Cost of development is very similar to the cost of a range of other technologies and resources, and the current wholesale cost of electricity at around 6 US¢/kWh. Consequently, commercial drivers will see a significant uptake of geothermal energy, provided access and regulatory barriers are not overly constraining.

On 8 November 2005, the Prime Minister announced plans to develop a formal, comprehensive New Zealand Energy Strategy (NZES) which is expected to be released in its final form during 2007. A draft NZES was released in 2006 for public consultation covering all aspects of the New Zealand energy scene. It is linked into parallel consultation on transport and climate change initiatives. The NZES is broadly supportive of renewable energy options, and emphasises the important role that geothermal energy will play especially in electricity generation (Figure 16.1).

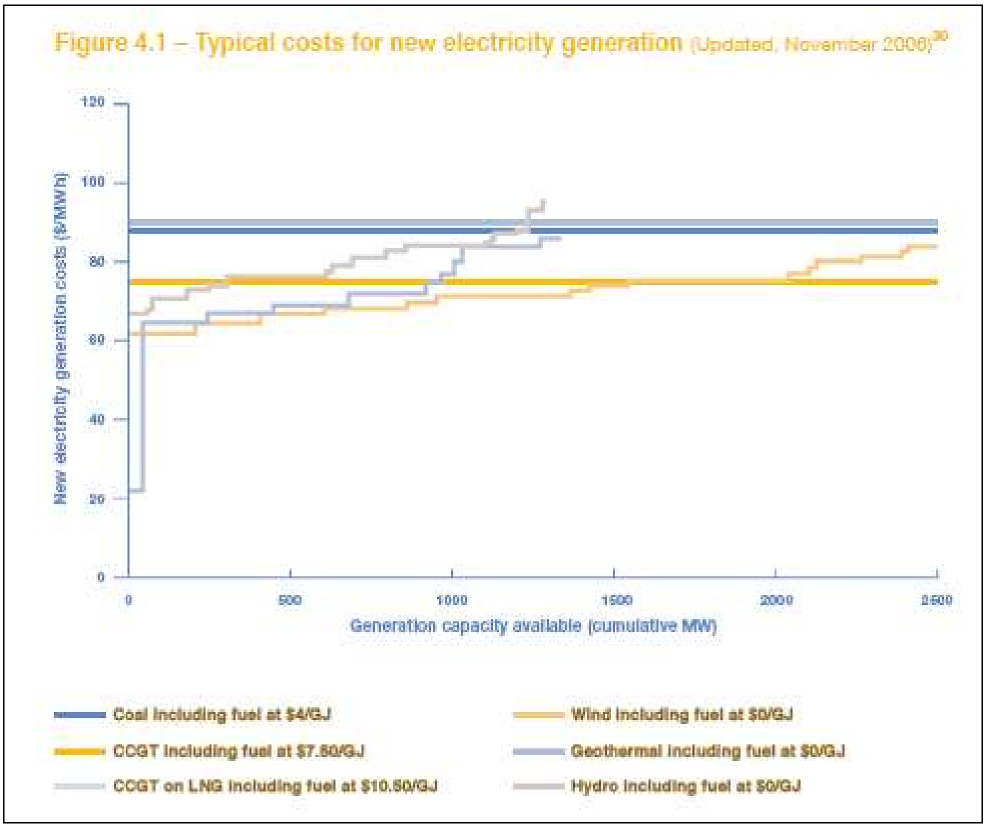


Figure 16.1 Typical costs for new Electricity generation in New Zealand (from the NZES).

Also linked to the NZES is the New Zealand Energy Efficiency and Conservation Strategy. The revision of the current document is discussed later, but will be tied in to the completion of the NZES, probably including a number of specific sector targets.

16.1.2 Legislation and Regulation

The Resource Management Act 1991 (RMA) is an all-encompassing environmental act that attempts to apply reasonable constraints on development, with delegation of decision making and plan/policy statement development down to regional and district level. Support and concerns about the RMA and its implementation have been expressed by a wide range of interests. As a result, the RMA has been reviewed and amended several times. One amendment specifically encourages positive consideration of renewable energy projects (including geothermal projects). Another addressed concerns about the balance between national and local interests and the allocation of natural resources. Work was also initiated on providing national guidance on infrastructure issues. During 2006, the Ministry of Economic Development was scoping a National Policy Statement and National Environmental Standards on transmission lines and will also consult on generation. The results of these consultations should flow through to the implementation of regional and district plans and policy statements developed under the RMA. Eventually these plans and policy statements will be revised to reflect direction given at the national level.

The Waikato Regional Council, with a geothermal resource base including 80% of the high temperature fields in New Zealand, has been reviewing and improving geothermal policies and plans under the RMA since 1998. An appeal process saw final resolution of the Regional Policy Statement and Regional Plan in 2006.

The Government has been looking for means to encourage distributed generation (DG), with several past geothermal projects representing examples of large DG projects. The Government is considering reforms of the Electricity Industry Reform Act which previously placed restrictions on electricity distribution companies from investing in generation and subsequently retailing that electricity. Decisions around reforms may have some impact on management structure for the new Ngawha extension, and could see further investment by the distributors who had been active investors in geothermal energy in the past.

Recent taxation improvements have included a clarified policy on geothermal well depreciation, allowing depreciation of all wells and the ability to write off the cost of wells that are unsuccessful.

16.1.3 Progress Towards National Targets

There has been a long term emphasis on promoting energy efficiency and further increasing the amount of energy produced from renewable resources reflected in the establishment of the Energy Efficiency and Conservation Authority (EECA) as a Crown entity in 2002 to assist with the implementation of the National Energy Efficiency and Conservation Strategy (NEECS) announced in 2001. This strategy had a 5 year term so has been actively reviewed over 2006. The strategy included the specific goals of improving energy efficiency by 20% and increasing consumer energy from renewable sources by 30 PJ by 2012 over levels recorded for the year 2000. Progress has been limited so goals will be revised. Perhaps more significantly, it has been recognised that incentives for action by industry have been inadequate. Consultation will soon identify a range of incentives and controls that might assist achievement of the new goals. The revised implementation of the NEECS will follow release of the NZES.

The Climate Change Response Bill enacted in 2002 in response to New Zealand's Kyoto commitments included a carbon emission charge, negotiated greenhouse agreements (NGAs) for at-risk industries and a bid-in Projects mechanism. Through to the end of 2006, several large industries had negotiated NGAs and a number of renewable energy projects (including geothermal projects) had benefited from the Projects carbon credits. Following a revised projection of New Zealand's greenhouse gas emissions during the Kyoto first commitment period, a full review of climate change initiatives was commissioned. The results of the review questioned the true benefits of the overall climate change policy package. By 2006 the carbon charge portion of the climate change package was dropped. It is still possible that a limited form of carbon charge may be applied to the electricity industry.

16.1.4 Government Expenditure on Geothermal R&D

NZ government funded geothermal research amounts to about NZ$ 2 M/y. The next phase of research spending, commencing in 2007, is expected to be at a similar level.

16.1.5 Industry Expenditure on Geothermal R&D

Both of the major commercial geothermal operators, Contact Energy and Mighty River Power, have recently announced plans to spend about NZ$ 2 billion in the near term on geothermal power projects. A small percentage of this (approx NZ$ 1 M/y each) is expected to be directed at commissioned research.

16.2 Current Status of Geothermal Energy Use in 2006

16.2.1 Electricity Generation

16.2.1.1 Installed Capacity and Electricity Generated

The total geothermal installed capacity in New Zealand in 2006 was 450 MW_e.

The total electricity generated in 2006 was 3,210 GWh/y.

16.2.1.2 New Developments in 2006

Wairakei Power Stations- The original Wairakei A and B Stations commissioned between 1958 and 1963 continue to operate reliably. In 2005, a 14.4 MW_e Ormat binary cycle station was commissioned near the original stations to take advantage of water brought down to the area for reinjection purposes. This brought the total output of the combined facility to 171 MW_e. The station and steamfield are owned and operated by Contact Energy, who in early 2006 was offering 157 MW_e into the market, due to a developing shortfall in steam supply over the last 2-3 years. However, Contact has been successfully drilling in the Te Mihi sector of the field, and has connected a number of wells to fully load the station. The station and steamfield continue to discharge some brine and condensate to the Waikato River, though about 30% of all fluid from the steamfield is now reinjected.

A further 55 MW_e station was built by Alistair McLachlan and Mercury Energy in 1996, on the western side of the Wairakei field (Poihipi Road). This Poihipi station was subsequently purchased by Contact Energy. The station took advantage of a shallow steam zone in that part of the field. The original consents were restrictive and did not allow full output. Hence the station tended to operate in day-night mode to maximize revenue recently offering 29 MW_e during the day and evening and 10 MW_e in the early morning, typically averaging about 25 MW_e output on any day. All of the condensate from the station is either evaporated through the cooling tower or reinjected.

Recently, Contact Energy has secured more favourable consents (subject to an appeal) for the combined operations of the Wairakei stations. Pipelines linking the Poihipi and Wairakei stations through the Te Mihi production area allow a more flexible operation.

Recently, Alistair McLachlan (through the Geotherm Group) has proposed a further 55 MW_e power station on the Wairakei field. Geotherm has obtained consents, purchased its own drilling rig and drilled one deep well on land owned by McLachlan (adjacent to shallow steam producing wells for the Poihipi station). Results were unsatisfactory and the investors have placed Geotherm into receivership.

Development and operational consents have been an issue for both Contact Energy and Geotherm. Contact Energy has been in the process of renewing consents for the operation of its existing facilities for several years, with formal consent applications lodged in 2001 after consultation and studies. Consents were granted in 2005 that allow the existing A and B stations and a fully-loaded Poihipi station to continue operation until 2026. These consents were appealed and have been referred to the Environment Court. Evidence and rebuttals were heard during 2006 and a decision is expected in mid-2007.

Tauhara Developments- The Tauhara geothermal field is connected with the Wairakei field and is affected by the exploitation of Wairakei. The Wairakei development and operation is contributing to observed subsidence at Tauhara. In the process of Wairakei consent renewals, and in the discussions and appeals around Environment Waikato geothermal plan and policy statements, the local Taupo community has developed a greater sensitivity to the subsidence issue. This has led to strong community reaction to proposed or continued operations, and some claims of property damage due to geothermal withdrawal at Wairakei, when there is evidence that other non-geothermal causes are also involved. Nevertheless, concerns have to be taken into account in any consenting process. The recent Environment Court decision (April 2006) on injection-related aspects of the changes to the regional plan and policy statement has given further weight to these subsidence concerns.

In 2006 Contact Energy undertook some deeper drilling into the Tauhara field (one production well, two injection wells, and 2 deep exploration wells). The new exploration wells provide renewed confidence in the extent and productivity of the Tauhara resource to the east, and Contact has announced its intention of applying for consents to develop Tauhara further (~ 200 MW_e).

Ohaaki Power Station- Contact Energy continues to own/operate the Ohaaki power station and steamfield originally commissioned in 1989. Contact successfully renewed consents for the station and steamfield in 1998 allowing continued operation to 2013. While the station continues to have a nominal capacity of 100 MW_e, following recent decommissioning of its high pressure sets, its actual output has dropped from a peak of 37 MW_e in July 2004 to 30 MW_e or less in early 2006. Contact is drilling deep make-up wells and working over existing wells to keep the station at a capacity of 45 MW_e (net). Three production wells were drilled at Ohaaki in 2006.

All geothermal fluid produced by the field is lost in cooling tower emissions, discharged onto land (where there were previously natural surface discharges) or is reinjected.

General operations at Ohaaki have been restricted by management of reinjection returns and cool fluids encroaching from the field margins or above, and by concern over the possibility that subsidence could lead to flooding of important Maori cultural sites by the Waikato River.

Rotokawa Power Station- The Rotokawa power station is an Ormat geothermal combined cycle power station initially developed in 1997 at 29 MW_e, but subsequently expanded by 6 MW_e in 2003. The expansion included further brine units to take advantage of the changing fluid conditions within the field. The Rotokawa project is divided into two companies; Rotokawa Joint Venture (a 50:50 joint venture between Tauhara North No.2 Trust and Mighty River Power) which owns the steamfield, and Rotokawa Generation (100% Mighty River Power) which owns the generation plant. Mighty River Power operates both the station and the steamfield.

Between October 2004 and February 2005, Mighty River Power drilled three deep reinjection wells to test the western side of the Rotokawa reservoir, and to help relieve the current shallow injection target. At least one of these wells is now used as an injector. In the process, other structures were observed in the area that may form production targets at some future date.

Reduction in shallow reinjection has lead to a drop in pressure at this level, and a hot spring discharge (previously stimulated by reinjection) has ceased.

The Rotokawa field could potentially support more than 250 MW_e of generation, and Mighty River Power has expressed interest in developing an initial 100 MW_e, including the existing development. An application has been filed by Tauhara North No 2 Trust for a further 35 MW_e. Adjacent land owners over the resource have indicated clear interest in development of the geothermal potential.

Mokai Power Station- The Mokai power station was commissioned in 2000. It is the first in New Zealand to be fully owned by a Maori trust (the Tuaropaki Trust, which subsequently placed assets in the Tuaropaki Power Company), with Mighty River Power contracted to operate and maintain the Ormat geothermal combined cycle station which has installed capacity of 55 MW_e. Mighty River Power has bought a 25% share in Tuaropaki Power Company. All condensate and cooled brine is reinjected. A 39 MW_e expansion of similar design was commissioned in 2005 and operates in parallel with the initial station. Rising pressure in the shallow injection aquifer has recently caused nearby thermal craters to fill with hot water and overflow. A new deep reinjection well has recently been drilled to relieve the pressure.

There is a steamfield management committee that meets regularly, and includes a Contact Energy representative. Contact Energy has land interests over part of the Mokai field with a view to a possible further development of their own, but no firm proposals are known.

Kawerau Developments- The fields described above are all located in Environment Waikato's region while the Kawerau field is located in Environment Bay of Plenty's region and is covered by a different regional policy and plan. The Kawerau field was initially developed in parallel with Wairakei through the 1950's for a direct heat supply to the Tasman pulp and paper mill, and this use continues today. The Tasman mill installed its own 10 MW_e geothermal back pressure turbogenerator in 1966. The new owners of the mill (Norske Skog) invested in a replacement turbogenerator which was commissioned in 2004.

There have been no known changes to the existing Bay of Plenty Electricity Ormat generators located on either side of the Tarawera River. These were installed in 1989 and 1993 and generate a total of 6 MW_e into the local network using a portion of the otherwise unused brine associated with the mill steam supply. Bay of Plenty Electricity has expressed interest in further development of generation on the Kawerau field. Currently about half of the brine is not used and much of it is discharged to the river.

Ownership of various aspects of the Kawerau developments has changed over the years. Some of the wells and steamfield system had been developed by the original owners of the mill, but were sold to the Crown in the late-1970s. As of 2005, the Crown owned 102 wells on many fields along with the Kawerau steamfield development and the steam supply contract with Norske Skog Tasman. The Crown signalled its interest in the development of its geothermal assets and identified Mighty River Power (a state owned enterprise) as the developer, partly because of a Government policy on non-sale of assets. As a first step to active development, in July 2005 the Crown transferred all Kawerau geothermal assets including wells to Mighty River Power. In a back-to-back deal, these assets were on-sold to Ngati Tuwharetoa Geothermal Assets (NTGA) as the holding company for some local Maori interests. Mighty River Power now operates and maintains the assets on behalf of NTGA. Several very productive wells were transferred to NGTA in the process, so NGTA is now considering further development options.

To the east of the mill is another large Maori land block under the management of the Putauaki Trust. The Trust was aware that there was a possibility of part of the Kawerau geothermal field underlying their property, so sought expressions of interest for geothermal development from several parties. A contract was signed with Mighty River Power to explore and possibly develop a power station using the resource and this has been progressed since 2003. Mighty River Power undertook further MT-TDEM and gravity surveys in the eastern part of the field to help delineate the productive reservoir and followed this with 6 deep exploration wells into the greywacke basement. In August 2005, Mighty River followed this with a resource consent application for a 90 MW_e power station and steamfield to be located on Putauaki Trust and Norske Skog Tasman land. Consents (with conditions) were granted in March 2006 for 35 years, and appeals settled so construction is in progress. A steamfield management agreement has been entered into by Mighty River Power, Norske Skog Tasman and Ngati Tuwharetoa Geothermal Assets with a view to ongoing sustainable management and integrated development of the Kawerau resource.

Ngawha Power Station- The Ngawha field is located in Northland. The Ngawha power station was commissioned in 1998 and is also an Ormat binary cycle station nominally 10 MW_e and intended as a first stage to a much larger development. A resource consent application was made for a 15 MW_e extension in 2005, but was turned down because of concerns over possible effects on the local springs used for bathing. The owner of the Ngawha station (Ngawha Geothermal Resource Co, a subsidiary of Top Energy) subsequently gained consents to operate a temporary supplementary injection trial (with up to 10% extra surface water being injected) to show effects on the springs could be avoided and this trial has been successfully completed. In 2006 Top Energy won its appeal through the Environment Court and is proceeding with the 15 MW_e expansion.

Top Energy is a lines company, and so there are limitations on its ability to generate electricity under current legislation (an arms-length company may have to be formed to own and operate this larger station). Relevant laws are currently being considered for revision by Government, and this may assist Top Energy in its goals.

16.2.1.3 Rates and Trends in Other Developments

Mighty River Power made progress in the Mangakino area through land negotiations with a large commercial forester, and so undertook further geoscientific work (including new MT-TDEM data) backed up by three deep wells (and a re-drill), all with a view to a possible power station development. The wells have confirmed temperatures exceeding 250 ^oC, but have failed to identify permeability targets. Currently the project is not being pursued.

Several parties have expressed interest in other geothermal developments. These are still at concept stage though it is known that Maori interests on the Tikitere and Rotoma-Tikorangi fields near Rotorua have been undertaking some more detailed studies. Mighty River Power is known to have undertaken some scientific exploration work at Atiamuri and Horohoro fields.

16.2.1.4 Number of Wells Drilled

It is estimated that about 15 wells were drilled in 2006 for production and reinjection purposes.

16.2.1.5 Contribution to National Demand

Geothermal installed capacity amounted to about 5% of New Zealand's total capacity.

Geothermal power generation provided approximately 6.5% of New Zealand's total generation.

16.2.2 Direct Use

About 9.6 PJ of thermal energy was used in 2006; however, the installed thermal power was not reported.

16.2.2.1 Categories of Direct Use

The categories of direct use are provided in Table 16.1 for the 2005 calendar year. There may be a reallocation between energy for bathing and energy for water heating in future assessments.

Table 16.1 Energy used in various geothermal direct use categories for 2005 (units are TJ).

Geothermal and Council Regions	Space Heating	Space Cooling	Water Heating	Greenhouse Heating	Fish and Animal Farming	Agricultural Drying	Industrial Process Heat	Bathing and Swimming	Other Uses	**Total**
Northern										
Northland								6		**6**
Auckland								65		**65**
Waikato	0							63		**63**
Hauraki										
Waikato								20	2	**22**
Bay of Plenty					2			412		**414**
Rotorua-Taupo										
Waikato	13		3	167	271		398	1,238	844	**2,935**
Bay of Plenty	19						5,315	786		**6,120**
Miscellaneous North Island										
Gisborne								0.1		**0**
Hawkes Bay								3		**3**
Taranaki								0.2		**0**
South Island										
Marlborough	0									**0**
Canterbury								30		**30**
West Coast								14		**14**
Total	**32**	**0**	**3**	**167**	**273**	**0**	**5,713**	**2,638**	**846**	**9,672**

There are several direct heat applications cascaded from the Contact Energy operation at Wairakei geothermal power station. One company (NETCOR) receives brine for a tourist centre that includes a Maori village and a replication of natural silica terraces. A nearby hotel receives steam for heating and a prawn farm beside the A station receives brine for heating pond water. The prawn farm supply had to be modified following the installation of the binary plant which cooled the brine supply to the farm. The brine from the prawn farm is subsequently discharged to the Waikato River. The Geotherm interests use a separate steam supply for heating greenhouses growing orchids.

Despite concerns about possible subsidence, the Tauhara geothermal resource which extends under parts of Taupo continues to be used for direct heat applications.

A small quantity of brine provided by the Ohaaki geothermal power development is used by the Ohaaki Timber Kilns in a direct heat application; and at Mokai geothermal field, a large geothermally heated glasshouse complex has been developed nearby the recent 39 MW_e expansion site.

16.2.2.2 New Developments in 2006

Some of New Zealand's first geothermal heat pumps are being installed by early adopters, these being in the high end residential market.

The most significant single installation was a 20 MW_{th} heat supply to the Tenon timber kilns at Taupo. These kilns are fed from steam from the Tauhara field.

16.2.2.3 Rates and Trends in Development

Overall, direct use of geothermal energy has been static through the decade (with the exceptions listed above).

Heat pumps are now being installed but still do not have high visibility (to accelerate interest) and there are few people capable of installing them.

Consenting requirements are driving greater attention to monitoring and management of use. There has been some recent investment in upgrading existing facilities

16.2.2.4 Number of Wells Drilled

There are currently no complete records of direct use wells drilled in any year. An incomplete survey of drillers indicates that many of these operators have inactive geothermal rigs, though one driller reported increased drilling activity near Tauranga (resource temperature around 40 ^oC) requiring purchase and use of a third drilling rig.

16.2.3 Energy Savings

16.2.3.1 Fossil Fuel Savings

The calculation of fossil fuel savings/replacement is based on a review of the fossil fuel mix in the New Zealand electricity system. It is assumed that all marginal generation will be fossil fuelled.

Electricity generation and geothermal direct heat use have been assessed at 9.7 PJ each; the total of 19.4 PJ is equivalent to 460,000 toe/y.

16.2.3.2 Reduced/Avoided CO_2 Emissions

The calculation of reduced/avoided CO_2 emissions is based on the CO_2 emissions from current fossil-fuelled power stations. In the case of direct heat use, it has been assumed that 80% of heating would have been from gas and 20% would have been from coal. Fugitive gas emissions (associated with current geothermal emissions) have been deducted from the CO_2 emissions of the equivalent fossil-fuelled plant. On this basis, the avoided CO_2 emission for power generation is 1,300 kt/y and that for direct use is 520 kt/y, making a total of 1,820 kt/y avoided CO_2 emissions.

16.3 Market Development and Stimulation

The “Projects to Reduce Emissions” initiative is mentioned above. This scheme benefited a number of projects in terms of allocating carbon credits to the developers, but is no longer operational.

Development cost trends are discussed in Section 16.4.

16.4 Economics

16.4.1 Trends in Geothermal Investment

There is increasing investment in geothermal power station development in New Zealand. This is especially driven by the expected long term price of electricity and the relative price of geothermal generation compared to alternative forms of generation (see Figure 16.1).

While there are direct use applications that are economic, uptake of these options is still very limited.

