International Energy Agency

Geothermal Energy

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International Efforts to Promote Global Sustainable Geothermal Development

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

Cover Photograph: *The 24 MW plant in Amatitlan, Guatemala, which survived without damage the eruption of the volcano in May 2010.* (Photo courtesy of Lucien Bronicki, Ormat Technologies, Inc.)

Message from the Chair

In the difficult 2099 global economic conditions, the Geothermal Implementing Agreement (GIA) has benefitted from the world-wide push for accelerated deployment of renewable energy resources. The United States, for example, has committed almost $400 million in supplementary geothermal research through the ARRA, administered by the Department of Energy. Reduction in greenhouse gas emissions and mitigation of the climate change effects of global warming are drivers. Several IEA-GIA Executive Committee members have also been actively involved as lead authors in preparing a chapter on deployment potential of geothermal energy in a special renewable energy report for the Inter-Governmental Panel on Climate Change (IPCC). The draft IPCC SRREN report is an example of how factual information in these IEA-GIA annual reports forms the basis for important geothermal deployment predictions, and policy and investment decisions.

Membership of the IEA-GIA organization continues to grow. In 2009, we welcomed France to our group as a country member, and Norway has indicated its willingness to join us, with support from the Norwegian drilling and exploration company Statoil, who are currently participating in the Icelandic International Deep Drilling Project (IDDP).

The work of the GIA can be viewed on its web site (www.iea-gia.org), through specially convened workshops, publications and presentations by members at key conferences, and by its contributions to the IEA which publishes information on geothermal technology. In 2009, this included preparation of a geothermal technology brochure, and contribution to the ***IEA Energy Technology Initiatives*** and ***IEA Renewable Energy in Cities*** reports to be published in 2010.

Highlights for the year included the GIA Executive Committee joining forces with the Board of Directors of the International Geothermal Association, in a jointly convened IEA-GIA~IGA workshop on global geothermal deployment potential. This was held in May 2009 and was hosted in Madrid by new member country, Spain, with assistance from new sponsor member the Geothermal Group- Spanish Renewable Energy Association (APPA). Other highlights of the 2009 year were the preparation of several key documents, including the ***IEA Renewable Energy Essentials: Geothermal*** brochure, a special issue of ***Geothermics*** dedicated to sustainable geothermal utilisation, and papers for publication at the 5-yearly World Geothermal Congress at Bali, Indonesia, and other international conferences.

In conclusion, I invite you to read and digest this comprehensive 2009 annual report. As you do, you will notice that about 80% of it is dedicated to national and sponsor reports. This is an indication of the enthusiasm and pride with which IEA-GIA members share with their colleagues geothermal success stories. The future for geothermal is very promising. I look forward to sharing with you more success stories in the years ahead, resulting from educational outreach, awareness campaigns, and reduction in investment barriers, as all aspects of geothermal development rapidly pick up pace around the world.

Chris Bromley
Chairman, IEA-GIA Executive Committee

Executive Summary

Krafla geothermal power station [operated by Landsvirkjun], NE Iceland.
(Photo courtesy of Jonas Ketilsson)

Introduction

2009 was another busy and successful year for the IEA Geothermal Implementing Agreement (GIA). Especially noteworthy was the joint ***IEA-GIA~IGA Workshop on Geothermal Energy- Global Development Potential and Contribution to Mitigation of Climate Change***, held in Madrid, Spain. This was the GIA's first major meeting with another large and influential international geothermal organization (for more information about the International Geothermal Association see IGA). The motivation for holding this joint IEA-GIA~IGA workshop grew out of the recognized need to have more accurate information on the global geothermal development potential and its possible contribution to mitigating climate change, the opportunity to contribute such information to the geothermal chapter of the IPCC special report; and the need and desire for both international organizations to join forces, seek a unified position and speak with a single, powerful voice that would be acknowledged. More than 50 attendees, including 40 official participants, from 17 countries participated. Proceedings will be available in early 2010.

Also significant was the GIA ExCo's decision to make available a portion of the GIA Common Fund to support Annex and other GIA activities through a proposal submission and approval procedure. The 70% growth in GIA membership in the past 4 years and the relatively stable cost for operating the GIA Secretariat have resulted in a sizeable annual carry-over that could be tapped for specific efforts the ExCo deemed worthy. The first successful proposal supports Annex I's sustainability endeavour by providing US$ 5 k over a 2-year period for the Secretary to act as a Guest Editor (with Guðni Axelsson, Leader of Task E Sustainable Utilization Strategies) for a ***Geothermics Special Issue on Sustainable Utilization of***

Geothermal Energy, scheduled for publication in December 2010. This output is based upon the contributions made at an Annex I Sustainability Modelling Workshop held in New Zealand in November 2008.