16.4.2 Equipment, Project and O&M Costs

In total, it is thought that capital costs of geothermal projects may have increased by about 20% over the last few years (after removing the effect of exchange rate movements). This affects both station plant and well costs and is associated with increasing competition for steel partly driven by China’s demand. The New Zealand Geothermal Association has commissioned a report on this topic which will be published in 2007.

16.4.3 Trends in the Cost of Energy

The current wholesale electricity price is about 6 US¢/kWh (based on fixed price contracts). The wholesale price of electricity has risen dramatically over the last four years. This has been due to dry years causing supply concerns for hydro (with generation still highly dependent on hydro generation with little storage), and to rising fossil fuel costs. Both gas and coal prices have increased as more expensive resources have been called on to meet increasing demand.

16.4.4 Employment in the Geothermal Sector

A report reviewing geothermal personnel capability identified about 350 personnel directly involved in geothermal consulting or development. This number excludes the construction work force.

16.5 Research Activities

16.5.1 Government Funded Research

New Zealand Government provides approximately NZ$ 2 M/y targeted at the following topics: deep high temperature resources, use of low-enthalpy resources, better use of waste geothermal fluids and environmental effects. In future, a focus will be added on technologies to improve sustainability.

16.5.2 Industry Funded Research

Industry funded projects on H_2S removal through bio-remediation from NCG waste from power plant for glasshouse use, and arsenic removal from separated brines

16.6 Geothermal Education

Both the New Zealand Geothermal Association and the University of Auckland continue to provide relevant seminars, the annual Geothermal Workshop, and short courses. Through 2006, the Auckland University was actively preparing for the resumption of their post graduate training through a revitalised Geothermal Institute. The first Geothermal Institute diploma course will be held in the second half of 2007.

16.7 International Cooperative Activities

New Zealand participated in several international geothermal projects, including: Coso (USA), Mutnowsky deep drilling (Kamchatka, Russia) and the Iceland Deep Drilling Project in Iceland.

In addition, New Zealand plays an active roll in the IEA-GIA as a Contracting Party and with GNS Science acting as Operating Agent for Annex I.

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NATIONAL ACTIVITIES

Chapter 17

Switzerland

Drill rig at the EGS project "Deep Heat Mining" in the city of Basel, Switzerland
(photograph courtesy of Geopower AG Basel).

17.0 Introduction

The reorganization of the key Swiss player and coordinator in geothermal energy development and utilization, the Swiss Geothermal Association SVG, has been completed. The SVG, an Affiliated Member of International Geothermal Association (IGA), now acts as the Swiss Geothermal

Competence Center under the label GEOTHERMIE CH. Its bi-lingual (German/French) Newsletter also carries the name GEOTHERMIE.CH.

Geothermal heat pumps still contribute the largest share to direct use, which grows steadily by about 10 % per year. Quality labels and engineering standards (presently under development) guarantee operation reliability and efficiency.

Increasing participation in international R&D efforts, besides in the IEA-GIA, can be reported: Switzerland cooperated in 2006 in the EU projects EGS Scientific Power Plant Soultz/F, ENGINE, I-GET and GROUNDHIT.

One negative, and important event in 2006, was that the largest Swiss geothermal project, DEEP HEAT MINING in Basel, was suspended in December, due to earthquake activity triggered by water injection for stimulation.

17.1 National Policy

On the political scene the main change is that a CO_2 tax has been introduced; its implementation- e.g. for new gas-fired power plants- is currently being discussed in the Parliament. The Energy Law already passed both chambers of the Parliament; and it shall include promotional measures like a “risk guarantee” for deep geothermal drilling for electricity production.

The governmental energy program *SwissEnergy*, which supports renewable energies, provides the general supportive framework for geothermal R&D. A new phase for the years 2006-2010 has now been implemented. Further, more general information about Swiss energy policy is available in previous Swiss Country Reports, which can be found on the IEA-GIA website under: http://www.iea-gia.org/publications.

Government funding on geothermal R&D was provided by the Swiss Federal Office of Energy (SFOE), and amounted to:

- Research and Development: 0.5 MCHF
- Activities of the SVG: 0.5 MCHF

Expenditure of industry provided significant contributions to the DEEP HEAT MINING project in Basel (> US$ 10 M).

17.2 Current Status of Geothermal Energy Use in 2006

17.2.1 Electricity Generation

There is currently no geothermal electrical power generation in Switzerland.

17.2.2 Direct Use

In 2004, a statistical survey was carried out on the subject of geothermal energy use in Switzerland. The data for installed capacities, energy produced, fossil fuel and CO_2 emission savings, *etc*. are included in the Swiss Country Update Report 2005 (available at the IEA-GIA website under http://www.iea-gia.org/publications). A new statistical survey (Geowatt AG, Zurich) provides the numbers for 2006. Table 17.1 shows the numbers in direct use in 2006 (usage category, installed capacity, and thermal energy used).

The key achievement of Switzerland is still in the use of shallow geothermal resources by ground-coupled heat pumps. An evaluation of available global data reveals that Switzerland occupies a prominent world-wide rank in installing and running geothermal heat pump systems. In 2006, more than 1,000 km was drilled for borehole heat exchangers. Geothermal heat pumps are now increasingly, and soon routinely, used for heating as well as for cooling

Table 17.1 Geothermal direct use in Switzerland in 2006.

Usage system	Installed capacity (MW_{th})	Heat produced (TJ/y)
Heat pumps with borehole heat exchangers	650	4272
Groundwater-based heat pumps	75	438
Geostructures, tunnel waters	14	87
Deep aquifers for district heating	5	64
Spas, wellness facilities	37	1126
Total	**781**	**5987**

17.2.3 Fossil Fuel Savings

The heat production from geothermal sources ("direct use") enables the savings of fossil fuels. The annual heat production in 2006, 5,987 TJ/y, corresponds to the saving of 140,000 toe.

Geothermal energy use in Switzerland thus reduces the emission of CO_2 by about 440,000 tons per year. All direct use, except partly for spas/wellness, is based on electric heat pumps. Here it must be emphasized that electricity in Switzerland is generated nearly completely CO_2-free, with 60% hydro and 40% nuclear capacity.

17.3 Market Development and Stimulation

17.3.1 Support Initiatives and Market Stimulation Incentives

Financial support or tax credits of different kinds and sizes can be obtained when installing geothermal heat pumps, depending on the site. Local electric utilities, communities, various entities provide support. This explains, at least partly, the rapid development of the Swiss geothermal heat pump market. Information about the various sources of support can be downloaded from the website of the Swiss Heat Pump Promotion Association FWS http://www.fws.ch/ under "Zahlen & Fakten" and "Förderbeiträge und Steuervergünstigungen" (= support finances and tax reductions).

17.3.2 Development Cost Trends

Technological progress (e.g. measurable by heat pumps COP), better materials, and increasing experience lead to progress on the learning curve; and absolute prices are constantly decreasing (Figure 17.1).

17.4 Development Constraints

For geothermal direct use in general, and for geothermal heat pumps in particular, there could be, irrespective of already impressive achievements, even more rapid development. Architects as well as engineers responsible for building energy supplies are still not familiar enough with geothermal heating and cooling. Often the attitude is “I do not know how to design a geothermal system so I will not apply it”. Therefore increased efforts in education and post-graduate training are undertaken (see below).

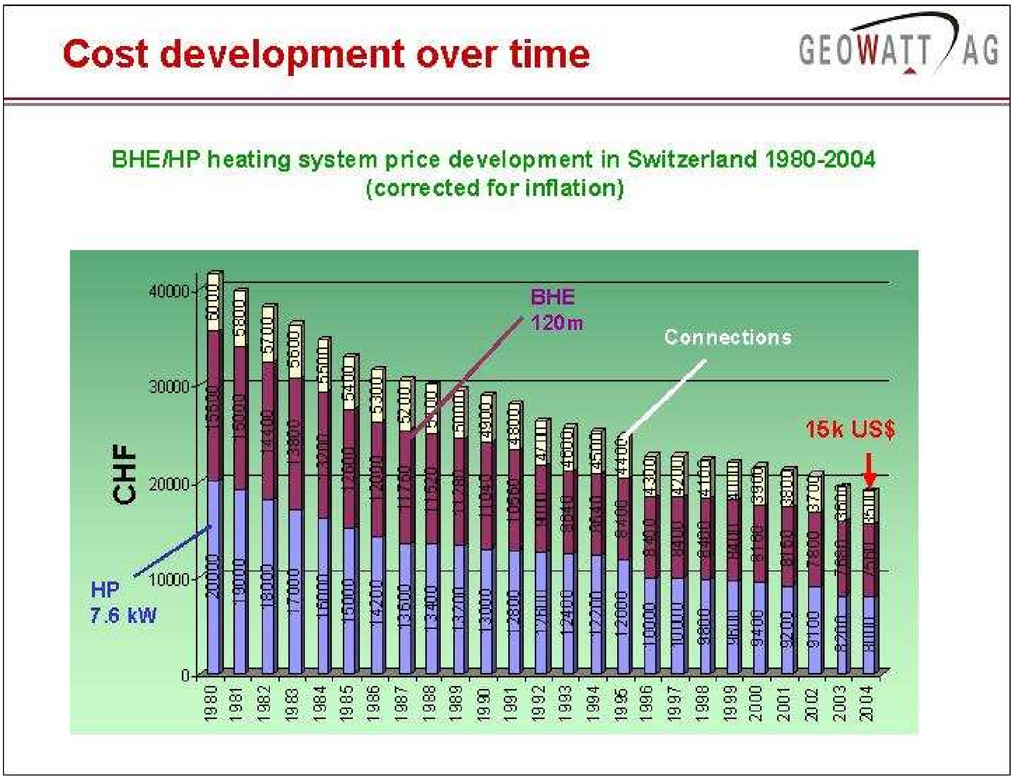

Figure 17.1 Installation costs of geothermal heat pumps decreased significantly over time (for a typical, singe family dwelling). Diagram from: http://www.fws.ch/.

Strange enough, a bottleneck becomes evident at the other end: the Swiss companies active in drilling for borehole heat exchangers (more than twenty) have so many orders that the waiting time to get borehole heat exchangers installed can be up to 5-6 months.

The stopping of the Deep Heat Mining project in Basel ordered by authorities due to induced seismicity also had repercussions on plans and expectations about geothermal power generation and EGS projects in Switzerland in the future. The Swiss vision (Figure 17.2: 50 MW_e EGS plants at 50 sites, mostly in densely inhabited areas) has to wait until basic questions about seismic risk and heat extraction efficiency are answered.

The Deep Heat Mining Project in Basel attempted to establish an EGS facility for co-generation (20 MW_{th} and 3 MW_e capacity to produce 20 GWh/y power and 80 GWh/y heat), with three 5 km deep wells (1 for injection, 2 for production). The first well (Basel-1) reached target depth of 5,000 m on 27 October 2006. Stimulation started on 23 November 2007: pre-stimulation with injection flow rates < 10 l/s, the main stimulation (planned for 3 weeks with 50,000 m^3 water total volume) on 2 December 2006 with p_{max} = 295 bar and Q_{max} = 63 l/s. Meanwhile the drilling rig moved over to Basel-2.

The stimulation caused thousands of microseismic events for reservoir development. Early in the morning on 8 December, a seismic event happened with ML=2.7. Event management actions have been taken by the project developer (Geopower AG Basel) according to the "Traffic Light Action Plan" (for details about the Traffic Light Procedure see the GIA website: http://www.iea-gia.org/publications.asp, under "Draft protocol"). Nevertheless an event with ML=3.4 took place at 17:48, the event was not announced but widely felt in the area. The next day the local Government stopped the project because of "frightening the population" (=public offence by Swiss law); and the drilling rig and crew had to leave. The injection has been stopped and water was bled off. The hypocenters of the seismic events were located at 5 km depth near the hole's bottom.

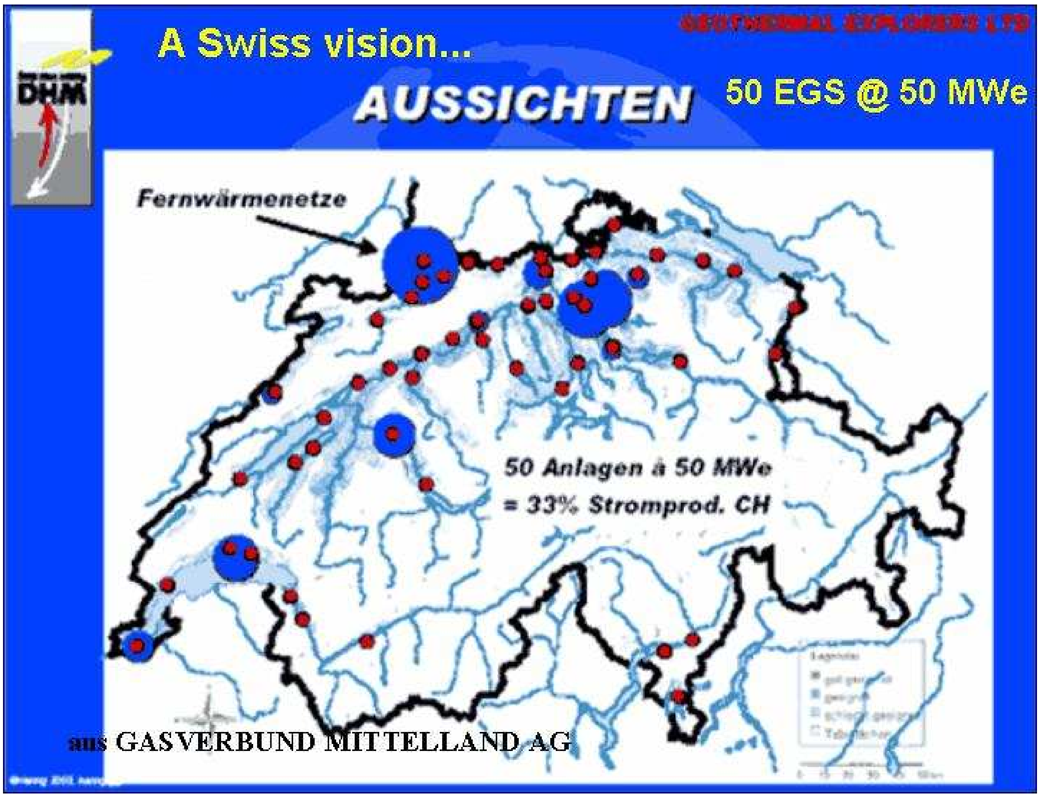

Figure 17.2 Vision of 50 EGS plants, each with 50 MW_e, to provide 33 % of Swiss electricity. "Fernwärmenetze": existing district heating systems.

The induced seismic events hit a completely uninformed, unprepared urban population. Nobody got injured but many citizens became upset. A large number of damage claims has been raised, also from neighbouring Germany and France. The project developer has 25 MCHF (US$ 20 M) indemnity insurance. Until the end of 2006, about 60 MCHF (US$ 50 M) has been spent for the project. The extensive documentation of the stimulation, the seismic events created, and the reaction of the local Authorities can be found (in German) on http://www.bd.bs.ch/geothermie. Before the Government can decide whether the project should continue (under restrictions) or is to be abandoned, a seismic risk study ("risk of triggering of larger quakes") must be conducted.

17.5 Economics

Concerning geothermal heat pumps, their economy becomes, in view of generally rising fossil fuel prices and the CO_2 tax, increasingly competitive. The geothermal option for heating alone is already favourable; in summer it is the only system that can also provide space cooling.

No new cost comparison with other heating systems has been performed in 2006, therefore the data from 2005 are included here (Table 17.2).

There are no official statistics about the number of people employed in the geothermal sector; from the number of drilling companies, institutions active in geothermal R&D, a rough estimate yields about 100-120 people.

Table 17.2 Cost comparison of heating systems in Switzerland (reference system capacity 10 kW), from Hubacher/FWS 2005.

Heating system	Efficiency (η/SPF*)	Investment (CHF)	Capital cost (Annuity, CHF)	Operating cost (CHF)	Total annual cost (CHF)
Oil boiler	**0.85**	**18,000**	**1,741**	**1,483**	**3,224**
Gas boiler	**0.95**	**14,500**	**989**	**1,882**	**2,871**
Biomass (pellets)	**0.90**	**33,500**	**2,692**	**1,814**	**4,506**
Geothermal heat pump (with BHE)	**3.4**	**30,500**	**2,055**	**872**	**2,929**
Air-source heat pump	**2.6**	**25,500**	**1,876**	**1,110**	**2,986**

17.6 Research Activities

The national activities financed by the Swiss Federal Office of Energy (SFOE) comprised:

- Feasibility study AGEPP (Alpine geothermal power production)
- Software development "Groundwater Energy Designer"
- Establishment of a hydrochemical data base for deep aquifers
- Documentation and evaluation of failures with geothermal heat pumps
- Economic feasibility study for an EGS installation at Geneva
- Energy conversion processes for the use of geothermal heat

All research projects have to deliver their final reports; these can be downloaded from the SFOE database: http://www.bfe.admin.ch/dokumentation/energieforschung/ .

The EGS project Deep Heat Mining Basel, financially the most focussed geothermal endeavour in Switzerland, is organized and managed by the shareholder company Geopower Basel AG. The project is financed from public and private sources; financing status was 53.2 MCHF (approximately US$ 40 M) at the end of 2005. The project has been suspended by the local authorities; now a risk study (including seismic risk) shall provide the basis for deciding whether the project ends or continues (with restrictions).

17.7 Geothermal Education

In 2006, significant efforts were undertaken for education and information dissemination. Besides regular courses at universities and technical schools, there were numerous special geothermal courses, workshops and excursions, including: special training for students (7 courses; 165 participants); postgraduate training (18 courses, 6 technical excursions, 800 participants), this year mainly concentrating on western and southern Switzerland. The activities are planned and implemented by GEOTHERMIE.CH and financed by the Swiss Federal Office of Energy (SFOE).

Since the establishment of the educational activities in 2001, a total of 88 events have been organized with over 3,000 participants. Figure 17.3 shows the development over the years. The events take place in all parts of Switzerland: the French speaking Romandie, the Italian speaking Tessin, and the German speaking Deutschschweiz.

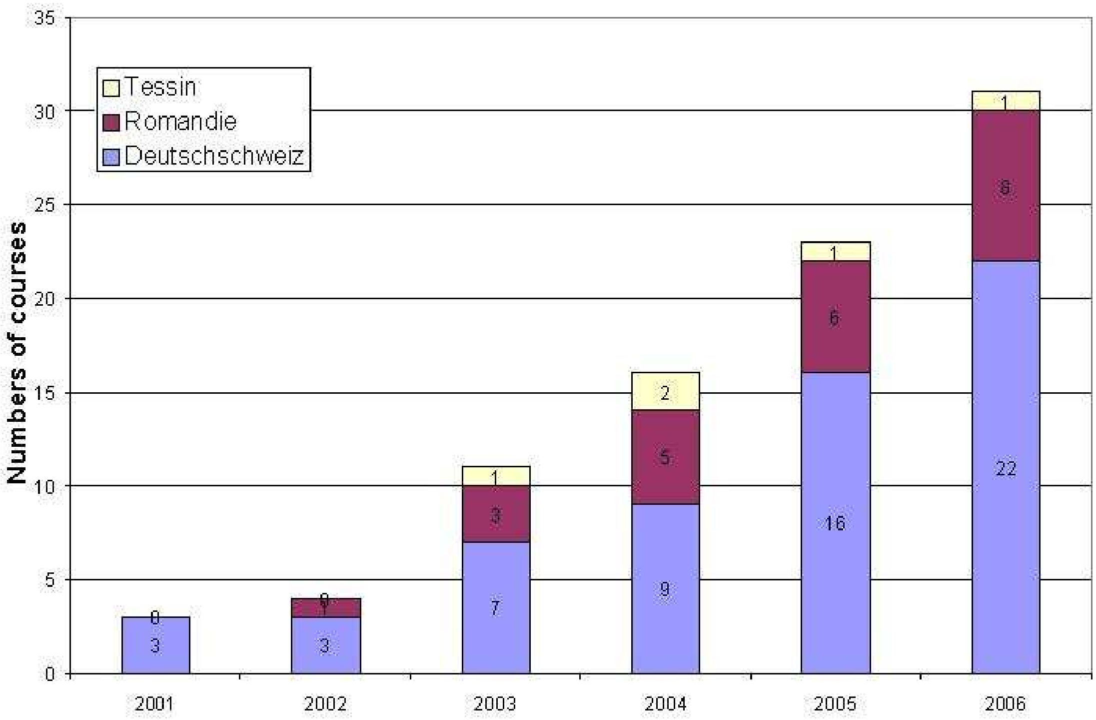

Figure 17.3 Geothermal educational events in Switzerland 2001 – 2006 (Geowatt AG Zurich).

17.8 International Cooperative Activities

First of all, the participation of Switzerland in the IEA Geothermal Implementing Agreement should be mentioned. The *Enhanced Geothermal System Project Management Decision Assistant* (EGS PMDA), completed under Annex III, Subtask C (Leader: Thomas Mégel, GEOWATT AG, Zürich), received international attention in 2006. The EGS PMDA can still be ordered through http://www.iea-gia.org/publications.asp .

The paper *Geothermal Sustainability - the View of the International Energy Agency Geothermal Implementing Agreement (IEA-GIA)*, prepared by L. Rybach and M. Mongillo was presented at the GRC 2006 Annual Meeting in San Diego, USA, where it received a Best Paper Award.

Switzerland is also active within R&D programs of the European Union. Cooperation is ongoing in the following geothermal projects:

- EGS Scientific Pilot Plant Soultz/F
- ENGINE

- I-GET
- GROUNDHIT

Strong involvement is to be reported especially in the project ENGINE ("ENhanced Geothermal Innovative Network for Europe"): ENGINE Workshop no. 3 "Stimulation of reservoir and induced microseismicity" was organized by Geowatt AG Zurich and held on 26 June-1 July in Ittingen/TG. L. Rybach is a member of the ENGINE Executive Group, the governing board of the project

17.9 Geothermal 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 http://www.fws.ch/
- Swiss Deep Heat Mining Project: www.dhm.ch
- Geopower Basel AG: www.geopower-basel.ch
- Geothermal Explorers Ltd.: www.geothermal.ch
- Geowatt AG: www.geowatt.ch

Acknowledgment

The participation of Switzerland in the IEA-GIA is financed by the Swiss Federal Office of Energy (SFOE), Berne. The continuous support of Markus Geissmann, responsible for geothermal energy at SFOE, and of Rudolf Minder, Geothermal R&D Project Leader SFOE, is gratefully acknowledged.

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NATIONAL ACTIVITIES

Chapter 18

United States of America

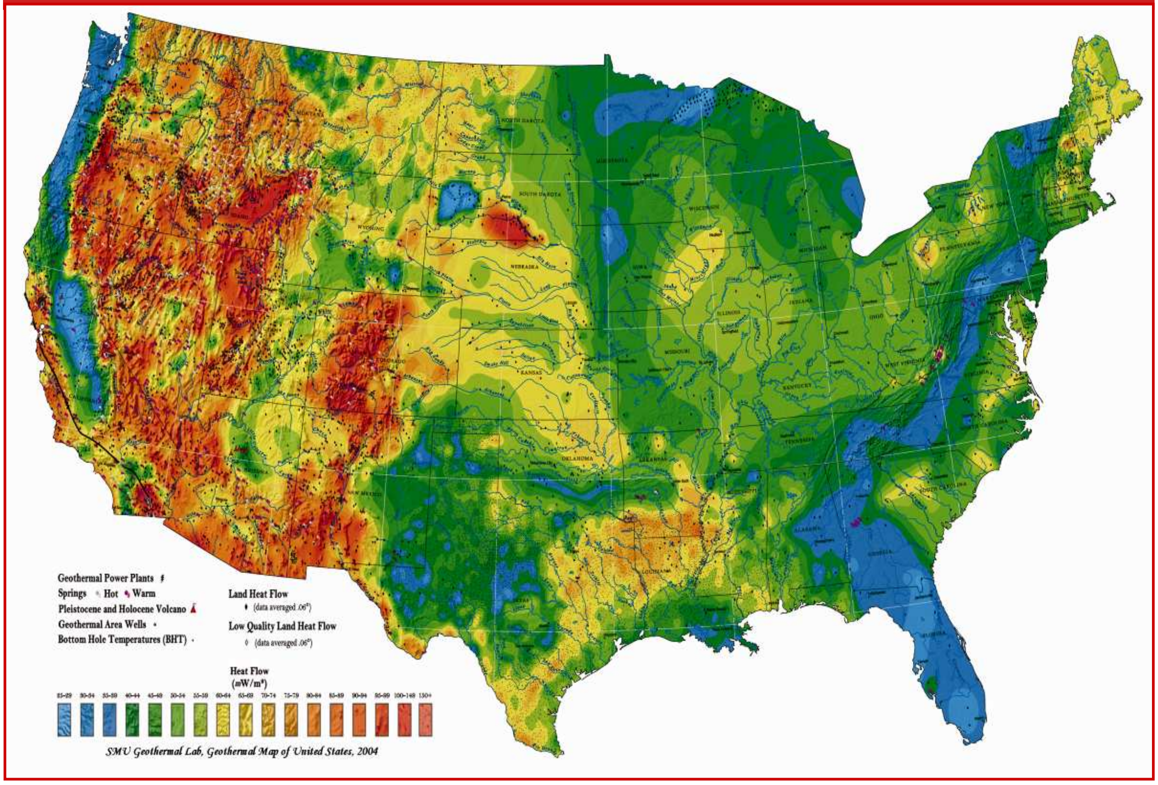

Figure 18.9 Heat flow of the conterminous United States (SMY, MIT).

18.0 Highlights for 2006

18.0.1 Geothermal Power

The major highlight of 2006 for geothermal energy in the United States was the resurgence of the geothermal industry. The Geothermal Energy Association (GEA) reported that 1,924.7 MW_e of new geothermal power plant capacity was under development in the United States, if projects in the initial development phase are included. One hundred and thirty one MW_e of capacity were under actual construction at 8 projects in 5 states. Major drivers for this expansion of U.S. geothermal capacity include state Renewable Portfolio Standards and the federal Production Tax Credit.

18.0.2 First Alaska Geothermal Power Plant

Chena Hot Springs now has the first geothermal power plant in Alaska. It is also the site of the lowest temperature resource ever used in the United States for commercial power. The UTC Power geothermal power plant employs an organic Rankine cycle to produce 400 kW of electricity from two 200 kW_e units using 72 °C (162 °F) water from a 213 m (700 ft) deep well. The technology may also have application in producing electricity from other low temperature resources and from hot water co-produced with oil and gas wells in Texas and other states.

18.0.3 Progress under the Energy Policy Act

A bill was signed containing modifications to the Energy Policy Act of 2005 (EPAct 2005). The bill extended, among other provisions, the production tax credit for geothermal and other renewables put in service through December 31, 2008. In compliance with EPAct 2005, the United States Geological Service (USGS) is conducting a new assessment of geothermal resources which will consider lower temperature resources, binary technologies, and other advances that have occurred in the past 25 years.

18.0.4 MIT Study

A comprehensive assessment of Enhanced Geothermal Systems (EGS) was carried out in 2006 by an 18-member expert panel assembled by the Massachusetts Institute of Technology (MIT) to evaluate the potential of geothermal energy from EGS to become a major energy source for the United States. The panel concluded that, with a "reasonable investment" in R&D, EGS could provide 100,000 MW_e, or more, of cost-competitive generating capacity in the next 50 years. Break-even levelized cost-of-energy could be achieved within 10-15 years.

18.1 National Policy

18.1.1 Strategy

It is the national policy of the United States to improve its energy security by fostering diverse sources of reliable and affordable energy. The Department of Energy (DOE) Strategic Plan, September 2006, states that keeping America economically strong requires reliable, clean, and affordable energy, and 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. The Department pursues both alternative fuels and energy efficiency technologies to reduce the energy-intensity and increase the fuel-flexibility of the economy. DOE also pursues energy diversity by supporting development of a suite of electricity generation options that can promote reasonable and stable prices and a variety of efficiency technologies that will improve energy productivity in all sectors of the American economy.

18.1.2 Legislation and Regulation

18.1.2.1 Energy Policy Act Amendments

Under EPAct 2005, geothermal energy was awarded the full 1.9 cents/kWh federal tax incentive. This production tax credit (PTC) was awarded for ten years to new facilities placed in service by 31 December 2007. On 20 December 2006, President Bush signed into law the *Gulf of Mexico Energy Security Act* as part of H.R. 6111, *The Tax Relief and Health Care Act of 2006*. The bill extended, among other provisions, the PTC for geothermal and other renewables through 31 December 2008. The new law contains a provision extending the U.S. Internal Revenue Service program for Clean Renewable Energy Bonds (CREB) through 31 December 2008 and provides for an additional $400 million of CREB bonding authority.

18.1.2.2 Renewable Portfolio Standards

California revised its Renewable Portfolio Standard (RPS) that requires regulated utilities to produce at least 20% of their electricity supply from renewable energy by 2010, advancing this goal from 2017. The Standard is currently for renewable content to increase 2%/y, beginning in 2003, to reach at least 20% by the end of 2010, with a goal of 33% by the end of 2020.

The State of Washington passed its first RPS incentive by ballot initiative. The initiative calls for electric utilities that serve more than 25,000 customers in the state to obtain 15% of their electricity from new renewable resources by 2020. Utilities subject to the standard must use eligible renewable resources, including geothermal energy, or acquire equivalent renewable energy credits, or a combination of both, to meet the following annual targets:

- At least 3% of its load by 1 January 2012, and each year thereafter through 31 December 2015
- At least 9% of its load by 1 January 2016, and each year thereafter through 31 December 2019
- At least 15% of its load by 1 January 2020, and each year thereafter

In 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. The previous standard was 1.1% in 2007. Arizona passed the nation's first Renewable Portfolio Standard in 1999.

18.1.3 National Targets

The Geothermal Technologies Program (GTP) of the U.S. Department of Energy (DOE) strives to establish geothermal energy as an economically competitive contributor to the Nation's energy supply. **The goal of the Geothermal Technologies Program is to reduce costs and risk to a level that will enable the commercial development of 40,000 MW_e of geothermal resources.** This level of development would supply a significant portion of the nation's energy, and industry development of this much resource would drive cost reductions through learning curve effects, enabling further development. The Geothermal Energy Association has stated that geothermal resources could support over 30,000 MW_e of generating capacity by 2025, which would meet 6% of total U.S. electricity needs and be equal to 100 percent of the electricity generated in California, Nevada and Idaho. The GEA estimated that one-half of the projected 30,000 MW_e would be highly dependent upon continued research and technology development supported through DOE's research program.

18.1.4 Government Expenditure on Geothermal R&D

Achievement of the Geothermal Technologies Program goal relies heavily upon projected technology improvements from the R&D program. The Fiscal Year 2006 budget by Subprogram area is presented in Table 18.1.

Table 18.1 Geothermal program budget for Fiscal Year 2006.

Subprogram	FY06 Appropriation
Technology Development	15,317
Enhanced Geothermal Systems	6,110
Systems Development	6,379
Resource Development	2,828
Technology Application	4,232
Technology Verification	1,547
Technology Deployment	2,685
Congressionally Directed Activities	3,750
Total	**23,299**

18.2 Geothermal Energy Use in 2006

18.2.1 Electricity Generation

18.2.1.1 Installed Capacity and Electricity Generated

In 2006, geothermal electric power was generated in five U.S. states: Alaska, California, Hawaii, Nevada, and Utah. Total installed capacity was 2,830.65 MW_e. California had 2,030.47 MW_e of net-capacity producing power with approximately 461 MW_e of capacity in California on standby; i.e., not producing power (GEA, November 2006).

Table 18.2 Existing geothermal capacity by state in 2006 (GEA, November 2006).

States Generating Geothermal Energy and Existing Capacity (2006)				
Alaska	California	Hawaii	Nevada	Utah
0.4 MW_e	2492.1 MW_e	35 MW_e	276.4 MW_e	26 MW_e
Total installed capacity: 2,830.65 MW_e				

Total electricity generation in the United States in 2006 was 4,054.9 billion kWh (10^9 kWh) (*Short Term Energy Outlook,* 6 February 2007, Table 8a, EIA). Renewable energy electricity generation in 2006 was 362.93 billion kWh (*Annual Energy Outlook 2007*, Table 16, EIA), of which geothermal was 16.25 billion kWh and conventional hydropower, 279.78 billion kWh.

18.2.1.2 New Developments in 2006

The year 2006 has been an active one for the United States geothermal industry. Some of the projects completed, under construction or announced include the following:

Alaska

Chena Geothermal Power Plant Project- Chena Hot Springs, just outside Fairbanks, has the first geothermal power plant (400 kW_e electric) in Alaska (Figure 18.1). It is now also the site of the lowest temperature resource ever used for commercial power generation in the United States. The Chena Hot Springs resort is a semi-remote site, which used diesel generators to produce electric power at 30 cents/kWh. The load is 180-280 kW and the daily cost for diesel fuel in 2005 was $1000/day. The first 200 kW_e unit of the Chena geothermal power plant came online in August 2006. The UTC Power PureCycle® geothermal system uses an organic Rankine cycle (ORC) with R-134a refrigerant to produce 200 kW of electricity. The power cost is expected to be about 7 cents/kWh. The power plant runs off 72 °C (162 °F) water from a 213 m (700 ft) deep well. Previously, Chena Hot Springs and the Department of Energy jointly funded an exploration project to determine the power generating capacity of the deep geothermal resource underlying Chena Hot Springs. The second ORC generator came online late in 2006 and was producing 230 kW_e gross (200 kW_e net) at year end. The second unit employs a dual condenser system with an air-cooled condenser during the winter months to take advantage of the extreme temperatures (the average winter day in Fairbanks is about -32 °C (-25 °F). In summer the unit will use a water-cooled condenser identical to the first ORC unit.

The power plant at Chena Hot Springs Resort in Alaska was selected as Project of the Year in the renewable/sustainable energy category by Power Engineering magazine. The U.S. Department of Energy and the U.S. Environmental Protection Agency also chose Chena Hot Springs Resort for a 2006 Green Power Leadership Award for significantly advancing the development of renewable electricity sources through green power markets. Chena Hot Springs is being developed as a sustainable community with commitments to renewable energy, energy independence and environmental stewardship. All 44 buildings at the resort, including a greenhouse, hotel, cabins and ice museum, are linked by a geothermal district heating system. The 4,320 ft^2 (~ 400 m^2) greenhouse provides the resort's restaurant with a variety of fresh produce on a year-round basis.

Figure 18.1 Unit 1 of Chena Power Plant (UTC Power).

Idaho

Raft River- Construction of Idaho's first geothermal power plant began in April 2006 when Ormat Nevada, a wholly owned subsidiary of Ormat Industries, commenced work at Raft River under a contract with U.S. Geothermal in December 2005. Ormat will supply equipment and construct a binary cycle geothermal power plant to deliver 10 MW_e to the Idaho Power Company under a 20-year term power purchase agreement for the first phase of the Raft River Project. The schedule provides for full commercial operations no later than November 2007. U.S. Geothermal Inc. held a groundbreaking celebration on Saturday, 29 July. This was followed by the signing of a renewable energy credit (REC) purchase agreement encompassing the first 10 years of Phase 1 of the Raft River project. Holy Cross Energy, a Colorado cooperative electric association, agreed to purchase the RECs associated with Phase 1 power production from 2008 to 2017. This agreement will help Holy Cross meet its requirements under the Colorado renewable energy standard, meet Holy Cross' corporate environmental goals and is an important part of the financing structure for the Raft River project development. The plant will also be eligible for the Federal renewable energy Production Tax Credit which will be worth approximately $1.7 million/y at $19/MWh for every MWh of energy produced over the next 10 years.

U.S. Geothermal deepened two existing injection wells as part of its well improvement program for the Phase One, 13 MW_e geothermal binary cycle power plant. Work was also completed on the two existing production wells. At the end of 2006, Raft River Rural Electric Coop, the local utility, began construction of the 5.2 km power line that will transmit power output to Idaho Power

Company. Construction of the above-ground production and injection pipelines was approximately 95% complete, but further pipeline work was suspended until spring 2007.

California

The Geysers- The Geysers Geothermal Field is located 120 km north of San Francisco, California. Commercial geothermal power has been generated continuously at The Geysers since 1960. The present generation level is about 900 MW_e, having declined from a peak of about 1,900 MW_e in 1988. Following the injection of reclaimed water into The Geysers from the Lake County Project starting in 1997 and the Santa Rosa Project starting in 2003, the earlier decline in productivity has been partially reversed, with an estimated potential increase of 100 MW_e of capacity and an extension to the life of the field.

Unit 15 Steam Field Project- Western GeoPower Corp announced the acquisition of a geothermal lease covering 140 acres contiguous to its Unit 15 Steam Field located within The Geysers Geothermal Field. The total area under lease by Western GeoPower at The Geysers exceeds 500 acres and it is anticipated that one power plant will process steam production from both leaseholds. A commercial power plant of 62 MW_e capacity, known as PG&E Unit 15, operated at the leasehold during 1979-1989. The plant was shut down in 1989 and eventually dismantled, and the wells were plugged and abandoned. It is now recognized that the Unit 15 plant was oversized for the available resource. For this reason, the wells supplying the plant experienced an unduly rapid decline in productivity, similar to the decline experienced throughout The Geysers at that time. Roads and drill pad infrastructure are in excellent condition throughout both leaseholds and a 115 kV transmission line connects the property to the transmission grid.

Bottle Rock- A 55 MW_e geothermal power plant at The Geysers, dormant since 1990, was approved to reopen by the California Energy Commission. The geothermal plant was shut after only five years of operation when production began to lag because of a lack of steam. The Bottle Rock Geothermal Power Plant will initially operate at 20 MW_e with plans to expand. The plant will be operated by the Bottle Rock Power Corp. Power generated by the plant will be sold to Pacific Gas & Electric Co.

Nevada

Blue Mountain- Nevada Geothermal Power Inc. (NGP) initiated development drilling at Blue Mountain Nevada in early 2006. NGP then signed a 20-year Power Purchase Agreement (PPA) with Nevada Power Company for up to 35 MW_e of geothermal power to be produced from a new geothermal power plant to be built at the Blue Mountain geothermal site. Contract provisions are in place which take into account the Production Tax Credit.

NGP completed production testing of its first production well at the end of summer. Well testing indicated that Blue Mountain is a major new geothermal discovery. Using conventional pumping technology, this single production well would produce over 9.6 MW_e gross output. The initial power plant at Blue Mountain, to be named the "Faulkner 1 Power Plant", will be a binary cycle geothermal plant with greater than 150 °C (300 °F) water from seven production wells.

Pumpernickel Geothermal Site- NGP also entered into an agreement with Ormat Technologies, Inc. for a power plant at NGP's Pumpernickel Geothermal Site. NGP stated that this relationship with Ormat would expedite the development of a potential 20-30 MW_e geothermal resource at Pumpernickel. The Pumpernickel exploration program will include a series of up to three 250 m (820 ft) gradient wells to further define the geothermal anomaly, followed by a deep reservoir test well to confirm the presence of a commercially viable geothermal resource.

Fallon- The U.S. Navy entered into a 50-year agreement with Ormat Technologies to develop geothermal energy on Naval Air Station property at Fallon, Nevada. The contract will begin with the development of a 30 MW_e geothermal power plant.

Galena #3- Galena No. 3 will be a new geothermal power plant to be built by Ormat in northern Nevada. The power plant would increase the total output supplied from the Steamboat Known Geothermal Resource Area (KGRA) to Sierra Pacific Power Company by between 15 and 25 MW_e, bringing the total output of the Steamboat KGRA to approximately 90 MW_e. Galena No. 3 is projected to come on line in 2008. The Galena No. 3 project will be an air-cooled binary power plant.

Reese River Project- The Nevada State Office of the BLM issued a geothermal drilling permit in December 2006 to allow for drilling on the Reese River Project, Lander County, Nevada. The well is planned as an exploration slim hole to a maximum depth of 1,200 m. The objective of the well is to test the geothermal reservoir characteristics. The slim hole well program is partially funded by the U.S. Department of Energy's GRED III program. Phillips Petroleum and Amax Exploration drilled 52 temperature gradient holes at the site during the 1970s and 1980s. Data showed that the 150 °C/km heat flow anomaly is approximately 4.8 km (3 mi) long by approx. 1.6 km (1 mi) wide. The center of the anomaly reaches a temperature gradient over 500 °C/km. GeothermEx in 2004 estimated the resource to have a 90% probability of generating 13 MW_e and a 50% probability of exceeding 30 MW_e.

Utah

Blundel- PacifiCorp Energy signed a contract with CEntry Constructors & Engineers of Salt Lake City to expand its Blundell geothermal electric generating plant by approximately 11 MW_e. Blundell’s current net generating capacity is 23 MW_e. The contract calls for installation of an Ormat Energy Converter, supplied by Ormat Nevada Inc. The current Blundell plant near Milford, Utah, has been operating since 1984 and utilizes steam from the underlying geothermal field to power a steam turbine electric generator. The new Energy Converter will be installed adjacent to Blundell and will use the heat from the brine to generate additional power. The project is scheduled to be on-line in November 2007.

18.2.1.3 Rates and Trends in Development

Geothermal power development is driven primarily by economics; i.e., does the geothermal developer or investor believe that the projected return on investment will be sufficient to justify the risks. The thrust is to maximize returns and minimize risks. Many of the projects now underway illustrate these two objectives and this is especially true for the Raft River, Idaho project where development began early in 2006 and was well underway by the end of the year with power-on-line scheduled for 2008. Risk at Raft River was reduced by having a proven resource with production and injection wells in place from an earlier development, even though they required rework. These “sunk” costs also reduced the up-front financial requirements. In addition, all of the power plants under development are modest in size (10-30 MW_e), at least in the initial stage. This reduces the capital requirements and facilitates obtaining investment capital.

There is a market for geothermal electricity, as evidenced by power purchase agreements (PPAs) between developers and utilities. PPAs are often the utilities’ response to demands in state Renewable Portfolio Standards. Power purchase agreements may offer a premium above what the utility might have to pay for natural gas and coal. Other revenue sources for the geothermal developer may be the PTC at 1.9 cents/kWh and the selling of Renewable Energy Credits (REC). Most of the planned power plants will use binary-cycle energy conversion equipment. Even for high temperature resources such as Blue Mountain, power costs may optimize for shallow wells with lower temperatures, but which can use a binary energy conversion cycle.

A report (*Geothermal Resource Development in Nevada – 2006*, GEA) by the Geothermal Energy Association (GEA) profiles geothermal power development in one state and concludes that Nevada is on-track to be producing over 1000 MW_e of geothermal power, quadrupling its current geothermal output, over the next 3 to 5 years. The report states that this dramatic success is due to four major factors:

- The state's Renewable Portfolio Standard (RPS)
- Extension of the federal production tax credit (PTC) to include geothermal energy
- The Bureau of Land Management's (BLM) efforts to reduce its leasing backlog
- The Department of Energy's (DOE) past support for cost-shared drilling and technical assistance
- The work of the Great Basin Center for Geothermal Energy at the University of Nevada Reno

The Ormat Burdette plant near Reno, Nevada, which came online in 2005 (Figure 18.2) is probably typical of new geothermal power plants in Nevada.

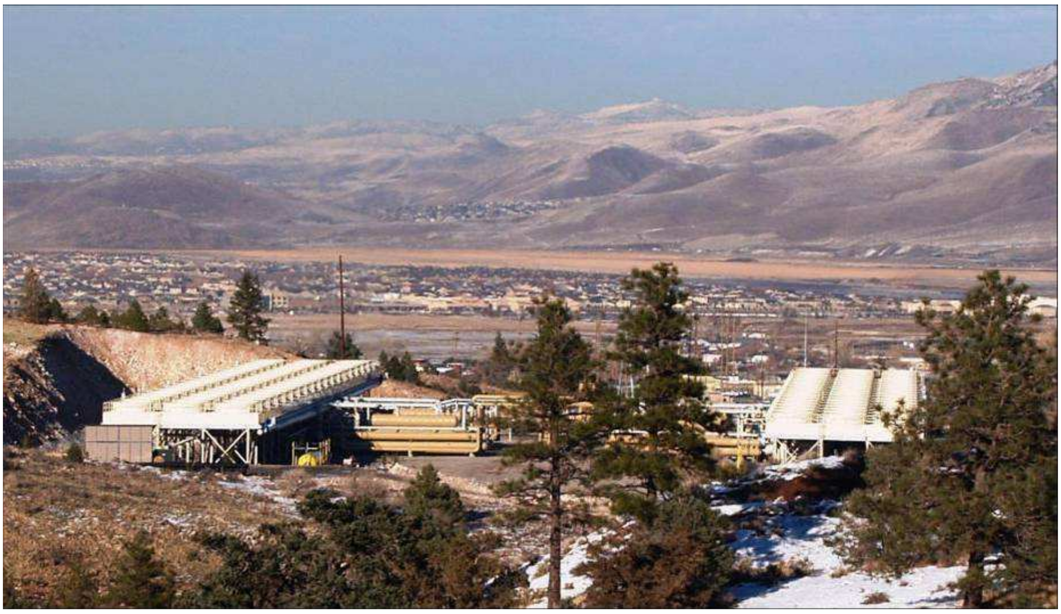

Figure 8.2 20 MW_e Burdette power plant (Ormat).

The next steps in geothermal development in the very near future will most likely be 1) add-ons to existing projects, 2) expansion at or within the boundaries of producing hydrothermal geothermal reservoirs using stimulation techniques and 3) development at identified, but undeveloped, geothermal resources. CalEnergy Generation is developing new projects in Southern California's Salton Sea geothermal area and has a contract with the Imperial Irrigation District for a new 215 MW_e power plant. Additional commercial development of the estimated 2,000 MW_e of available resource at the Salton Sea may also occur.