The GIA's 2009 membership of 19 (25% higher than in 2007) comprised 12 Country and 6 Sponsor (industry/industry organization) Members, and the EC. This broad based membership, from Europe, Asia, the Americas and Oceania, cooperates on a multitude of R&D projects, and shares experience and information in order to overcome technical and other challenges to advance the sustainable development of geothermal energy worldwide and so contribute to the mitigation of climate change.

In 2009, the 12 GIA Member Countries had a combined installed capacity of 6,735 MW_e and generated 38,910 GWh/yr, contributing about 64% of the global geothermal installed capacity and 67% of the geothermal generation. The average national geothermal installed capacity and power generation for GIA Member Countries with non-negligible contributions were about 6.0% and 7.7%, respectively; with a "contribution efficiency" of 5.8 GWh/MW_e, by far the highest of all renewables.

This Summary sets the global scene in which the IEA-GIA operates. A review of the current world energy situation is first provided, then the considerable worldwide geothermal energy potential is discussed and the contribution that geothermal made to the global energy supply in 2009 is described. An overview of the IEA-GIA and a review of the four Annexes' activities and summaries of their accomplishments are presented. Highlights of GIA Members' 2009 activities are provided and the major achievements of the GIA as an organization are described. Finally, the GIA's plans for 2010 and beyond are outlined.

Current World Energy Situation

The global demand for energy has grown nearly every year since 1981, with the 2008 worldwide total primary energy supply reaching 12,267 Mtoe, or about 514 EJ_{th} (142,670 TWh_{th}); a growth of about 2.0% on 2007 (IEA, 2010). The electricity generation amounted to 20,181 TWh (ibid.). Assuming no change in government policies, the IEA's Reference Scenario indicates that by 2030, the energy demand will be 40% higher than in 2007, or about 16.8 billion [10^9] toe (Btoe) (706 EJ_{th}) (IEA, 2009b). Approximately 90% of the increase is expected to be from non-OECD countries, or 63% of the total primary energy demand. The dominant energy supply will remain fossil fuels, making up 77% of the increase from 2007 to 2030; demand for oil will increase by about 24%, for gas 42% and for coal 53% during this period. Though the world's fossil fuel resources will probably be able to meet these needs to 2030, and beyond, this path will likely lead to serious energy security and economic development problems, and catastrophic climate change consequences.

Urgent, tough action is needed to curb the greenhouse gas (GHG) emissions growth and resulting rise in global temperatures predicted in the Reference Scenario: GHG concentration of 1,000 ppm and temperature increase of 6 °C relative to pre-industrial levels, by the end of the century (IEA, 2009b). The IEA has developed two alternative climate-based scenarios to stabilize GHG concentrations at 550 ppm (550 Policy Scenario) and 450 ppm CO2-eq (450 Policy Scenario), resulting in a 50% chance of restricting global temperature increases to about 3 °C and 2 °C, respectively (ibid.). The CO_2 and total GHG emissions in both of these scenarios are significantly less in 2030 than in the Reference Scenario; however, both scenarios require major efficiency gains; CO_2 capture and storage (CCS) deployment; a major decrease in the contribution of fossil fuels, to be replaced by nuclear and renewables; as well as considerable public and private RD&D spending. Awareness of these possible future outcomes is a strong incentive for expanding the use of clean, renewable energy resources. Providing affordable, reliable and clean energy to meet future needs is an enormous challenge, and geothermal energy can make an important contribution.

Geothermal Energy- a Global Perspective

The main sources for geothermal energy are the heat flow from the earth's core and mantle (~40%), and that generated by the gradual decay of radioactive isotopes in the earth's continental crust (~60%). Together, these result in an average terrestrial heat flow rate of 44 TW_{th} (1,400 EJ/yr), nearly 2.7 times the 2008 worldwide total primary energy supply, 514 EJ_{th} (IEA, 2010). Though the world's geothermal heat resources are enormous and ubiquitous, their generally *hidden* nature (subsurface) makes it difficult to accurately determine potentials on a global basis (GIA, 2009). This uncertainty is accentuated because the technologies used to develop geothermal resources are evolving, extending capabilities and reducing costs, and thereby increasing technical and economic potentials. Therefore, there are considerable uncertainties in estimating the global geothermal resource potentials, and revisions are likely as more information and new technologies become available.