The GEA reports that up to 1,924.7 MW_e of new geothermal power plant capacity is currently under development in the United States (including projects in the initial development phase). Up to 131.6 MW_e of capacity is under construction at 8 projects in 5 states. Unconfirmed projects (some of which are likely to be developed within the next few years) raise these numbers to 2,376.7 MW_e of potential capacity. 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. Figure 18.3 shows the breakdown of the near-term power production potential in 11 western states including Hawaii and Alaska.

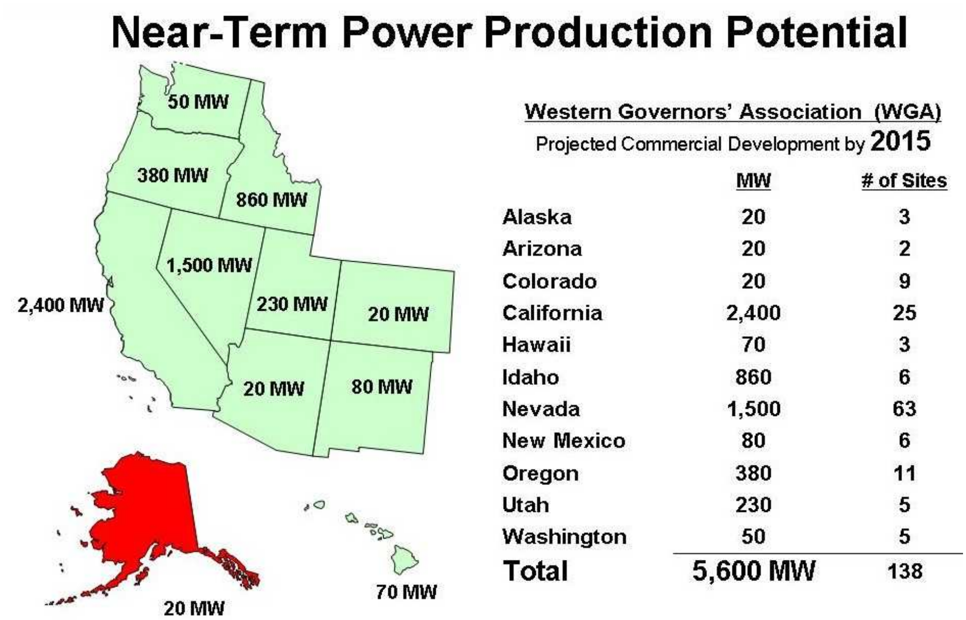

Figure 18.3 Geothermal power production potential by 2015 (WGA).

A new supply characterization *(Updated U.S. geothermal supply characterization*, Petty and Porro, Stanford Geothermal Workshop 2007*)* characterizes and presents an updated assessment of geothermal supply for use in forecasting the penetration of geothermal electrical generation in the National Energy Modeling System (NEMS). The new supply representation incorporates five specific resource types: hydrothermal flash, hydrothermal binary, geothermal fluids co-produced with oil and gas, and two types of Enhanced Geothermal Systems (EGS) resource – convective EGS associated with hydrothermal resources at depths < 3 km, and conductive EGS potential for depths 3-5 km. This new representation comprises 126 GW_e of resource potential nationally (89 GW_e across all resource types in Western regions and 37 GW_e mostly from co-produced potential in non-Western regions). The updated supply features significantly lower levelized cost of energy (LCOE) for hydrothermal resources and somewhat lower LCOE for EGS than used previously. Further, the inclusion of a significant amount of relatively low-cost co-produced resource from oil and gas wells further accentuates these cost differences and contributes to a significant increase in the amount of geothermal resource that is likely to be technologically and economically accessible in the next few years. The representation is based on recently available updated supply estimates for hydrothermal and convective EGS resources, and new estimates for co-produced and conductive EGS resources completed as part of the MIT study of EGS resource supply and costs. Figures 18.4 and 18.5 illustrate the temperature information on which the supply representation and the MIT study are based.

A comprehensive assessment of Enhanced Geothermal Systems was carried out in 2006 by an 18-member panel of experts assembled by MIT to evaluate the potential of geothermal energy becoming a major energy source for the United States. As stated in the report, the panel took a completely new look at the geothermal potential of the United States. With a "reasonable investment" in R&D, the panel concluded that EGS could provide 100,000 MW_e or more of cost-competitive generating capacity in the next 50 years. Performance verification at a commercial scale could be achieved within a 10- to 15-year period nationwide. (*The Future of geothermal energy: impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st century*, MIT, 2006). The MIT study estimated the stored thermal energy in place from 3 to 10 km depth as well as the recoverable EGS resource for three different recovery factors (Figure 18.6).

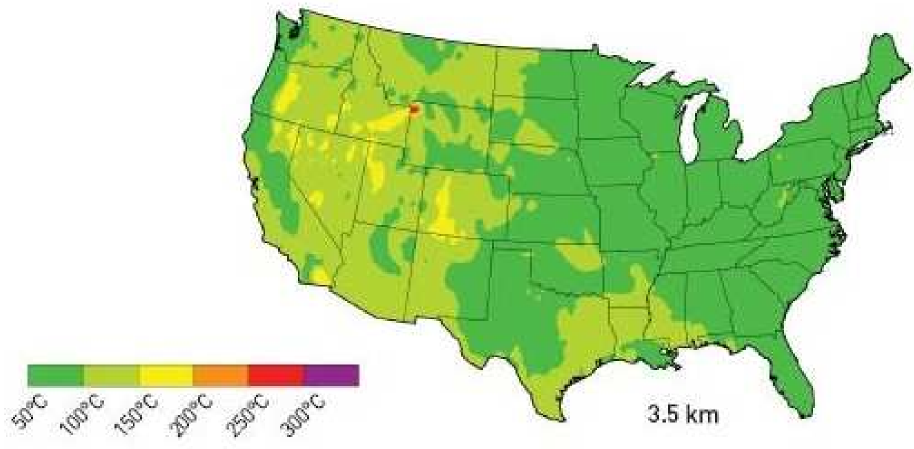

Figure 18.4 Temperatures at 3.5 km.

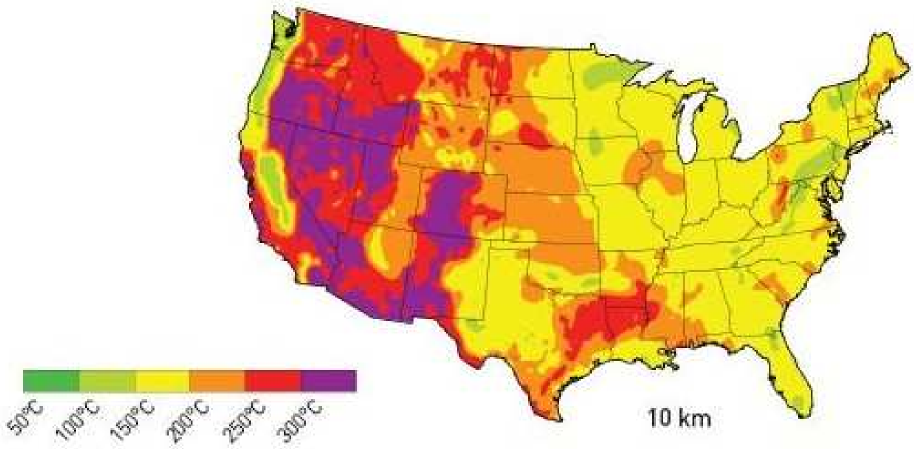

Figure18. 5 Temperatures at 10 km.

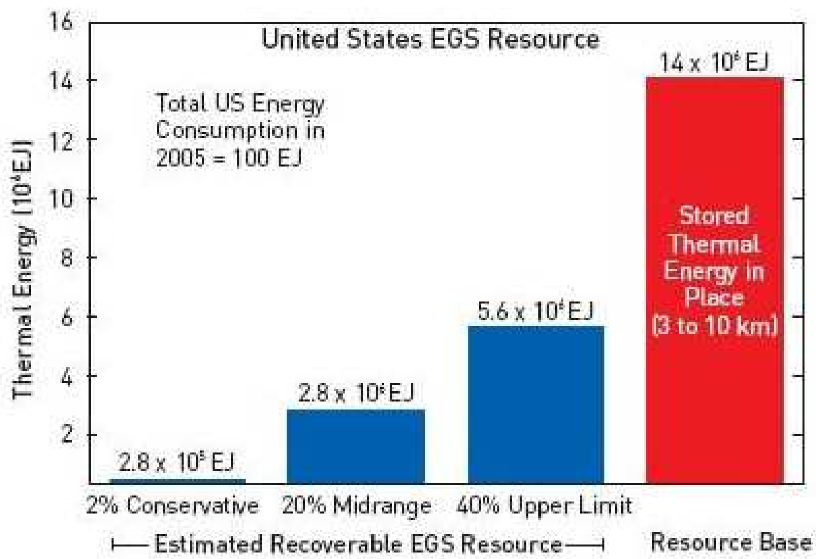

Figure 18.6 Estimated United States EGS resource (MIT).

Figure 18.7 is from the MIT study (Figure 1.14) and shows the levelized break-even cost of energy by year using the MIT EGS model. When EGS break-even prices are greater than competitive market prices for electricity, additional institutional investment is needed. For the example chosen (Figure 18.7), this corresponds to the period from 0 to about 12 years. The study also presents other scenarios, but all show the EGS break-even price crossing the competitive market price at approximately 10-12 years.

For its assessment, the MIT study group defined EGS as including all geothermal resources that are not currently in commercial production and which require stimulation or enhancement. This definition excludes high-grade hydrothermal, but does include conduction-dominated, low-permeability resources in sedimentary and basement formations, as well as geopressured, magma, and low-grade, and unproductive hydrothermal resources. In addition, MIT included co-produced hot water from oil and gas production as an unconventional EGS resource type that might be developed in the short term. (Note: The U.S. Department of Energy has broadly defined Enhanced Geothermal Systems (EGS) as engineered reservoirs that have been created to extract economical amounts of heat from low permeability and/or porosity geothermal resources).

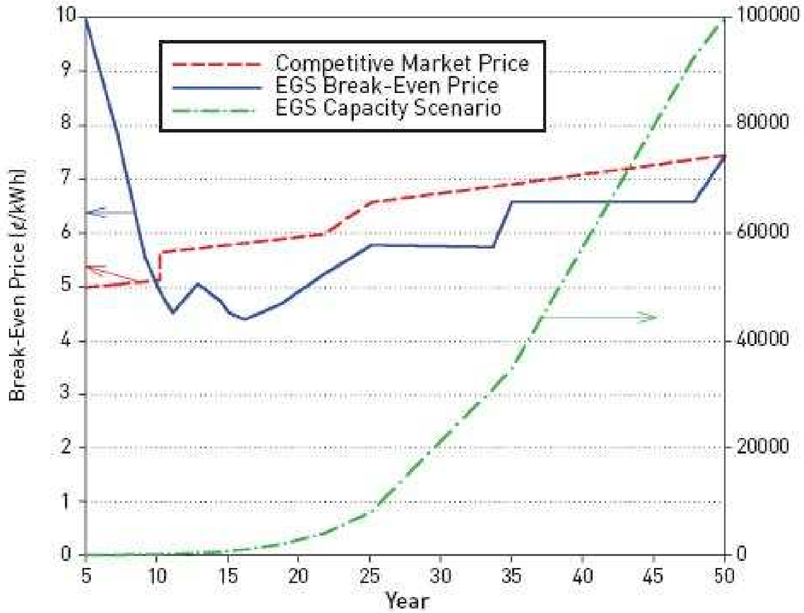

Figure 18.7 Levelized break-even cost of energy using the MIT EGS model.

18.2.1.4 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, do provide readily accessible information on geothermal wells on their Internet sites. The California Geothermal Annual Report is an excellent source for wells drills, completed, re-drilled or deepened, and plugged and abandoned. Unfortunately, the most current report is for the year 2004. Utah's Internet site has an interactive map of the state's geothermal wells and springs.

18.2.1.5 Contribution to National Demand

Geothermal electricity is currently being generated in California, Nevada, Hawaii, Alaska, and Utah. Geothermal electricity generation in 2006 was 16.25 billion kWh, which was 0.4% of the total U.S. electricity generation of 4,054.9 billion kWh. Geothermal electricity generation was 4.5% of all renewable electricity production, which includes hydropower (*STEO, AEO 2007).*

18.2.2 Direct Use

18.2.2.1 Installed Thermal Power

In 2005, Lund reported total installed direct-use capacity at 7817.4 MW of thermal power (MW_{th}), utilizing about 31,239 TJ/y. Of this capacity, 617 MW_{th} and 9,024 TJ/y corresponded to traditional direct use and the remainder to heat pumps (7,200 MW_{th} and 22, 215 TJ/y). Using Lund's overall escalation factor of 8%/y for all direct use categories, the total installed capacity for 2006 is estimated to be 8,442.8 MW_{th}.

18.2.2.2 Thermal Energy Used

Annual thermal energy use reported by Lund in 2005 was 31,239 TJ/y (8,675 GWh/y) at a capacity factor of 0.13 (Lund et al, *Geothermics* 34 (2005) 691-727). Using an overall escalation factor of 8%, the annual energy use for 2006 is estimated to be 33,738 TJ/y (9,369 GWh/y).

18.2.2.3 Category of Use

Direct utilization of geothermal energy in the United States includes the 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 energy growth rate of the direct use categories, increasing in annual use by 9.3% and 10.4 %, respectively, compounded over the past 5 years (Lund et al, Geothermics 34). 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 2005. For the period 2000-2005, the annual growth rate for heat pumps was 11.0%, and for the combined total, 8.0%. The equivalent number of installed 12-kW_e geothermal heat pump units, typical of homes in the United States, was approximately 600,000 in 2005. 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/y for a capacity factor of 0.14 (Lund et al, *Geothermics* 34 (2005) 691-727). Lund estimated heat pump capacity in the United States in 2005 to be 7,200 MW_{th} and geothermal energy use at 22,215 TJ/y. Using Lund's annual increase factor of 11%, the geothermal heat pump capacity in the United States in 2006 was approximately 7,992 MW_{th} and energy use was 24,659 TJ/y.

18.2.2.4 New Developments during 2006

New geothermal heat pump projects were reported almost daily throughout 2006. Three interesting examples are:

General Theological Seminary- The General Theological Seminary of the Episcopal Church in Manhattan, New York City, is converting its present heating-cooling system, which uses fossil fuel, to a geothermal heat pump system. Drilling for a series of wells for the new system began in fall 2006. The Seminary is planning to install a field of 22 wells beneath the sidewalks surrounding the campus. For each well, a steel casing will run from the surface down to the bedrock. From there, an unlined bore hole, eight inches in diameter, is drilled to a depth of 455 m (1,500 ft). Ground water, which maintains a temperature of about 12.8 °C (55 °F) year-round, is pumped out of the bore hole into a cellar mechanical room to the heat pump. The water is then returned to the standing wells. The Seminary's system will provide 850 tons of cooling to 260,000 ft^2 of buildings. Construction costs will be offset in nine years.

St. John's College- St. John's College, Annapolis, Maryland, dedicated its second new dormitory in January 2006. This new dormitory, like the first, uses a geothermal heat pump system. The system has 49 vertical ~45 m (150 ft) deep wells. An interconnected set of pipes runs through the wells, and biodegradable antifreeze is pumped through the pipes. In the summer, the moving liquid absorbs heat from the air and sends it down through the wells. Pumped back up, the chilled solution cools the air. In winter, because the ground below the frost line never drops below 14.5 °C (58 °F), the moving liquid helps keep the building warm. Air from the system is circulated through interior ductwork, and each room has its own thermostat. The original cost of the geothermal heat pump was around $294,000. That is $28,000 more than the estimate for a traditional heating and cooling system for the 20,000 ft^2 dorm. Based on energy costs at the time of construction, it was estimated that the system would save the college $4,500-$5,000/y in energy costs, recouping the additional investment in about six years.

The Creamery Brewpub and Grill- Klamath Basin Brewing Company, located in Klamath Falls, Oregon, is the only known beer brewing company in the world that uses geothermal energy in the brewing process. The brewery opened in 2005 after renovation of the historic Crater Lake Creamery Building, which was built in 1935. The Creamery Brewpub and Grill uses geothermal energy for all its heating purposes. Uses include space heating, snow-melting and generation of hot water for the brewing process. The City of Klamath Falls is located in a KGRA that has been used to heat homes, businesses, schools, and institutions since the early 1900s. The Creamery Brewpub and Grill is part of the Klamath Falls district geothermal heating system. The year 2006 marks the 25th anniversary of the district heating system, which provides heat to 24 buildings, greenhouses, sidewalk snow-melting areas, and also provides process heat to the Klamath Falls wastewater treatment plant. (*GHC Bulletin*, December 2006).

18.2.2.5 Rates and Trends in Development

The major trend in development in direct use of geothermal energy is the rapid growth of geothermal heat pumps. Whether it is 11%/y (Lund, 2005) or closer to the 20%/ year stated by the Geothermal Heat Pump Consortium, the number of heat pumps in the United States is probably doubling about every five years. There are many reasons for this popularity including:

- The technology can be used throughout the United States
- GHPs are relatively simple with reasonable payback times
- There are state and federal incentives
- Promotion by the industry association
- High electricity prices
- Reputation as a green technology

18.2.3 Energy Savings

18.2.3.1 Fossil Fuel Savings/Replacement

Power Plants- The United States generated 16.25 billion kWh (58,500 TJ) of electricity from geothermal hydrothermal resources in 2006 (*AEO 2007*). This amount of geothermal electricity would displace about 4.118 million tonnes of oil (Mtoe) equivalent, assuming an efficiency of 35% for the production of electricity from oil. The oil equivalent factor used was 1 TJ is approximately equal to 70.4 toe.

Direct Use- Annual thermal energy use for 2006 is estimated to be 33,738 TJ/y (9,369 GWh/y) (Section 8.2.2.2). The fuel oil savings is estimated to be 2.375 Mtoe, assuming an efficiency factor of 35% for the production of electricity. This is for all categories of direct use including geothermal heat pumps. Because of the rapid growth in geothermal heat pumps, they are also discussed separately below.

Using an average unit size of 12 kW, the installed capacity of geothermal heat pumps in the U.S. in 2006 was 7,992 MW_{th}. Based on approximately 1,200 full-load equivalent operating hours/y and a coefficient of performance (COP) of 3.5 (Lund, 2005); the annual energy removed from the ground was 6,848 GWh (24,659 TJ/y). The energy displacement, in the heating mode, was at least 1.736 Mtoe assuming that the displaced energy was electricity generated from oil at an efficiency of 35%. Any potential 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 2,357 Mtonnes of carbon dioxide (*AEO 2007,* Table 18). Geothermal generation in the United States annually offsets the emission of approximately 15.49 Mtonnes of carbon dioxide if it is assumed that geothermal electricity would offset electricity generated by coal. The calculation assumes 16.25 billion kWh (million MWh) of geothermal electricity at a net offset of 953 kg/MWh. Equivalent offsets would be 13.0 Mtonnes for oil and 3.14 Mtonnes for natural gas. Net offset factors are from Lund et al (*Geothermics* 34 (2005) 691-727).

Direct Use- Annual thermal energy use for 2006 was estimated to be 9,369 GWh/y (33,738 TJ/y). The carbon dioxide savings from this thermal energy use is estimated to be 7.654 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 8.929 Mtonnes of carbon dioxide.

18.3 Market Development and Stimulation

18.3.1 Supportive Initiatives and Market Stimulation Incentives

Renewable energy initiatives and incentives at the federal, state, and local government levels are catalogued and kept current on the DSIRE website. Established in 1995, the Database of State Incentives for Renewables & Efficiency (DSIRE) is an ongoing project of the North Carolina Solar Center and the Interstate Renewable Energy Council (IREC) with funding by the U.S. Department of Energy.

18.3.1.1 The Energy Policy Act of 2005 (EPact)

Under EPAct 2005, the USGS was directed to update its 1978 assessment of geothermal resources (*Circular 790*). The new assessment will consider the utilization of lower temperature resources, binary technologies, and other advances that have occurred in the past 25 years. The USGS will complete its initial report by September 2008.

The U.S. Internal Revenue Service (IRS) established a new program under a provision in EPAct 2005 for Clean Renewable Energy Bonds. In 2006, the IRS allocated $800 million in these tax-credit bonds for a total of 610 renewable energy projects to be located throughout the United States. The lending authorities can be state or local governments or electrical cooperatives. No geothermal projects received funds in 2006.

EPACT 2005 also provided for the establishment of a rebate program for expenditures made to install renewable energy systems in connection with a dwelling unit or small business. The amount of the rebate is 25% of the expenditures for qualifying equipment made by the consumer or $3,000, whichever is less. An analysis conducted by the Energy Information Administration (EIA) of the potential impact of the program indicates the following results showed 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. For comparison, EIA estimates total delivered residential energy consumption in its AEO 2006 Reference Case to be about 12,000 trillion Btu from 2006 through 2010. Geothermal heat pumps account for the largest share of the increase.

In August 2006, the U.S. Department of Energy announced a new $2 billion Federal Loan Guarantee Program. The program is intended to help spur investment in projects that employ new energy technologies. Under the loan guarantee program, the Department will share some of the financial risks of projects that employ new or significantly improved energy technologies that avoid, reduce, or sequester air pollutants and greenhouse gases. In the mid-1970s, the federal government began offering loan guarantees for the development of new geothermal energy projects. The Geothermal Loan Guarantee Program (GLGP) had some successes and some failures in using the power of loan guarantees to spur geothermal energy development and innovation. The GLGP projects resulted in the construction of several direct-use projects, plus power plants totaling 140 MW_e. Loan guarantees for geothermal energy development were discontinued in 1988.

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 U.S. 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 two main factors. The first is the industry interest in exploring and developing geothermal resources and reducing the leasing backlog on federal lands. The second driving factor is the growing 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 five-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 The EPA Green Power Program

The EPA Green Power Partnership encourages organizations to voluntarily purchase “green” power as a way of reducing the environmental impacts associated with electricity generation. Green power is a marketing term for electricity that is generated from environmentally preferable renewable energy sources, such as solar, wind, geothermal, biomass, biogas, and low-impact hydropower. The EPA “Top 25 Partners” are partners in the Green Power Partnership whose annual green power purchase is the largest nationwide. Combined, their purchases amount to almost 4.4 billion kWh annually, which is approximately 60% of the green power commitments made by all the Partners. Number 3 on the list in 2006 was the U.S. Air Force at 457,500,000 kWh green power usage, 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.

The Department of Energy last reported on federal purchases of electricity from renewable energy sources in November of 2005. The Department stated at that time that the federal government exceeded its goal of obtaining 2.5% of its electricity needs from renewable energy sources by 30 September 2005. Summary information is not yet available for 2006. In September 2006, the DOE Federal Energy Management Program (FEMP) provided reporting guidance for FY 2006 for Federal Government Energy Management and Conservation Programs. The information collected will be used to develop the FEMP FY 2006 annual report to the United States Congress.

18.3.1.4 GeoPowering the West

The GeoPowering the West (GPW) initiative was started in 2000 by the Department of Energy to increase the use of geothermal energy in the United States. GPW works with the geothermal industry, power companies, industrial and residential consumers, as well as federal, state, and local officials to provide technical and institutional support and cost-shared funding at the state and local levels. Networking is achieved through collaborative partnerships with the National Conference of State Legislators, the Western Governors' Association, Western Interstate Energy Board, Western Electricity Coordinating Council, and the Western Renewable Energy Generation Information System. There are 14 active grants to State Governments and GPW Partners. These awards are part of the GPW emphasis on fostering geothermal projects through State Working Groups that have been created in 11 states throughout the West.

18.3.1.5 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. The funds are available to support a wide range of technologies encompassing biomass, geothermal, hydrogen, solar, and wind energy, as well as energy efficiency improvements. A total of 435 grants totaling $66.7 million have been awarded in 36 states since the program began, and in 2005, for the first time, renewable energy loan guarantees were made under the program. In June 2006, USDA announced the availability of $176.5 million in loan guarantees and almost $11.4 million in grants to support investments in renewable energy and energy efficiency improvements by agricultural producers and small businesses.

18.3.1.6 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. Fifty-five of those are producing geothermal energy, including 34 power plants**.** The BLM has been expediting the application process for geothermal leases, issuing more than 200 leases since 2001, compared to 25 leases during the period 1996-2001.

The Department of Interior announced proposed rules that would require more competitive leasing, offer simplified royalty calculations and share current royalties with counties where production occurs. The Bureau of Land Management's proposed rule would require competitive leasing for geothermal resources on nearly all federal lands designated for this type of development. If no bids are received, then these resources would be offered non-competitively for two-year periods. Proposed regulations by the Minerals Management Service (MMS) would establish a fee schedule, in lieu of royalties, for the direct use of geothermal resources which would provide an incentive to encourage the development and expansion of this alternative energy source. The MMS rule also would simplify the royalty calculations for electrical generation by basing them on a percentage of gross proceeds from the sale of electricity. The two sets of proposed rules were written in response to EPAct 2005, which mandated comprehensive changes to leasing and royalty policies to encourage geothermal energy use without imposing additional administrative burdens on industry or government agencies.

18.3.1.7 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. There are currently 116 geothermal leases on National Forest lands. Five are producing leases providing geothermal fluid for a 12 MW_e power plant and a 45 MW_e power plant.

18.3.1.8 Renewable Portfolio Standards (RPS)

At the state level, the most popular and effective policy tools have been Renewable Portfolio Standards. Generally, the Standards mandate that utilities operating within a state must provide a designated amount or percentage of power from renewable sources as a portion of their overall provision of electricity. These have been adopted by 23 states and the District of Columbia as of the end of 2006. Many of them explicitly include geothermal electricity and some mention geothermal heat pumps. States anticipate significant economic development benefits from promoting renewables, particularly given the promise of developing home-grown energy sources. States are also attracted to renewable portfolio standards by the prospect of greater reliability of electricity supply in coming decades 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*).

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 environmental impacts. On the other hand, rapidly rising U.S. energy costs have increased interest in and support for all forms of renewable energy. The best hydrothermal geothermal sites are often in scenic, but isolated areas. As the geothermal industry expands and residential development intrudes into these areas, land uses will come increasingly into conflict. On a site-by-site basis, with geothermal development comes concerns about scenic vistas, tribal sacred lands, and induced seismicity.

Induced seismicity is an emerging issue which may or may not prove to be a significant impediment to the development of geothermal resources in the United States. Natural microearthquakes occur in both undeveloped and developed hydrothermal reservoirs. And larger events do occur; for example, a magnitude 4.4 earthquake, centered in The Geysers geothermal area occurred in May 2006 and tripped three Calpine geothermal plants offline. A second quake, magnitude 2.3, occurred six minutes later. The USGS reported that a total of 37 microearthquakes followed the initial event. The strongest quake the USGS ever recorded in the area was a magnitude 4.6 on 29 May 1987.

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 to 7.3 cents/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.

Most geothermal developers contend that the cost for new projects is in a range of 5.5 to 7.5 cents/kWh.

In its *Geothermal Task Force Report,* 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 on specific sites within a reasonable timeframe. Of this total, 5,600 MW_e are considered by the geothermal industry to be viable for commercial development by 2015. The 5,600 MW_e is estimated to be developable at busbar costs in a range of levelized costs of energy (LCOE) of about 5.3 to 7.9 cents/kWh and assumes commercial project financing conditions and the extension of a production tax credit (PTC). Lacking a PTC to catalyze renewable energy development, the WGA stated that LCOE values would be 2.3 cents/kWh higher.

The cost of geothermal electricity is not the same as the price paid by a utility to the seller, although the distinction is not always made. For example, Southern California Edison (SCE) and four of its largest renewable power suppliers announced an agreement in 2006 establishing a fixed price for SCE's wind, solar, biomass, geothermal, and small hydro power purchases through mid-2012 starting in May 2007. SCE's agreements with Caithness Energy, Colmac, Ormat, and FPL Energy established a five-year price of 6.15 cents/kWh that increases 1% annually starting in the second year. Renewable facilities participating in the agreement supply approximately 45% of the renewable energy SCE buys for its customers.
The 2,376 MW_e of potential capacity cited by the GEA cited earlier as currently under consideration will be strongly driven by the price offered under Renewable Portfolio Standards, actual development costs, and the existence of a Production Tax Credit for geothermal projects.

18.5.2 Geothermal Power Plant Costs

Costs for a 50 MW_e geothermal power plant are presented in Figure 18.8. The GEA estimated that a typical 50 MW_e power plant costs approximately \$140 million, including site development and exploration costs (*A Handbook on the Externalities, Employment, and Economics of Geothermal Energy*, GEA, October 2006).

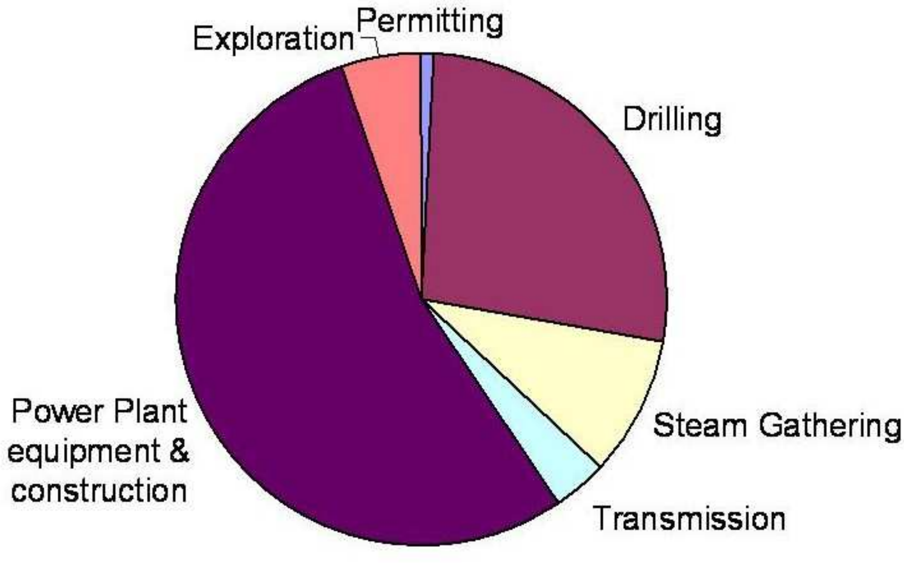

Figure 18.8 Typical costs for a geothermal power plant (GEA).

18.5.3 Employment in the Geothermal Sector

From a geothermal employment survey conducted by the GEA (*Geothermal Industry Employment: Survey Results and Analysis,* Hance, 2005), it was determined that the United States geothermal industry supplied about 4,583 direct jobs in 2004. This corresponded to 1.7 jobs/MW_e of installed geothermal power capacity. The GEA assumed a multiplier of 2.5 and concluded that the direct, indirect, and induced job impact of the industry in 2004 would have been 11,460. The GEA further stated (Hance) that achieving the 5,600 MW_e of geothermal production 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 $140 million would produce an economic output of nearly $750 million over 30 years, of which over $20 million would be delivered directly to the federal, state, and county governments where the plant is located. That 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 conducts focused research to: 1) enhance the performance of geothermal systems through the application of advanced technologies; 2) reduce risk and cost through improved reservoir engineering, drilling and conversion techniques; and 3) expand the resource base with improvements in methods for finding new resources and cost-shared exploration with industry. Technology improvements will accelerate the discovery and production of geothermal power. The technologies being pursued are grouped into five major categories:

- Exploration and resource characterization
- Well field construction and management
- Resource management
- Productivity/permeability enhancement
- Energy conversion

Under the National Energy Policy of 2001 (NEP), the Departments of the Interior (DOI) and Energy (DOE) are charged with characterizing the Nation's energy resources and removing obstacles to their development. In order to meet the NEP mandate and provide the geothermal community with updated resource information, the USGS and DOE signed an MOU for collaborative studies in support of geothermal resource assessments.

18.6.2 Government Funded Research

18.6.2.1 Geothermal Technologies Program- Department of Energy

The DOE Geothermal Technology Program (GTP) works with the private sector to develop the technology base that will enable private sector investment in geothermal energy in the future. The GTP is focused on partnerships with industry, universities and other Federal entities to:

- Understand the potential of the geothermal resource
- Develop the technology to access and capture geothermal energy

- Cost-effectively convert geothermal energy to electricity
- Facilitate implementation and deployment of technology by the private sector

DOE is working on developing new exploration tools with its national laboratories including the Idaho National Laboratory, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Sandia National Laboratory, and the National Renewable Energy Laboratory. In the past, DOE also sponsored cost-shared exploratory drilling projects with industry resulting in the discovery of significant new hydrothermal fields for development by the private sector. Other areas of R&D are fracturing and subsurface imaging to maximize the extent and amount of energy that can be recovered from a geothermal reservoir. DOE is also evaluating the potential use of supercritical carbon dioxide as a working fluid. Using carbon dioxide has the potential for increased efficiency and possible sequestration of the carbon dioxide in geologic strata.

18.6.2.2 United States Geological Survey- Department of the Interior

The new USGS 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 also support the development of geothermal energy by quantifying uncertainties in the assessment process and highlighting ways for future funded research to better constrain those uncertainties and advance the state of geothermal knowledge.

18.6.2.3 United States Navy- Department of Defense

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 the Department of Energy are cooperating 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, manages and develops geothermal resources for the military.

18.6.3 Industry Funded 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. The GEA has stated that the geothermal industry supports a continued DOE geothermal research program to address the near-term need to expand domestic energy production and the longer-term need to find the breakthroughs in technology that could revolutionize geothermal power production.

18.6.4 Other Research

The following organizations conduct geothermal research as well as having educational components:

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 view and analyze this data and to produce maps of 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 areas such the geothermal resources, plate tectonics behavior and the mapping of Earth's thermal properties at the surface and subsurface levels.

Figure 18.9 (this chapter title page) shows the heat flow of the conterminous United States where one easily sees that the western region of the country has higher heat flow than the eastern part. This heat flow map was developed by SMU and used in the MIT Study.

18.6.4.3 Geo-Heat Center, Oregon Institute of Technology

The Geo-Heat Center, Oregon Institute of Technology, was established in 1975 and 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 in the area of equipment and materials selection, feasibility studies, design, trouble-shooting and economic evaluations. The Center publishes the *Quarterly Bulletin*, technical papers, software and monographs on geothermal energy.

18.6.4.4 Stanford Geothermal Program, Stanford University

The primary objective of the Stanford Geothermal Program is the development of reservoir engineering techniques to allow for the production of the nation's geothermal resources in the most efficient manner possible. The focus currently is on reinjection into vapor-dominated reservoirs such as The Geysers. Stanford sponsors an annual Geothermal Workshop. The workshops, which have been held since 1975, bring together engineers, scientists and managers involved in geothermal reservoir studies and developments and provide a forum for the exchange of ideas on the exploration, development and use of geothermal resources. The 31st Stanford Geothermal Workshop was held 30 January-1 February 2006.

18.6.4.5 Intermountain West Geothermal Consortium

The Intermountain West Geothermal Consortium (IWGC) was initiated in 2006 and is comprised of six institutions from four states and will be conducting targeted studies of low, moderate, and high temperature geothermal systems in Idaho, Oregon, Utah, Nevada, and elsewhere. Language in EPAct 2005 authorized the creation of the Intermountain West Geothermal Consortium. The IWGC is currently comprised of the Idaho National Laboratory, the Idaho Water Resources Research Institute at the University of Idaho, the Geo-Heat Center at Oregon Institute of Technology, the Desert Research Institute (Nevada), the Energy and Geoscience Institute at the University of Utah, and Boise State University.

18.7 Geothermal Education

18.7.1 Geothermal Technologies Program

The educational aspects of the Geothermal Technologies Program activities are implemented primarily through its GeoPowering the West (GPW) program. The GPW provides State-based technical assistance and education for decision-makers, policymaker, utilities, regulators, and other stakeholders. The GPW also identifies appropriate target audiences and produces suitable information products. Its efforts reach all education levels (K-12, university, and research staff). Geothermal outreach publications can be accessed through the DOE geothermal website.

18.7.2 Geothermal Legacy Project

The DOE Office of Scientific and Technical Information (OSTI) and the DOE Geothermal Technologies Program, supported by Princeton Energy Resources International, LLC, conducted a project to collect DOE-sponsored reports and other documents important to the history of the DOE geothermal program. Thousands of documents identified as "Geothermal Legacy" documents, many previously available in print only in a handful of archives, were converted to PDF and electronically stored in a searchable database. The Geothermal Legacy Project concluded September 2006 with approximately 7,300 documents in the database and available online.

18.7.3 Geothermal Education Office

The Geothermal Education Office (GEO) promotes public understanding about geothermal resources and its importance in providing clean sustainable energy while protecting our environment. 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.

18.7.4 Geothermal Resources Council

The Geothermal Resources Council (GRC) is a tax-exempt, non-profit, educational association. The GRC has members in 30 countries and actively seeks to expand its role as a primary professional educational association for the international geothermal community. The GRC convenes 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.

18.7.5 Geothermal Energy Association

The Geothermal Energy Association (GEA) is a trade association composed of U.S. companies who support the expanded use of geothermal energy and are developing geothermal resources for electrical power generation and direct-heat uses. The GEA also conducts education and outreach projects. In November, the GEA; Glitzier, a leading Nordic specialty bank; Bob Lawrence and Associates; US Renewables Group; and Ormat hosted the first East Coast Geothermal Finance Workshop. The workshop highlighted geothermal energy projects around the nation, policies and issues influencing growth, and opportunities in geothermal energy.

18.8 International Cooperative Activities

The United States is a Contracting Party to the International Energy Agency Geothermal Implementing Agreement (*Implementing Agreement for a Co-Operative Programme on Geothermal Energy Research and Technology*) signed on 7 March 1997. The DOE Geothermal Technologies Program and its research organizations participate in and host international conferences and meetings. The Department of Energy, Division of Geothermal Technologies, participated in the *Second International Conference and Roadmapping Workshop on Mineral Extraction from Geothermal Brines* held in Tucson, Arizona on 6-8 September 2006. This conference was sponsored by the World Bank, Russian Geothermal Society, the U.S. Department of Energy, and the International Geothermal Association.

18.9 Websites of Interest

A listing of some Internet websites for additional information on geothermal energy in the United States is provided below (in no particular order):

- Federal geothermal program: www.eere.energy.gov/geothermal/
- The "Nevada Geothermal Update" is available at: http://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) references, this report: www.geo-energy.org
- Direct use; Geo-Heat Center: http://www.geoheat.oit.edu
- Geothermal Legacy Project: http://www.osti.gov/geothermal
- Geothermal resource maps: http://geothermal.inel.gov
- Geothermal wells and springs in Utah: http://geology.utah.gov/geothermal/interactive/index.html
- MIT EGS study: http://web.mit.edu/newsoffice/2007/geothermal.html and http://geothermal.inel.gov.
- EIA Annual Energy Outlook: http://www.eia.doe.gov/oiaf/aeo/index.html
- EIA Short Term Energy Outlook: http://www.eia.doe/emeu/steo/pub/contents.html
- Geothermal Heat Pump Consortium: http://www.geoexchange.org

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SPONSOR ACTIVITIES

Chapter 19

Geodynamics

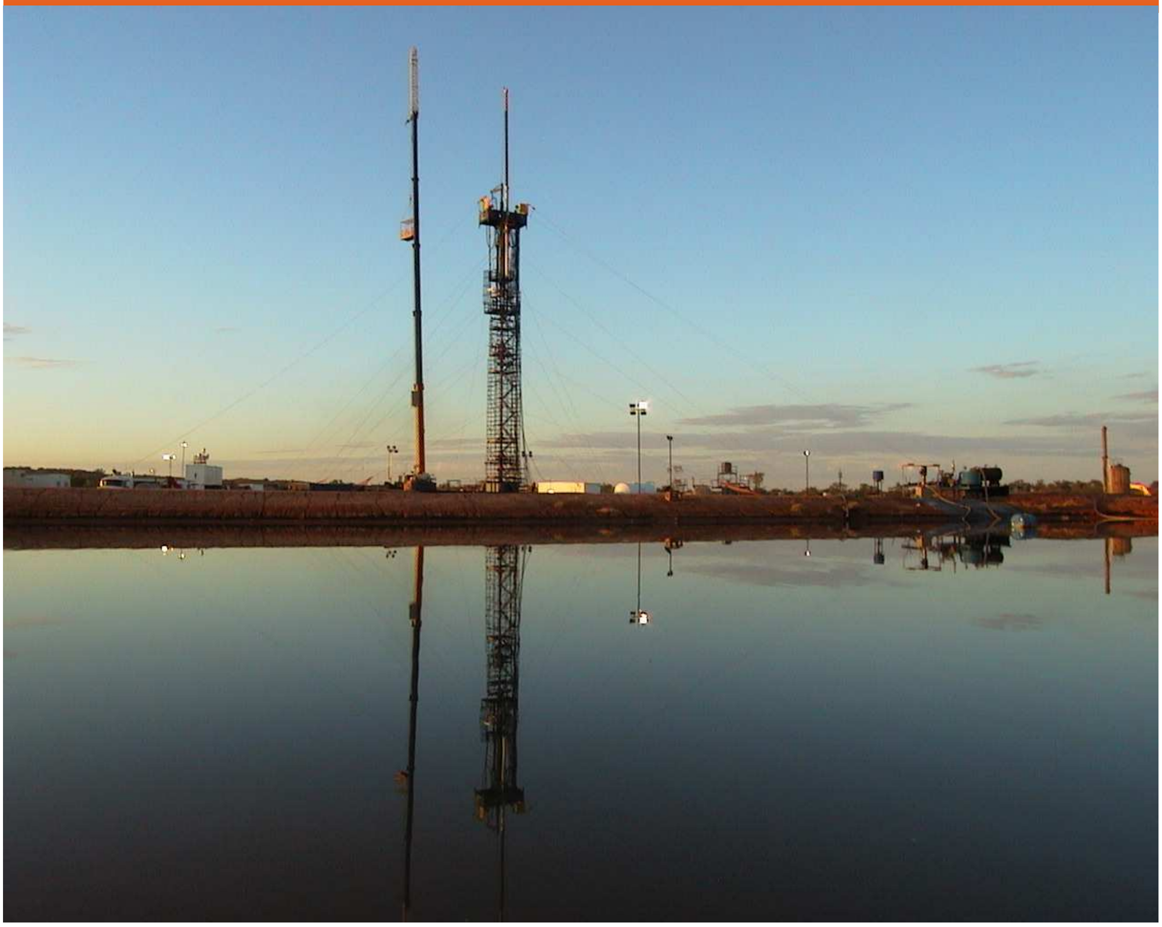

Figure 19.4 Snubbing unit setup over Habanero 2, 20 March 2006. The actual snubbing unit was set 33 m above ground level on a scaffold and 10,000 psi rated 7-inch riser pipe.

19.0 Introduction

19.0.1 Background

Brisbane-based Geodynamics is the corporate pioneer in Hot Fractured Rock (HFR) geothermal energy in Australia. The Company's goal is the development of a large known HFR resource for the generation of zero-emission, base-load electricity (1,000 MW_e and more).

The development of this geothermal resource located in the Cooper Basin, South Australia, will make Australia a world leader in lowering greenhouse gas emissions. To underpin this aim, Geodynamics has acquired rights to the high efficiency power generation technology known as the Kalina Cycle.

To reach its objectives, the Company has a business plan focussed on:

- A three-stage plan for the development of the Cooper Basin HFR geothermal electricity project
- A development plan for Kalina Cycle electricity generation in the geothermal and industrial waste heat industry

During the year 2006, Geodynamics:

- Had delays in its HFR testing program due a failed drilling campaign using a snubbing unit to drill around a blockage at depth in its second well Habanero 2
- Carried out flow tests indicating the presence of a large permeable reservoir with large water storage around the Habanero wells
- Completed a Reservoir Enhancement program which established a second parallel reservoir and a 52% increase of the existing main geothermal reservoir
- Completed front end engineering design for the demonstration plant using Kalina cycle
- Measured high geothermal gradients at the Company's Bulga exploration license in the Hunter Valley, NSW
- Formulated the plan for a 280 MW_e multi-well staged commercial HFR development with connection to the National electricity grid
- Submitted an application to the Federal Government for an AUS$ 75.4 million grant from the Low Emission Technology Demonstration Fund (LETDF) for the first 40 MW_e stage of the 280 MW_e project
- Raised AUS$ 17 million from a share placement in April 2006
- Assisted in an independent study of the economic benefits of large scale HFR generation by The Centre for International Economics which showed overall national benefits of more than AUS$ 10.3 billion
- Made significant contributions to a USA Department of Energy planning meeting on HFR geothermal development in the US
- Was awarded Mootanna Geothermal Exploration License 211 in the Cooper Basin
- Was offered two new geothermal exploration tenements in SW Queensland
- Was awarded Sustainable Small Company of the Year 2005

Geodynamics was listed on the Australian Stock Exchange in September 2002. The Company has the support of the Federal Government through a previous AUS$ 6.5 million AusIndustry Grant (2002-3) and an AUS$ 5 million REDI grant awarded in December 2005 for its Stage Two demonstration plant.

In addition, Geodynamics has the invaluable support of its two cornerstone investors, Woodside Petroleum Limited and Origin Energy Limited- two of Australia's largest energy companies. Both shareholders have warmly endorsed Geodynamics application for a grant under the Federal Government's Low Emission Technology Demonstration Fund and in recent times promptly provided resources for the Company's independent drilling review.

19.0.2 Highlights- Geodynamics Progress Since Listing

Geodynamics' progress since listing:

- Listed on ASX as a renewable energy developer in September 2002
- Owns 100% of Geothermal Exploration Licenses (GEL's) 97, 98, 99 and 211 in the Cooper Basin, in the north-east of South Australia
- Major high temperature granite resource in GEL 97 and 98 starts at a depth of 3,700 metres and covers an area of approximately 1,000 km^2
- Target granite temperatures of 250 °C plus, making it the hottest spot on Earth outside volcanic centres
- Contained, in place, thermal energy in GEL's 97 and 98 between 3,700 m and 5,000 m depth is estimated at equivalent to 50 billion barrels of oil, considerably greater than the energy in total oil reserves of the USA
- First deep geothermal injection well (Habanero 1) completed in October 2003 to a depth of 4,421 m
- Discovered over-pressured water (35 MPa) within the target granites, i.e. project has its own water supply
- Created an enhanced underground reservoir using hydraulic stimulation in late 2003. The stimulated zone, or underground heat exchanger, is seven times larger than expected and is the largest developed in the world to date
- In January 2004, acquired global rights to high efficiency Kalina power cycle with superior power conversion efficiency for heat sources within the range of 100 °C to 250 °C
- Established Geodynamics Power Systems with a power engineering team in Auckland NZ to commercialise Kalina for HFR, conventional geothermal and waste heat electricity generation
- First deep geothermal production well (Habanero 2), completed in December 2004 to a depth of 4,359 m
- Produced first high temperature geothermal flows in Australia, demonstrating the extraction of deep underground heat in May 2005 (15 megawatts thermal production)
- Conditional award of AUS$ 2.1 million Greenhouse Gas Abatement Programme (GGAP) grant for development of a waste heat Kalina Cycle plant
- Completed scoping studies and front end engineering design for a 2.6 MW_e Kalina Cycle generation plant for Stage Two of the Cooper Basin project and awarded a AUS$ 5 million REDI grant from AusIndustry for this project
- Modelling suggests that a planned multi-well HFR reservoir and power station at a scale of 280 MW_e will have an economic life exceeding 50 years

19.1 Status of Geodynamics' Geothermal Activities in 2006

19.1.1 Cooper Basin HFR Geothermal Project

19.1.1.1 Reservoir Testing Programme

The 2005 flow testing program from Habanero 2 started in late May 2005. After producing artesian flow rates of up to 25 l/s, it was shut down on 8 October 2005. Artesian flow in Habanero 2 was coming from the top fracture system, but not from the larger bottom fracture at the time. The bottom fracture was blocked off by an obstruction.

The eight remote seismic monitoring stations continue to collect data which is manually downloaded each month. This monitoring indicates that a small number of acoustic events continue to take place around the margins of the activated zone. Figure 19.1 shows the extent of the activated zone in 2005 compared to the end of 2003. The figure is colour contoured for the number of events in a given area.

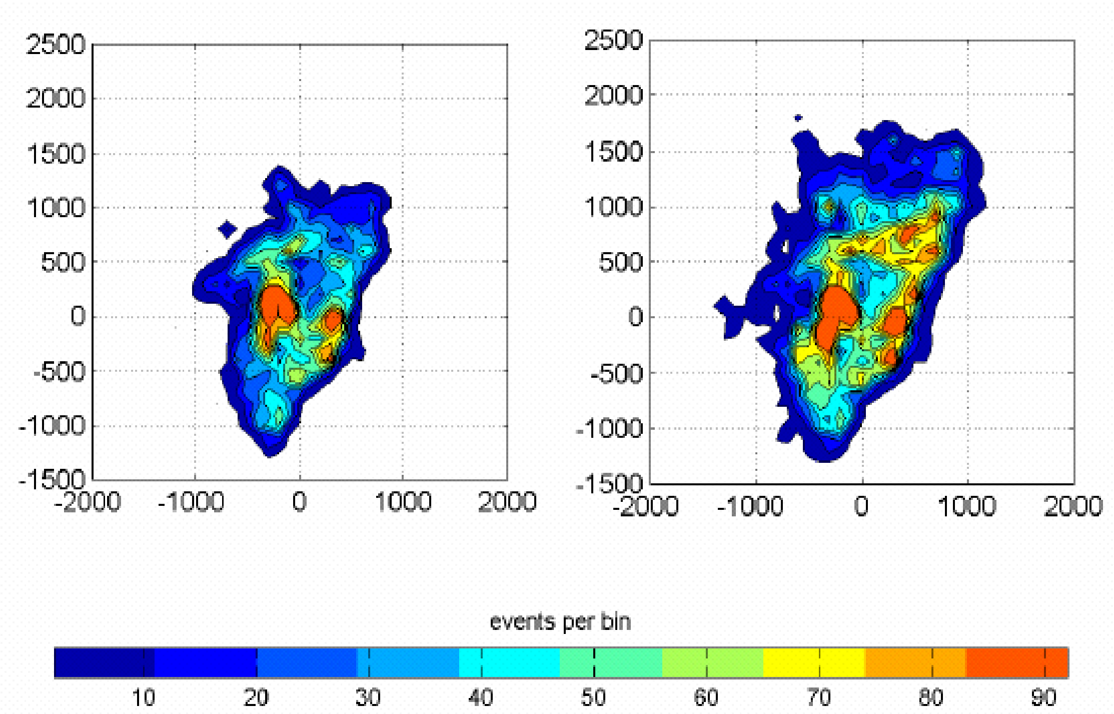

Figure19.1 Seismically activated region on 2003 (left) compared to 2003 and 2005 combined (right). Scale in metres. The colour scaling refers to the number of acoustic events per lateral bin (100 m by 100 m bin).

During the top zone stimulation in August 2005, the Company established through pressure monitoring at Habanero 1 that there was virtually no hydraulic communication between the top and bottom zones despite both zones extending horizontally for hundreds of metres and only being 100 m apart vertically. This is a favourable result as it clearly demonstrates that parallel sub-horizontal reservoirs can be independently developed, a goal that was set during the initiation of the project in 2002.

19.1.1.2 Reservoir Modelling

During 2005/06, we considerably improved our understanding of the longevity, scale-up and performance of multi-well HFR geothermal systems. This work was carried out by Q-con GmbH in Germany. The thermo-hydraulic simulation was based on a geological model with fracture porosity and transmissibility parameters derived from observations in the Habanero system. The modelling was implemented with a commercial finite element software package (FEMLAB®). It examined a flow field of wells spaced at 700 m and 1,000 m in triangular (43 wells) and square (41 wells) grid patterns as shown in Figure 19.2.

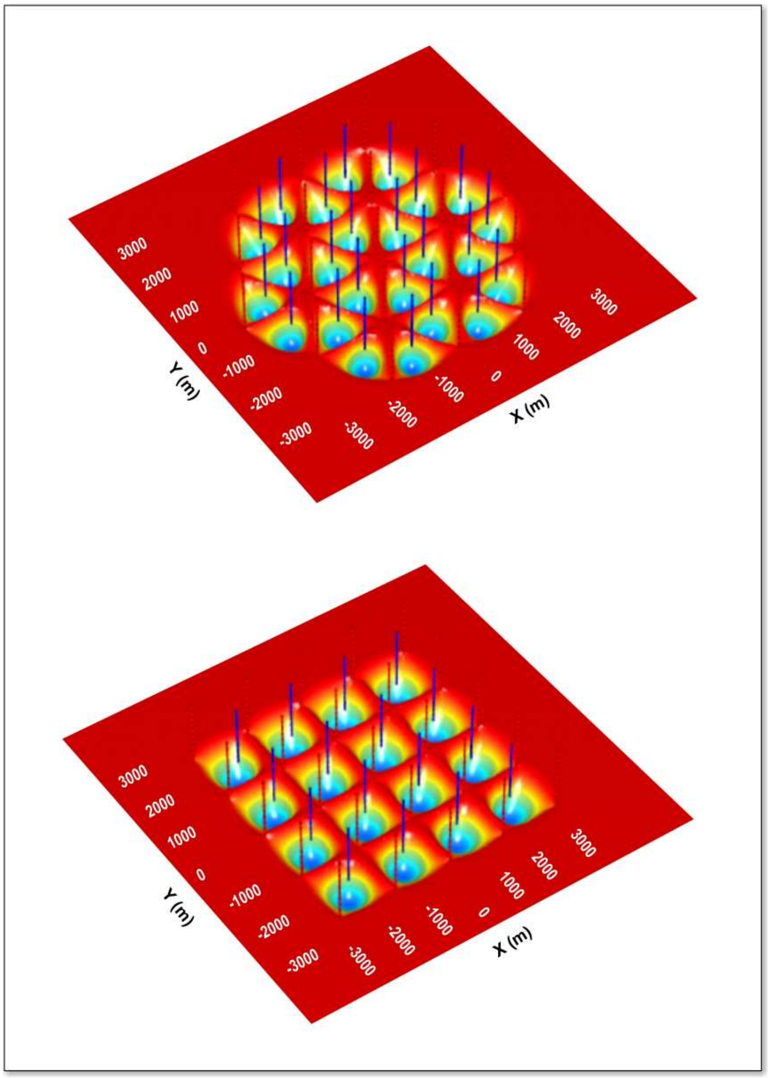

Figure 19.2 Temperature draw-down modelled with triangular and square well patterns after 20 years for 43 and 41 wells respectively, with a 1,000 m spacing between injection and production wells. The original high temperature of the system is shown in red with lower temperatures grading through yellow and green to blue. Note that temperature breakthrough at the production wells has not yet taken place.

Flow rates across the field were designed to produce a net electrical output of 280 MW_e at an initial output temperature of 252 ºC. The model was run over 20 and 50 years to examine the temperature drawdown over those periods.

The modelling showed that for the parameters and well field layout adopted, the temperature reduction over 25 years would be 20 °C or less. Over 50 years, the temperature would decline by 40 °C or less (Figure 19.3).

This has important (and favourable) implications for the life of an HFR power station. For a given geothermal fluid flow rate, the power generated declines as the fluid temperature falls. If the temperature falls too far, then the whole economic basis of the project can be badly affected. However, analysis of the temperature decline above shows an economic life of more than 50 years which is very satisfactory.

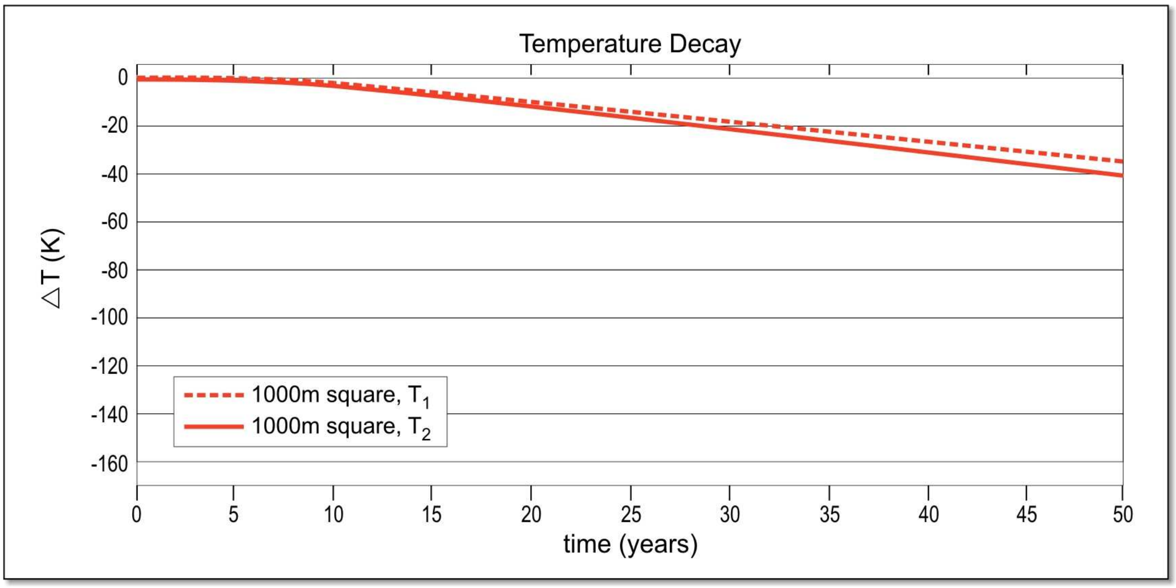

Figure 19.3 Model of temperature draw-down of an HFR reservoir consisting of a heat exchanger between 4,200 m and 5,000 m depth connected to a well-field of 41 wells arranged in square pattern with 1,000 m well spacing. Solid line is the modelled temperature at 5,000 m, dashed line is at 4,200 m.

19.1.1.3 Habanero 2- Well Intervention

The well intervention was designed to restore the connection between Habanero 2 and the Bottom Zone reservoir by drilling a new 550 m long open hole side track from near the bottom of the existing 7-inch casing. The decision was made to use a different drilling approach using fully under-balanced drilling with water.

Under-balanced drilling eliminates the problem of lost drilling mud into the reservoir which has caused damage to the fracture permeability during previous drilling. This approach also favoured the use of a "snubbing" unit over a conventional drilling rig. Use of a conventional drilling rig would have delayed the program. It would also have required considerable modification to safely control the resulting surface pressures. The decision was also made to use down-hole turbines to drive the bit, rather than a more conventional surface "top drive". These are all advanced but established techniques. The snubbing unit (Figure 19.4, this chapter title page) allowed entry into the over-pressured well (35 MPa) through the well head without "killing" the well with heavy drill mud, without the need to remove the Christmas tree (well head assembly above the ground) and without the use of a bridge plug, all major advantages. In addition evidence from other under-balanced operations indicated that considerable increases could be expected in the drilling rate of penetration (ROP) compared to balanced drilling.

Blade Energy Partners (Blade) of Houston Texas were commissioned to carry out the drilling operation and a small team ably lead by Jim Carr of Blade and assisted by Dave Baillargeon of Flow Drilling Engineering Limited of Canada carried out the preparation. This included the manufacture of an elaborate support structure and scaffold, and installation of a complex pumping system using pumps supplied by Halliburton. The pumps were required to contain the reservoir overpressures and to cool the surface equipment if flow from the reservoir became too great. Following extensive planning, rig-up and commissioning of Imperial Snubbing Service's (ISS) Snubbing Rig 15 together with ancillary specialised under-balanced drilling equipment, Habanero 2 was re-entered on 10 March 2006.

An attempt to re-enter the previously drilled sidetrack 1, with the objective of pushing down the blockage caused by the sunken bridge plug, was not successful due to a failure to trip through the casing window (due to pinched casing or a misaligned whipstock). Consequently, a new whipstock (a metal wedge cemented in the hole designed to deviate the drill bit) was set inside the casing to enable the drilling of a second sidetrack. A new casing window was successfully milled at a depth of 3,845 m using the "one trip" whipstock system.

The drilling of sidetrack 2 was beset by technical difficulties including two broken turbines (requiring two additional sidetracks), stuck drill pipe events and the failure of seals in tri-cone bits due to the high down-hole temperatures and long tripping times in and out of the hole (i.e. the time taken to reach the bottom of the hole, and the time to bring the bit back to the surface). There were a total of 19 bit runs before the drill bit became irretrievably stuck one joint off bottom with the hole at a depth of 4,226m. This depth was close to the level of the upper reservoir and approximately 145 m above the target main zone.

The snub drilling equipment performed reliably at surface. However it was clear early in the operation that this was going to be difficult drilling. The borehole breakout (spalling of small rock chips off the borehole wall) was much worse than with balanced drilling. This had been anticipated ahead of the program, but its degree was underestimated. In hindsight this was a mistake. The slow tripping and cumbersome method of making connections for the snubbing unit added to this difficulty.

The snubbing unit was released on 30 June 2006.

Geodynamics put in place a program to ensure what was learned from this well intervention would be captured. An "After Action Review" was carried out by Management on 11-12 July 2006. In addition, a Board initiated external review was held on 31 July and 1 August 2006 chaired by non-executive director Robert Flew.

Both reviews recommended that the next drilling campaign take place with a conventional drilling rig operating under managed pressure drilling (MPD) for the bulk of the granite section. Drilling through the main fracture system would require a system capable of drilling under-balanced with snub assist, but MPD may be the initial *modus operandi* even at that depth.

It has been determined that a new well, Habanero 3, will be drilled as soon as practicable and that the fracture network will be drilled with 5-inch drill pipe rather than the 3½-inch used in Habanero 1 and 2. This higher specification pipe is considerably more robust and less prone to twist-offs. The hole diameter will be 8½-inch and cooling will be more effective because higher circulation rates can be achieved in the bigger hole.

Once connection to the main reservoir has been established in Habanero 3, the circulation testing program will resume. The test of at least six weeks duration will include tracer injection. The Company expects that this programme will provide the necessary technical parameters to result in the declaration of a proven geothermal reserve and allow the company to proceed to Stage Two of its business plan.

19.1.2 Exploration not Associated with the Habanero Test Site

19.1.2.1 Cooper Basin, South Australia

Bulyeroo (GEL 97), Innamincka (GEL 98), Moomba (GEL 99) and Mootanna (GEL 211)- The Company's Mootanna exploration license application was accepted by the South Australian Department of Primary Industries and Resources in September 2005. Mootanna connects our flagship GEL's 97 and 98 with the Moomba license (GEL 99). There has been no drilling to basement in Mootanna and it is unclear whether granitic rocks amenable to HFR development are present though temperatures in excess of 200 ºC at the bottom of the Cooper Basin cover rocks are predicted. One well drilled by Santos in 2001 reached a depth of 3,050 m with a bottom hole temperature of 173 ºC only 16 hours after circulation stopped.

19.1.2.2 Hunter Valley, New South Wales

Bulga, (EL 5886); Muswellbrook, (EL 5560)- On the Bulga lease, two temperature monitoring wells, GBD-1 and 2, were drilled using a diamond coring rig to a depth of 300 m and completed with plastic casing. The two holes are 4.3 km apart with the northern-most hole showing a considerably higher temperature gradient (70 ºC/km in coal measures) than the southern one (50 ºC/km in coal measures). The recorded temperature gradient in the northern hole is also greater than those previously measured in holes in the Company's Muswellbrook tenement to the north-west, whereas the gradient recorded in the southern hole is comparable to the other results. These new results come from relatively shallow depths in the coal measures sequence and merit further investigation.

19.1.2.3 Queensland Geothermal Exploration Blocks

Geodynamics is preferred tenderer for two geothermal tenements in western Queensland. These are known as Nappa Merrie (EPG6) and Tennaperra (EPG5). Both are approximately 600 km^2 in area. The locations of the two successful Geodynamics bids are shown in Figure 19.5. Nappa Merrie

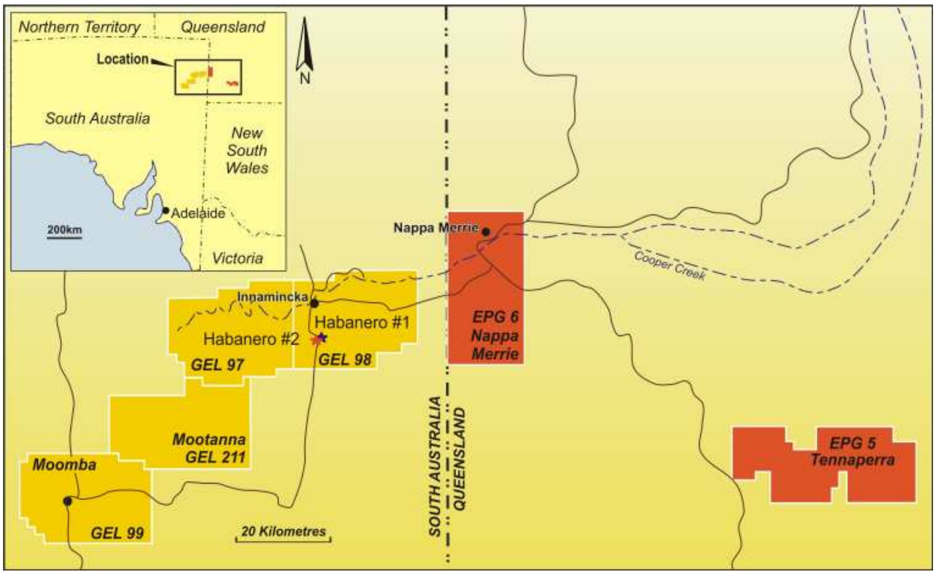

Figure 19.5 Location of Tennaperra (EPG5) and Nappa Merrie (EPG6) geothermal exploration tenements in Queensland in relation to Geodynamics' geothermal tenements in the Cooper Basin, South Australia.

is on the border with South Australia, close to Geodynamics' tenements at Innamincka. It covers the extension of the Nappa Merrie Trough from South Australia into Queensland. Granite within the basement to this trough in South Australia contains the only known geothermal resources in Australia where Geodynamics is developing its program at Habanero. To date, no wells have been drilled in the Nappa Merrie tenement area.

Tennaperra contains a number of petroleum exploration wells and the depth to basement is quite well known, being in the range 1,800 m to 2,500 m. Temperature gradients above the basement are in the range of 45 to 60 °C/km. A number of wells close to the area have drilled into granite in the basement.

The issuing of the two tenement licenses is yet to be completed by the Queensland Government.

19.2 Planned Activities for 2007 (and Beyond?)

Geodynamics has been searching for a drilling rig to carry out its Habanero 3 drilling in mid-year 2007. Unfortunately there are no rigs in Australia, nor drilling contractors willing to mobilise a rig to Australia for one well. As a result Geodynamics has decided to purchase its own rig. The company completed a global evaluation and selected an advanced U.S.-built rig ideally suited to drilling the deep geothermal wells it has planned.

The rig will be operated for Geodynamics by an Australian-owned specialist well servicing and drilling contractor, Easternwell Group, who are firmly established in the Cooper Basin where Geodynamics is drilling. The new Lightning rig will cost Geodynamics AUS$ 32 million, and while Geodynamics has taken the step of acquiring a rig, the company is not planning to have its capital tied up in such an asset in the long term. A unique modular design allows the rig to be moved from one well to another within three days instead of the usual weeks, using around 30 truckloads instead of the normal 70. The rig's supplier, Texas-based LeTourneau Technologies, has its Australian headquarters in Brisbane, ensuring Geodynamics access to skilled maintenance and spare parts.

The rig is due to arrive in Australia mid-2007 and commence drilling Habanero 3 as its first operation. Casing well head and Christmas tree have been ordered for delivery by July.

Once circulation testing is complete between Habanero 1 and 3 the company intends to commence its first commercial development of 40 MW net. This will consist of 3 injection wells and 4 production wells each drilled to 5 km. The aim is to have 40 MW powered into the Australian national grid by the end of 2010.

19.3 Comments on the Geothermal Market

19.3.1 Opportunities and Constraints from Geodynamics' View

The Australian and state governments are becoming acutely aware of the problems of climate change and the high per-capita CO_2 emissions of greenhouse gases in Australia. There is more support for renewable energy programmes, and a much greater public awareness of geothermal development in Australia. Much of this extra interest is described in Australia's country report.

19.4 Company's Research Activities (where they can be disclosed)

Geodynamics has been developing thermal modelling and fracture modelling programs through its consultant reservoir engineering company Q-con. It is also supporting similar work being carried out at the University of Queensland. The field operations are being undertaken in a unique geological setting where temperatures are high because radiogenic granites are buried under insulating sedimentary cover. High horizontal stresses in the centre of the continent and high fluid pressures in the natural granite fractures mean that drilling conditions are also unique. The full field program is classified as research.

19.5 Websites

- Geodynamics: www.geodynamics.com.au
- Letourneau: http://www.letourneau-aust.com
- Easternwell Group: http://www.easternwell.com.au

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SPONSOR ACTIVITIES

Chapter 20

Green Rock Energy

Well Blanche No. 1 at Olympic Dam, Australia.

20.0 Introduction

20.0.1 Background

Green Rock Energy Limited (“Green Rock”) is a public company listed on the Australian Stock Exchange and its funds have mainly been obtained from its shareholders.

Green Rock was admitted as a sponsor member of GIA in June 2006. The Company is focusing on the development of renewable, clean, geothermal energy projects with a strong commercial objective. The company is pursuing engineered geothermal systems (EGS) where water has to be introduced into engineered fractures and conventional geothermal systems where hot water is produced from water saturated natural geothermal reservoirs. Given suitable reservoir temperatures, both types of geothermal energy depend on achieving sufficient sustainable water flow rates to recover enough energy at the surface to ensure commercial success. The chief challenges for both are the costs of drilling and pumping for geothermal waters that are not self flowing. For EGS, success is dependent on establishing proficiency in fracture stimulation. Because of this, the Company is participating in Annexes III (Enhanced Geothermal Systems), IV

(Deep Geothermal Resources) and VII (Advanced Geothermal Drilling Techniques). Green Rock also wishes to develop expertise in the use of direct heat for industry and agriculture as an adjunct to commercial electricity production.

20.1 Green Rock's Geothermal Energy Projects

Currently the Company has two principal projects, a conventional geothermal energy project in Ortaháza in Hungary (32% interest) and an EGS project at Olympic Dam in Australia (100% interest).

20.1.1 Hungary

Green Rock Energy is a participant in a joint venture with the Hungarian Oil and Gas Company (MOL) and Enex the Icelandic geothermal consulting company to develop geothermal energy in Hungary. The joint venture is refurbishing and flow testing existing oil wells, drilled and owned by MOL, to access hot geothermal water encountered during drilling for petroleum, but which discovered hot water in Triassic carbonate reservoirs. The aim is to produce electricity with residual geothermal heat used for direct heating.

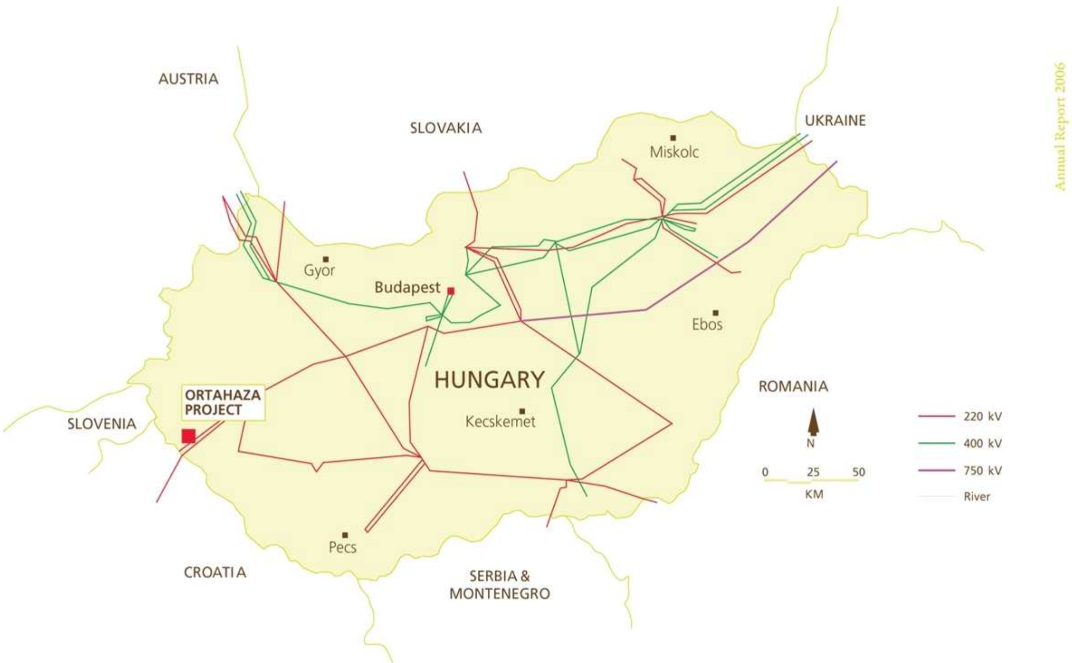

Figure 20.1 The Ortaháza project in western Hungary.

The Ortaháza project in western Hungary (Figure 20.1) is the first of what is expected to be a number of geothermal energy projects to be undertaken in Hungary by the joint venture. Short term water flow production testing has recently been completed on Ortaháza No. 5 well, from Triassic carbonates at a depth of around 3,000 m (Figure 20.2). As expected, the geothermal water temperature at the bottom of the well was confirmed to be 146 ºC and the formation water chemistry exhibited relative low concentrations of dissolved solids. After the initial short term production testing, acid was injected into the fractured carbonate reservoir to enhance the water flow rates from the well. This acidizing substantially increased the water flow rates. Results are still being assessed but it appears that while the commercially pumpable flow rates achieved from Ortaháza No 5 are suitable for supply of energy for direct heat applications they are considered to be insufficient for commercial generation of electricity under current conditions.

As a consequence, most of Green Rock Energy's expenditures incurred on the Ortaháza well testing program are expected to be refunded from the World Bank backed risk insurance Geofund.

The joint venture has started evaluation of its next geothermal energy project in Hungary.

Figure 20.2 Drill rig on Ortaháza No. 5 well, Hungary.

20.1.2 Australian Projects

20.1.2.1 Olympic Dam Project

The aim of Green Rock's Olympic Dam geothermal project in South Australia (Figure 20.3) is to supply the current and proposed electricity needs of BHP Billiton's copper operation at Olympic Dam and the surrounding area.

The Company has already drilled a fully cored slim exploratory well to a depth of 1,935 m at a site about 8 km from the Olympic Dam mine facilities. Indications from the core and logs are that the hot granites are subject to a compressional stress regime which may facilitate horizontal fracturing at greater depths required for production of electricity. In the next six months Green Rock plans to carry out a mini hydraulic fracturing ("mini-frac") program in the geothermal exploratory well to provide an understanding of the magnitude and direction of the ambient stress field and geo-mechanical fracturing properties of the hot granites. This information will assist in the design of the hydraulic fracture stimulation program.

The Company then plans to drill new wells much deeper into hot dry granite than the already diamond cored slim exploratory well (1,935 m depth) and circulate water through fractured reservoirs engineered by them in the hot dry granite to provide hot water to generate electricity.

Figure 20.3 Location of the Olympic Dam geothermal project in South Australia.

20.1.3 Future Projects

The Company has applied for additional geothermal licences in South Australia and is reviewing other potential geothermal projects within Australia and internationally with the objective of acquiring a portfolio of commercial geothermal projects.

20.1.4 Current Situation in Australia and Hungary

The situation in Australia is summarized in Australia's report to the GIA.

In Hungary, which is not yet a member country of the GIA, there is no electricity production from geothermal energy, but Hungary has a fiscal regime which is attractive for the production of electricity produced from geothermal energy.

20.2 Future Challenges for the Geothermal Industry

One of the challenges faced by the geothermal energy industry is the high cost of drilling to the depths required to obtain sufficiently high geothermal temperatures and the cost of downhole tools which have in many cases been developed by the petroleum industry. The lower profit margins in the geothermal industry compared to the petroleum industry mean that the geothermal industry can not afford to bear as much failed exploration and evaluation. This means the geothermal industry needs to work even smarter and use the best scientific information available, to reduce costs and to limit wasted expenditure.

The Company is in the early stages of developing know how in EGS and fracture stimulation technologies. It aims to assist the further development of technological improvements to assist exploration for and exploitation of geothermal energy.

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SPONSOR ACTIVITIES

Chapter 21

ORMAT Technologies

The 21 MW_e Ormat geothermal power plant at Burdette, Nevada, USA (owned and operated by Ormat).

21.0 Introduction

21.0.1 Company Description and Activities

Ormat Technologies, Inc. is a leading vertically integrated company engaged in the geothermal and recovered energy power business. We design, develop, build, own and operate clean, environmentally friendly geothermal and recovered energy-based power plants, in each case using equipment that we design and manufacture. We conduct our business activities in two business segments. In our Electricity Segment, we develop, build, own and operate geothermal and recovered energy-based power plants in the United States and geothermal power plants in other countries around the world and sell the electricity they generate. In our Products Segment, we design, manufacture and sell equipment for geothermal and recovered energy-based electricity generation, remote power units and other power generating units and provide services relating to the engineering, procurement, construction, operation and maintenance of geothermal and recovered energy power plants.

In the past 25 years Ormat has designed and supplied about 900 MW_e of geothermal power plant, nearly all of which are still in operation.
Ormat has developed and manufactures organic vapor turbines from 200 kW_e (non geothermal applications) to 15 MW_e. Initially focused on low temperature resources only (as low as 45 °C! in Alaska), it has been expanded to a wide range of resource conditions (up to 225 °C in Hawaii). Today, the Ormat Rankine Cycle (ORC) portfolio includes Organic Rankine Cycles, Steam Rankine Cycles and combinations of both.

Most of the projects that we currently own or operate produce electricity from geothermal energy sources.

In addition to our geothermal energy business, we have developed and continue to develop products that produce electricity from recovered energy or so-called "waste heat." We also own and are constructing new recovered energy projects to be owned and operated by us. Recovered energy or waste heat represents residual heat that is generated as a by-product of gas turbine-driven compressor stations and a variety of industrial processes, such as cement manufacturing, and is not otherwise used for any purpose. Such residual heat, that would otherwise be wasted, may be captured in the recovery process and used by recovered energy power plants to generate electricity without burning additional fuel and without emissions.

21.0.2 Business Strategy

Our strategy is to continue building a geographically balanced portfolio of geothermal and recovered energy assets, and to continue to be a leading manufacturer and provider of products and services related to renewable energy. We intend to implement this strategy through:

- **Development and Construction of New Projects -** continuously seeking out commercially exploitable geothermal resources, developing and constructing new geothermal and recovered energy-based power projects and entering into long-term power purchase agreements providing stable cash flows in jurisdictions where the regulatory, tax and business environments encourage or provide incentives for such development and which meet our investment criteria

- **Developing Recovered Energy Projects -** establishing a first-to-market leadership position in recovered energy projects in North America and building on that experience to expand into other markets worldwide

- **Acquisition of New Assets -** acquiring from third parties additional geothermal and other renewable assets that meet our investment criteria

- **Increasing Output from Our Existing Projects -** increasing output from our existing geothermal power projects by adding additional generating capacity, upgrading plant technology, and improving geothermal reservoir operations, including improving methods of heat source supply and delivery

- **Technological Expertise-** investing in research and development of renewable energy technologies and leveraging our technological expertise to continuously improve power plant components, reduce operations and maintenance costs, develop competitive and environmentally friendly products for electricity generation and target new service opportunities

21.0.3 Highlights for 2006

In the year ended 31 December 2006, revenues from our electricity segment were US$ 195.5 million, constituting approximately 72.7% of our total revenues in 2006. Revenues from the sale of electricity by our domestic projects were US$ 162.8 million, constituting approximately 83.3%

of our total revenues from the sale of electricity, and revenues from the sale of electricity by our foreign projects were US$32.6 million, constituting approximately 16.7% of our total revenues from the sale of electricity.

The revenues from our product segment were US$ 73.4 million.

21.1 Status of Geothermal Activities in 2006

21.1.1 Active Geothermal Projects and Their Status

We increased our net ownership interest in generating capacity by 51 MW_e between 31 December 2005 and 31 December 2006, resulting from the following:

- An increase of 19 MW_e, attributable to the acquisition of an additional 79.0% ownership interest in the Zunil project in Guatemala
- An increase of 22 MW_e, attributable to the construction of the OREG 1 recovered energy project
- An increase of 6 MW_e, attributable to the Gould geothermal power plant
- An increase of 5 MW_e, attributable to increased generating capacity of our existing geothermal power plants resulting from improvements to the geothermal well fields of some of our existing projects
- We experienced a 1 MW_e reduction in generating capacity at our Brady project as a result of cooling
- During the fourth quarter of 2006, we completed the construction of the Desert Peak 2 project in Nevada, which added 12 MW_e to our generating capacity. We have not yet declared this project commercially operational, which would trigger our obligation to provide the contracted generating capacity under the power purchase agreement.

In the year ended 31 December 2006, revenues from our electricity segment were US$ 195.5 million, constituting approximately 72.7% of our total revenues in 2006. Revenues from the sale of electricity by our domestic projects were US$ 162.8 million, constituting approximately 83.3% of our total revenues from the sale of electricity, and revenues from the sale of electricity by our foreign projects were US$ 32.6 million, constituting approximately 16.7% of our total revenues from the sale of electricity (Table 21.1).

21.1.2 Operations of Products Segment

Power Units for Geothermal Power Plants- We design, manufacture and sell power units for geothermal electricity generation, which we refer to as Ormat Energy Converters or OECs. Our customers include contractors and geothermal plant owners and operators.

The consideration for the power units is usually paid in installments, in accordance with milestones set in the supply agreement. Sometimes we agree to provide the purchaser with spare parts (or alternatively, with a non-exclusive license to manufacture such parts). We provide the purchaser with at least a 12-month warranty for such products. We usually also provide the purchaser (often, upon receipt of advances made by the purchaser) with a guarantee, which expires in part upon delivery of the equipment to the site and fully expires at the termination of the warranty period. The guarantees are at times covered by letters of credit. Ormat has not received any claims under the performance guarantees to date.

Table 21.1 Ormat's projects in operation.

Projects in Operation (1)					
Project	**Location**	**Ownership (2)**	**Generating Capacity in MW (3)**	**Power Purchaser**	**Contracts Expiration**
Domestic					
Ormesa Complex	East Mesa, California	100%	47	Southern California Edison Company	2017/2018
Heber Complex (4)	Heber, California	100%	82	Southern California Edison Company and Southern California Public Power Authority	2015/2023/2031
Steamboat Complex (5)	Steamboat, Nevada	100%	53	Sierra Pacific Power Company	2007 (6) /2018/ 2022/2026
Mammoth Complex	Mammoth Lakes, California	50%	29	Southern California Edison Company	2014/2020
Puna	Puna, Hawaii	100%	30	Hawaii Electric Light Company	2027
Brady	Churchill County, Nevada	100%	19	Sierra Pacific Power Company	2022
Desert Peak 2 (7)	Churchill County, Nevada	100%	12	Nevada Power Company	2027
OREG 1	North and South Dakota	100%	22	Basin Electric Power Cooperative	2031
Total For Domestic Projects in Operation:			**294**		
Foreign					
Leyte (8)	Philippines	80%	49	PNOC - Energy Development Corporation	2007
Momotombo	Nicaragua	100%	30	DISNORTE/DISSUR	2014
Zunil	Guatemala	100%	24	Instituto Nacional de Electricidad	2019
Olkaria III (Phase I)	Kenya	100%	13	Kenya Power and Lighting Co. Ltd.	2020 (9)
Total For Foreign Projects in Operation:			**116**		
Total For Projects in Operation:			**410**		

21.1.3 Results of Operations

Our historical operating results in dollars and as a percentage of total revenues are presented below. The different periods described below may not be comparable, as a result of effects on our historical operating results of our recent acquisitions and enhancements of acquired projects and construction of new projects (Table 21.2).

Table 21.2 Results of operations (in US$).

	Year Ended December 31,		
	2006	2005	2004
	(in thousands, except per share data)		
Statements of Operations Historical Data:			
Revenues:			
Electricity Segment	$ 195,483	$ 177,369	$ 158,831
Products Segment	73,454	60,623	60,399
	268,937	237,992	219,230
Cost of revenues:			
Electricity Segment	124,356	103,615	89,742
Products Segment	51,215	45,236	46,336
	175,571	148,851	136,078
Gross margin:			
Electricity Segment	71,127	73,754	69,089
Products Segment	22,239	15,387	14,063
	93,366	89,141	83,152
Operating expenses (income):			
Research and development expenses	2,983	3,036	2,175
Selling and marketing expenses	10,361	7,876	7,769
General and administrative expenses	18,094	14,320	11,609
Gain on sale of geothermal resource rights	-	-	(845)
Operating income	61,928	63,909	62,444
Other income (expense):			
Interest income	6,560	4,308	1,316
Interest expense	(30,961)	(55,317)	(42,785)
Foreign currency translation and transaction loss	(704)	(439)	(146)
Other non-operating income	694	512	112
Income before income taxes, minority interest and equity in income of investees	37,517	12,973	20,941
Income tax provision	(6,403)	(4,690)	(6,609)
Minority interest in earnings of subsidiaries	(813)	-	(108)
Equity in income of investees	4,146	6,894	3,567
Net income	$ 34,447	$ 15,177	$ 17,791
Earnings per share:			
Basic	$ 1.00	$ 0.48	$ 0.72
Diluted	$ 0.99	$ 0.48	$ 0.72
Weighted average number of shares used in computation of earnings per share:			
Basic	34,593	31,563	24,806
Diluted	34,707	31,609	24,806

21.2 Planned Activities for 2007

21.2.1 Projects Currently Under Construction and Under Development

The Tables 21.3 and 21.4 summarize key information relating to the projects that are currently under construction and under development, respectively.

Table 21.3 Projects under construction.

Projects under Construction						
Project	**Location**	**Ownership**	**Projected Commercial Operation Date**	**Projected Generating Capacity in (MW)**	**Power Purchaser**	**Contract Expiration**
Steamboat Complex (1)	Washoe County, Nevada	100%	2007	14	Nevada Power Company / Sierra Pacific Power Company	2018/2027
Ormesa	East Mesa, California	100%	2007	10	Southern California Edison Company (2)	N/A
Amatitlan (10)	Guatemala	100%	2007	20	Instituto Nacional De Electricidad	2026
Heber South	East Mesa, California	100%	2007/2008	10	N/A	N/A
Puna	Puna, Hawaii	100%	2007/2008	8	N/A	N/A
Galena 3	Nevada	100%	2007/2008	17	Sierra Pacific Power Company	20 years following commercial operation date
OrSumas	Washington State	100%	2007/2008	5	Puget Sound Energy	20 years from Jan. 1st following commercial operation date
Brawley (Phase I)	Imperial County, California	100%	2008	50	N/A	N/A
Olkaria III (Phase II)	Kenya	100%	2008	35	Kenya Power and Lighting Co.	N/A(3)
Total				**169**		

Table 21.4 Projects under development.

Projects under Development						
Project	**Location**	**Ownership**	**Projected Commercial Operation Date**	**Projected Generating Capacity in (MW)**	**Power Purchaser**	**Contract Expiration**
Carson Lake	Nevada	100%	2009	18-30	Nevada Power Company	20 years following commercial operation date
Buffalo Valley	Nevada	100%	2009	18-30	Nevada Power Company	20 years following commercial operation date
Brawlley (Phase II)	Imperial County, California	100%	2009	50	N/A	N/A
OREG II		100%	2008/2009	27.5	Basin Electric Power Cooperative	N/A
Total				**113.5 - 137.5**		

- On 20 July 2006, we entered into a contract valued at US$ 4.4 million with Geo X GmbH of Ludwigshafen, Germany, for the supply of one OEC for a geothermal power plant located in Landau, Germany. The equipment is to be supplied and installed within 17 months from the date of the contract.

- On 7 June 2006, one of our wholly-owned subsidiaries received supply and construction orders for three REG power plants on the Alliance Pipeline. Each facility will have a capacity of 5 MW_e net and will convert the recovered waste heat from the exhaust of existing gas turbines into electricity. The contracts are in the total amount of US$ 29.0 million. The three plants are expected to be commissioned in 2007 or early 2008.

- On 26 April 2006, we received a notice to proceed on an engineering, procurement and construction (EPC) contract to construct a geothermal power plant for the Raft River project in Idaho, for a total sales price of US$ 20.2 million. Construction of the power plant is expected to be completed in the last quarter of 2007.

- On 4 April 2006, we signed a contract to supply a 10 MW_e OEC power unit to PacifiCorp Energy in the Northwest region of the United States. The contract is in the amount of US$ 11.5 million. The existing PacifiCorp plant, to which an additional OEC will be added, uses single-flash technology to produce approximately 23 MW of net power to the grid. The PacifiCorp plant utilizes only steam, which is separated from the brine and delivered to the plant, while the brine is reinjected into the ground. Ormat's technology enables recovery of heat from the brine before reinjection and PacifiCorp Energy will utilize this new OEC power unit to generate 10 MW_e of additional power in the OEC without additional resources or wells. The OEC power unit will be delivered in the second quarter of 2007 for installation adjacent to the existing plant.

21.2.2 Products Backlog

The Company and its wholly owned subsidiaries have a products backlog of US$ 89.5 million as of 28 February 2007, which includes revenues for the period between 1 January 2007 and 28 February 2007, compared to US$ 81.8 million as of 15 March 2006. Table 21.5 shows the breakdown of the products segment backlog.

Table 21.5 Products backlog.

Products backlog	Expected Completion of Contract	Sales Expected to be Recognized in 2007 (in millions)	Sales Expected to be Recognized in the Years Following 2007 (in millions)
North America			
Raft River	2007	$ 16.2	$ -
Blundell	2007	5.0	-
NRGreen, Canada	2007	24.8	-
Enpower Green, Canada	2008	4.9	4.1
Total North America		**50.9**	**4.1**
Worldwide (Except North America)			
ICQ, Italy	2007	0.5	-
Enagas Almendralejo, Spain	2007	3.1	-
Comita, Russia	2008	-	2.4
Mokai 1A, New Zealand	2007	0.4	-
Landau Geo X GmbH, Germany	2007	3.6	-
Sakhalin, Russia	2007	2.4	-
Bongkot, Thialand	2007	0.4	-
Ngawha II, New Zealand	2008	10.3	10.5
Other Units	2007	0.9	-
Total Worldwide (Except North America)		**21.7**	**12.9**
Total Products Backlog		**$ 72.5**	**$ 17.0**

21.3 Comments on the Geothermal Market

21.3.1 Marketing Initiatives and Market Stimulation Incentives

An important factor fueling recent growth in the renewable energy industry is global concern about the environment. Power plants that use fossil fuels generate higher levels of air pollution and their emissions have been linked to acid rain and global warming. In response to an increasing demand for “green” energy, many countries have adopted legislation requiring, and providing incentives for, electric utilities to sell electricity generated from renewable energy sources. In the United States, Arizona, California, Colorado, Connecticut, Delaware, Hawaii, Illinois, Iowa, Maine, Maryland, Massachusetts, Minnesota, Montana, Nevada, New Jersey, New Mexico, New York, Pennsylvania, Rhode Island, Texas, Vermont, Washington Wisconsin and the District of Colombia have all adopted renewable portfolio standards, renewable portfolio goals, or other similar laws requiring or encouraging electric utilities in such states to generate or buy a certain percentage of their electricity from renewable energy sources or recovered heat sources. Of these twenty-three states, fifteen states and the District of Columbia (including California, Nevada and Hawaii, where we have been the most active in our geothermal energy development and in which all of our U.S. geothermal projects are located) define geothermal resources as “renewables”. A bill establishing renewable portfolio standards is currently before the Kansas legislature.

We believe that these legislative measures and initiatives present a significant market opportunity for us. For example, California generally requires that each investor-owned electric utility company operating within the state increase the amount of renewable generation in its resource mix by 2% per year so that 20% of its retail sales are procured from eligible renewable energy sources by 2010, ahead of the previous statutory mandated target of December 2017. Presently, approximately 11% of the electricity generated in California is derived from renewable resources (not counting hydroelectricity as renewable power). Nevada’s renewable portfolio standard requires each Nevada electric utility to obtain 9% of its annual energy requirements from renewable energy sources in 2007-2008, which requirement thereafter increases by 3% every two years until 2015, when 20% of such annual energy requirements must be provided from renewable energy sources or energy efficiency projects. At least three-quarters of the annual total requirements must come only from renewable energy projects. Hawaii’s renewable portfolio standard requires each Hawaiian electric utility to obtain 8% of its net electricity sales from renewable energy sources by 31 December 2005, 10% by 31 December 2010 and 20% by 31 December 2020.

In addition, a new Act was signed into law in California to reduce carbon emissions to 1990 levels by 2020, representing a 25% reduction in greenhouse gas emissions. To accomplish this, the Act provides a framework for greenhouse gas emissions reductions through the use of emissions control technologies and other cost-effective reduction strategies. One such strategy may involve the use of market-based trading of emissions rights that will allow some greenhouse gas sources to over-control their emissions and sell the rights to their surplus reductions to other sources for whom the cost of reducing emissions would be significantly more costly. Although programs under the Act will take some time to develop, its requirements, particularly the creation of a market-based trading mechanism to achieve compliance with emissions caps, should be highly advantageous to in-state energy generating sources that have low carbon emissions such as geothermal energy.

The federal government also encourages production of electricity from geothermal resources through certain tax subsidies. We are permitted to claim approximately 10% of the cost of each new geothermal power plant in the United States as an investment tax credit against our federal income taxes. Alternatively, we are permitted to claim a “production tax credit,” which in 2006 was 1.9 cents/kWh and which is adjusted annually for inflation. The production tax credit may be claimed on the electricity output of new geothermal power plants put into service by 31 December 2008. Credit may be claimed for ten years on the output from any new geothermal power plants put into service prior to 31 December 2008. The owner of the project must choose between the production tax credit and the 10% investment tax credit described above. In either case, under current tax rules, any unused tax credit has a one-year carry back and a twenty-year carry forward. Whether we claim the production tax credit or the investment credit, we are also permitted to depreciate most of the plant for tax purposes over five years on an accelerated basis, meaning that more of the cost maybe deducted in the first few years than during the remainder of the depreciation period. If we claim the investment credit, our “tax base” in the plant that we can recover through depreciation must be reduced by half of the tax credit; if we claim a production tax credit, there is no reduction in the tax basis for depreciation.

Collectively, these tax benefits (to the extent fully utilized) have a present value equivalent to approximately 30% to 40% of the capital cost of a new project.

The Kyoto Protocol entered into force on 16 February 2005, making the Protocol’s emission targets for the 2008 to 2012 period legally binding on the more than 30 developed countries, including the EU members, Russia, Japan, Canada, New Zealand, Norway and Switzerland, all of which have ratified the Protocol. We expect that the effect of the Kyoto Protocol will be to encourage renewable energy installation outside of the United States, as the United States has not ratified the Kyoto Protocol.

Outside of the United States, the majority of power generating capacity has historically been owned and controlled by governments. During the past decade, however, many foreign governments have privatized their power generation industries through sales to third parties and have encouraged new capacity development and/or refurbishment of existing assets by independent power developers. These foreign governments have taken a variety of approaches to encourage the development of competitive power markets, including awarding long-term contracts for energy and capacity to independent power generators and creating competitive wholesale markets for selling and trading energy, capacity and related products. Some countries have also adopted active governmental programs designed to encourage clean renewable energy power generation. For example, China, where we are currently trying to develop a project, has recently enacted a Renewable Energy Law (effective 1 January 2006) defining fiscal incentives, priority dispatching, preferential pricing and other supporting mechanisms, and has announced long-term targets for renewable energy capacity growth, including mandatory renewable portfolio standards for large generation utilities. Several Latin American countries have rural electrification programs and renewable energy programs. For example, Guatemala, where our Zunil and Amatitlan projects are located, approved in November 2003, a law which creates incentives for power generation from renewable energy sources by, among other things, providing economic and fiscal incentives such as exemptions from taxes on the importation of relevant equipment and various tax exemptions for companies implementing renewable energy projects. We believe that these developments and governmental plans will create opportunities for us to acquire and develop geothermal power generation facilities internationally as well as create additional opportunities for us to sell our remote power units and other products.

In addition to our geothermal power generation activities, we have also identified recovered energy- based power generation as a significant market opportunity for us in North America and the rest of the world. We are initially targeting the North American market, where we expect that recovered energy-based power generation will be derived principally from compressor stations along interstate pipelines, from midstream gas processing facilities, and from processing industries in general. Several states, as well as the federal government, have recognized the environmental benefits of recovered energy-based power generation. For example, Nevada, Connecticut, New Mexico and Hawaii allow electric utilities to include recovered energy-based power generation in calculating their compliance with renewable portfolio standards. In addition, North Dakota, South Dakota and the U.S. Department of Agriculture (through the Rural Utilities Service) have approved recovered energy-based power generation units as renewable energy resources, which qualifies recovered energy-based power generators (whether in those two states or elsewhere in the United States) for federally funded, low interest loans. We believe that the European market has similar potential and we expect to leverage our early success in North America in order to expand into Europe and other markets worldwide. In North America alone, we estimate the potential total market for recovered energy-based generation to be approximately 1,000 MW_e.

21.4 Ormat's Research Activities

21.4.1 Exploration Activity

In addition to the geothermal projects under construction and development, we have various leases for geothermal resources, in which we have started exploration activity. These geothermal resources include the following:

- Grass Valley – Lander County, Nevada
- Jersey Valley – Pershing County, Nevada
- Magic Hot Springs - Blaine & Camas Counties, Idaho
- Fireball Ridge - Churchill County, Nevada
- Gabbs Valley - Nye County, Nevada
- Rock Hills - Esmeralda County, Nevada

Our exploration activity is intended to provide us with an indication and better understanding of the availability of geothermal resources in the areas covered by these leases and will enable us to make a decision regarding their development. We do not expect that our exploration activity will lead to commercial projects in each case.

21.4.2 R&D Activity

Our current collaboration is in the use of geothermal fluids produced in oil and gas wells. We submitted a CRADA with the Rocky Mountain Oil Test Center where we will be supplying an Ormat 200 kW_e geothermal power plant as our shared contribution to a "concept verification program".

Ormat has been working in cost shared research programs with DOE in the area of EGS research, where we are a long time participant in the Program with our collaborative program including Geothermex and others at our Desert Peak facility. With the publication of the Comprehensive MIT Led Study of the Potential of Geothermal Energy In the US, this program is getting the exposure to raise the awareness of the huge contribution that geothermal can make to the US energy supply.

21.5 Ormat's Technology- Background

21.5.1 The Ormat Approach to Power Cycle Design

The Ormat approach to geothermal power cycle design is based on:

- **Sadi Carnot's Teachings-** some of which were overlooked by generations of engineers until the last few decades. Sadi Carnot, in his famous treatise of 1824, in which he actually defined what we call "thermal efficiency" realized that this was by no means the most important consideration; his concluding paragraph is so relevant today that it deserves to be quoted: "the Economy of the Combustible (Carnot's term for thermal efficiency) is only one of the considerations to be fulfilled in heat engines. In many cases, it is only secondary. It should often give precedence to safety, to strength, to the durability of the engine, to the small space which it must occupy, to small cost of installation, *etc.* to balance them properly against each other, in order to attain the best results by the simplest means".

  Carnot was mainly concerned with speculation as to the best possible performance of a heat engine using any working fluid in any possible cycle. He recognized early on several promising directions in the development of practical heat engines which, if given the attention they deserved when published, could have brought about the development much sooner of both vapor cycle engines using fluids other than steam, and of combined cycles.

- **Efficiency of the Heat Cycle-** In most of the low temperature geothermal resources, where the heat source is single phase (sensible heat), the ideal cycle would have a varying source temperature, being a succession of infinitesimal Carnot cycles. A supercritical cycle provides such characteristics. In a sub-critical Rankine cycle the constant temperature of the evaporation leads to a loss of exergy. However, because of the lower latent heat of vaporization this drawback is smaller than in a steam cycle (Figure 21.1).

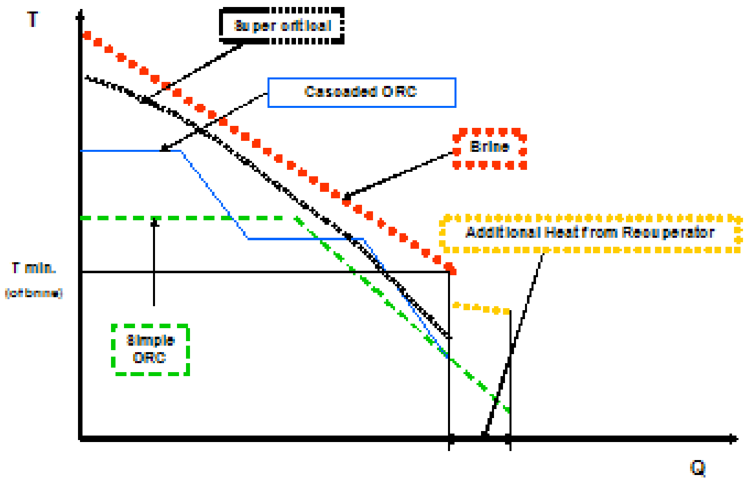


Figure 21.1 Heat cycle.

- **Efficiency and Work Ratio-** The usual definition of thermal efficiency as the ratio between the net work done by the fluid and the total heat input to the cycle can be misleading in assessing the suitability of a given cycle in a heat engine. A concept of paramount importance in evaluating the suitability of a particular cycle for use in a heat engine is that of *work ratio,* which may be defined as the ratio of the net work output of the cycle to the total positive (expansion) work of the cycle.

  If there is very little negative work, as in a typical sub critical vapour cycle where only liquid of small specific volume has to be pumped at moderate pressure back into the boiler, the work ratio will be high. By contrast, this ratio is lower in a super critical cycle where, because of the high pressure, a larger portion of the positive work of the turbine is used to drive the feed pump.

  Taking into account all these practical implications of work ratio, it can be seen that in many ways the concept of work ratio can be regarded as almost more important than the concept of ideal cycle efficiency.

- **Matching and Optimization in the Design of Heat Engines-** The process of design of a geothermal power plant can be considered as one of matching and optimization. We have a source and a sink of heat of certain characteristics and the problem is to match them with the working cycle, match the working cycle with the working fluid, and match the working fluid with the expander. But what matters most is the optimization of the whole system, involving the well-known process of trading-off a loss or gain. To get the overall efficiency of the system it is of course necessary to consider the output net of parasitics, such as cycle pumps, production pumps, injection pumps, cooling systems and non-condensable gas extraction power consumption. These considerations guided us in the choice of fluids away from supercritical cycles in-spite of their higher cycle thermal efficiency.

  In the matching processes, one has to consider the impacts not only on efficiency, but also on the environment, on the long-term pressure support and the geothermal resource availability.

21.5.2 Examples of Ormat Low Temperature Plants

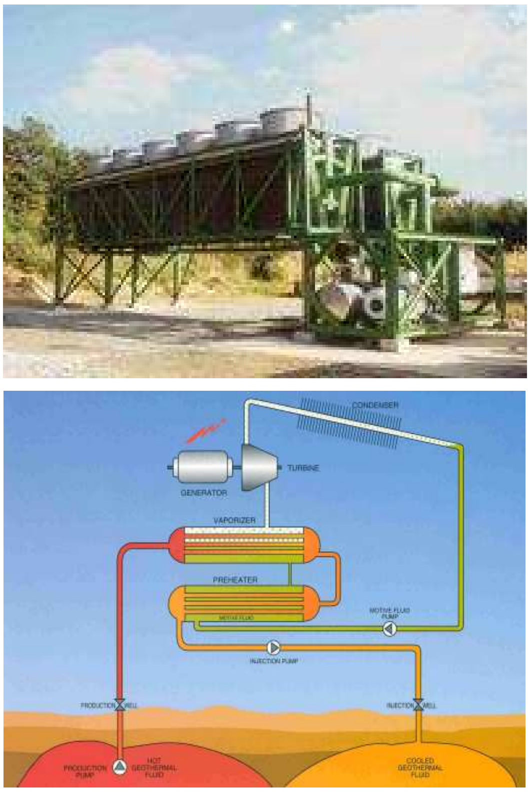
- The first Ormat ORC supplied in 1980 to the University of Alaska for a geothermal application was a small hermetically sealed unit of about 4 kW_e, designed for operation with a hot spring at 45 °C and cooling water at 4 °C.

- The first commercial unit was supplied in 1984 and is still in operation at Wabuska, Nevada. It supplies 700 kW to the grid from a 104 °C resource (Figure 21.2).

Figure 21.2 The Ormat unit at Wabuska, Nevada.

- Other representative small units are: a 300 kW_e in Fang, Thailand (Figure 21.3), a 200 kW_e at the Rogner Hotel in Bad Blumau, Austria (Figures 21.4A & B), supplied respectively in 1984 and 2001, and still in operation from a resource at about 100 °C.

Figure 21.3 Ormat 300 kW_e unit at Fang, Thailand.



Figures 21.4A (top) and **4B** (bottom) 200 kW_e at the Rogner Hotel in Bad Blumau, Austria.

- A similar unit was supplied for a solar pond application where it operated from 1986 to 2002 at temperatures as low as 65°C in El Paso, Texas, USA.

- Larger units to use spent geothermal brine from single or double flash existing power plants:

Figure 21.5 Hatchobaru, Japan providing 2 MW from a 143°C brine.

Figure 21.6 Miravalles V, Costa Rica, providing 18 MW from 166 °C brine.

Figure 21.7 Brady, Hot Springs, USA, providing 6.5 MW from 110 °C brine.

21.5.3 Examples of Ormat Rankine Cycle for Moderate to High Temperature Applications

21.5.3.1 Cascaded ORC

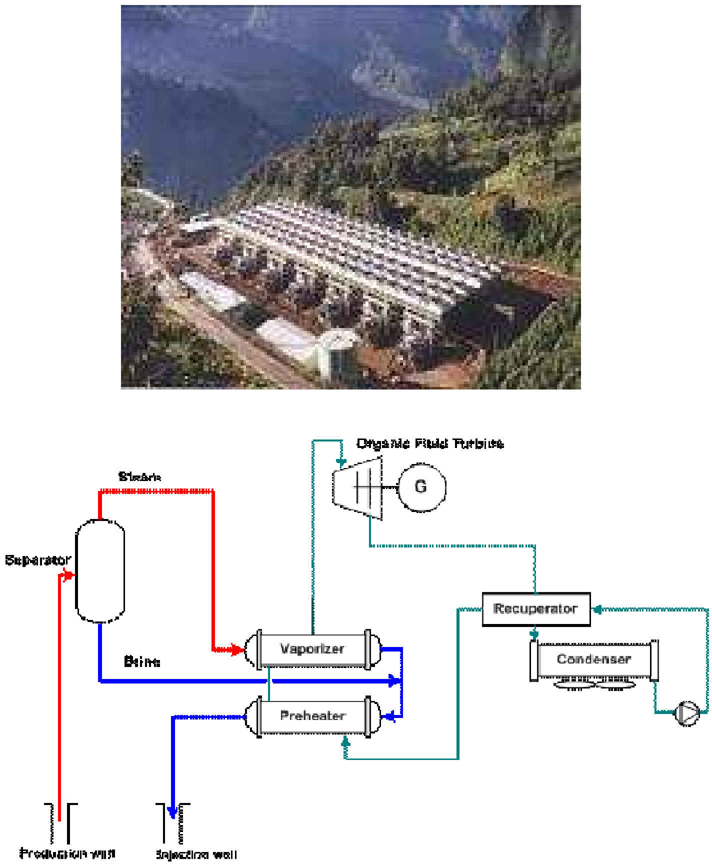
A 30 MW water-cooled Ormesa I geothermal power plant in East Mesa, California, USA is shown in Figure 21.8. It is comprised of 26 1.2 MW_e units arranged in three cascading levels, with a resource temperature of about 150 °C.

Figure 21.8 East Mesa, California, USA.

21.5.3.2 Recuperated Cycle

In most of the actual cases, the perfect match as above is not feasible, mainly because of limitation in the cooling temperature of the brine to avoid scaling. A method for partially overcoming the cooling temperature limit is to add a recuperator which provides some of the preheating heat from the vapor exiting the turbine. This typically increases the efficiency by 10 to 15% (Figure 21.1).

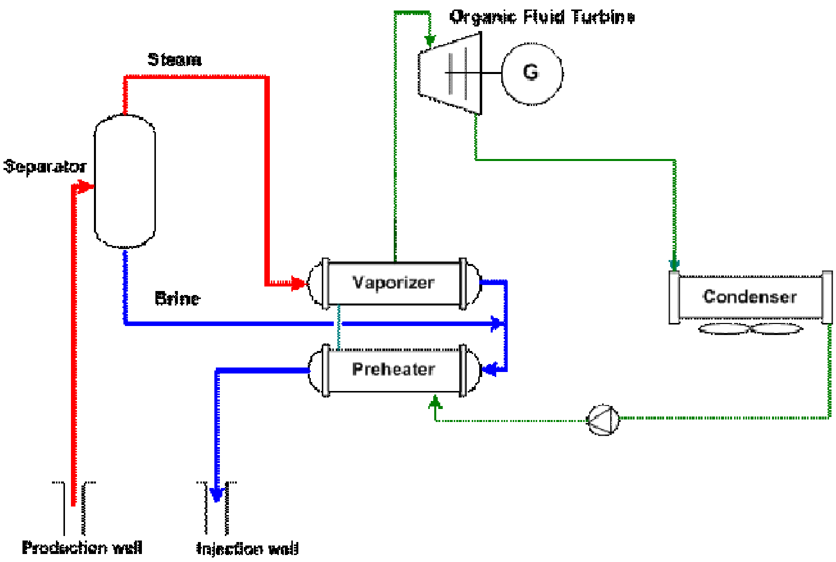
The recuperated process is used by Ormat in many geothermal projects all over the world, such as the 20 MW_e Zunil in Guatemala (Figures 21.9 A & B), 1.8 MW_e Oserian and 13 MW_e Olkaria III in Kenya.



Figures 21.9A (top) and **9B** (bottom) The Ormat recuperated process at Zunil, Guatemala.

21.5.3.3 Two-Phase Geothermal Power Plant

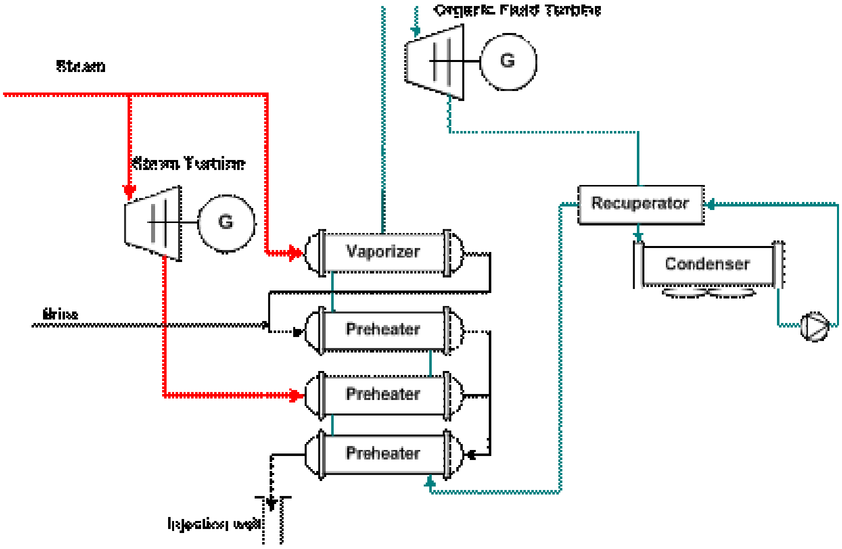
In the majority of geothermal resources, the geothermal fluid comes in two phases which are separated in an above-ground separator into a stream of steam and a stream of brine. In a low to moderate enthalpy resource the steam quality is 10 to 30% as a function of fluid enthalpy and separation pressure. The two streams can very efficiently be utilized in a "Two-Phase ORC Unit". Separated steam (usually with some percentage of non-condensable gases or NCGs) is introduced in the vaporizer to vaporize the organic fluid. The geothermal condensate is mixed with the separated brine to provide the preheating medium of the organic fluid. Since 1994 this process has been utilized in the 14 MW_e plant in San Miguel, Azores (Figure 21.10A & B), with a resource enthalpy of 1,108.5 kJ/kg.



Figures 21.10A (top) **and 10B** (bottom) Two-phase ORC units at San Miguel, Azores.

21.5.3.4 Geothermal Combined Cycle

For high enthalpy fluids with very high steam content a solution is the geothermal combined cycle configuration where the steam flows through the back pressure turbine to the vaporizer, while the separated brine is used for preheating or in a separated ORC. This configuration is used in the 30 MW_e Puna plant in Hawaii (Figures 21.11A & B) as well as in the 125 MW_e Upper Mahiao in the Philippines, the 100 MW_e Mokai and the 27 MW_e Rotokawa (Figure 21.12) both in New Zealand. This last plant is probably the most efficient geothermal plant in the world, using per MWh only 5.2 ton of 24 bar steam.



Figures 21.11A (top) **and 11B** (bottom) Geothermal combined cycle plant at Puna, Hawaii, USA.

Figure 21.12 Geothermal combined cycle plant at Rotokawa, New Zealand.

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Appendix A Members and Observers at the 17th ExCo Meeting, Nice, France, March 2007.

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3rd Row: Chris Bromley, Patrick Ledru, Barry Goldstein, Isao Matsunaga
4th Row: Steve Bauer, Fabrice Boissier, Thomas Mégel
5th Row: John Lund, Elisa Boelman, Rudolf Minder
Back Row: Jeroen Schuppers, Roy Baria, Guðni Axelsson, Philippe Laplaige, Tony Hill, Jörg Baumgärtner, Christian Fouillac, Einar Gunnlaugsson, Helgi Torfason

IEA Geothermal Implementing Agreement Executive Committee (31 December 2006)

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IEA Geothermal Implementing Agreement Executive Committee (continued)

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