The most likely worldwide total technical potential for geothermal resources located along tectonic plate boundaries and near volcanic hot spots has been estimated to be about 6.5 TW_{th} (205 EJ_{th}/yr) (Stefansson, 2005), about 40% of the 2008 worldwide total annual supply. Of this total, hydrothermal resources capable of development for electricity generation using conventional methods ($T > 130$ °C) amount to some 240 GW_e (6.5 EJ_e/yr, or 65 EJ_{th}/yr), assuming a 10% electrical conversion efficiency. The remaining 4.4 TWh_{th} (140 EJ_{th}/yr), comprise lower temperature resources ($T \leq 130$ °C) considered useful mainly for direct heat applications. These estimates may increase by factors of 5-10 if approximations for as yet hidden/unidentified resources are included (ibid.). Power generation potentials are also increasing as a result of technological advances providing conversion efficiencies now ranging up to 20% (for high temperature [> 180-200 °C] fluids).

In addition to hydrothermal resources, several other potentially significant geothermal sources capable of power generation and direct heat use exist: 1) binary generation from the use of the hot water discharged from conventional plants (co-generation) and that available from the lower temperature geothermal resources (75 - 130 °C); 2) the cascaded use of hot water discharged from geothermal power stations for direct heat applications; 3) the massive geothermal energy potential available within drilling depths (3-10 km) in the hot rock of the earth's crust using enhanced geothermal systems technology (EGS); 4) the energy resources in the form of super-critical fluids inferred to exist deep (3-5 km) beneath hydrothermal systems; 5) hot water produced from oil and gas wells; 6) hot water present in deep sedimentary basins; 7) off-shore (under-sea) hydrothermal resources located along the submarine rifts and identified by the presence of hydrothermal vents and 8) the ubiquitous shallow geothermal resources utilized by geothermal heat pumps for heating and cooling and available almost anywhere on the earth's surface.

Of the above non-hydrothermal resources, EGS is the first to have been identified as having an extremely large theoretical potential. Recent estimates indicate that by using EGS techniques, in the USA alone, about 100 GW_e of cost-competitive generating capacity is developable by 2050, given reasonable R&D investment (MIT, 2006). Incorporating preliminary estimates of EGS potential for two geothermal fields in China (Wan et al., 2005); parts of India (Chandrasekhar and Chandrasekharam, 2007), Switzerland, South Australia, and much of Germany, a total of ≥360 GW_e is obtained. A first-order estimate of global EGS theoretical potential of ~2 TW_e was obtained by assuming the EGS capacity of 100 GW_e for the US continental area applied to worldwide continental land masses. Fridleifsson et al. (2008) and discussions at the IEA-GIA~IGA Workshop (GIA, 2010) suggest that ~100 GW_e of EGS could be deployed globally by 2050. Recent discussions also highlight the continued uncertainties associated with estimating geothermal potentials (ibid.).

Geothermal development for electricity generation and direct use have experienced a high growth rate worldwide for the past few years (Figure ES1 and Table ES4) and future prospects look very positive.

Geothermal is a key global renewable energy resource, with many valuable characteristics, including its: extensive global distribution, environmentally friendly character, independence of season, immunity from weather effects, indigenous nature, contribution to development of diversified power, effectiveness for distributed application, sustainable development capabilities and small areal foot-print. Though geothermal predominantly 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, although at lesser efficiency.

Clearly, geothermal resources have the potential to make a considerable contribution towards meeting the world's current and future energy needs well into the future, while contributing to reduced future emissions and to the mitigation of climate change. The global geothermal potential is enormous; however, more detailed studies are needed to produce confident estimates of its possible contribution.

Status of Global Geothermal Energy in 2009

In 2009, 24 countries were producing electricity from geothermal resources, with a total geothermal installed capacity exceeding 10,565 MW_e, based on 2007 data (Bertani, 2007), revised with 2009 GIA Country Member data (Figure ES1, Table ES1). As stated in the 2008 GIA Annual Report, the worldwide geothermal generation has not been comprehensively updated since 2005; however, using 2009 GIA data in conjunction with the 2005 information, a minimum estimate of 58,494 GWh/yr is obtained for 2009. The worldwide geothermal installed capacity and power generation figures will be updated for the World Geothermal Congress 2010. In 2009, the 12 GIA Member Countries contributed about 64% of the global installed geothermal capacity, and 67% of the total geothermal power generated.

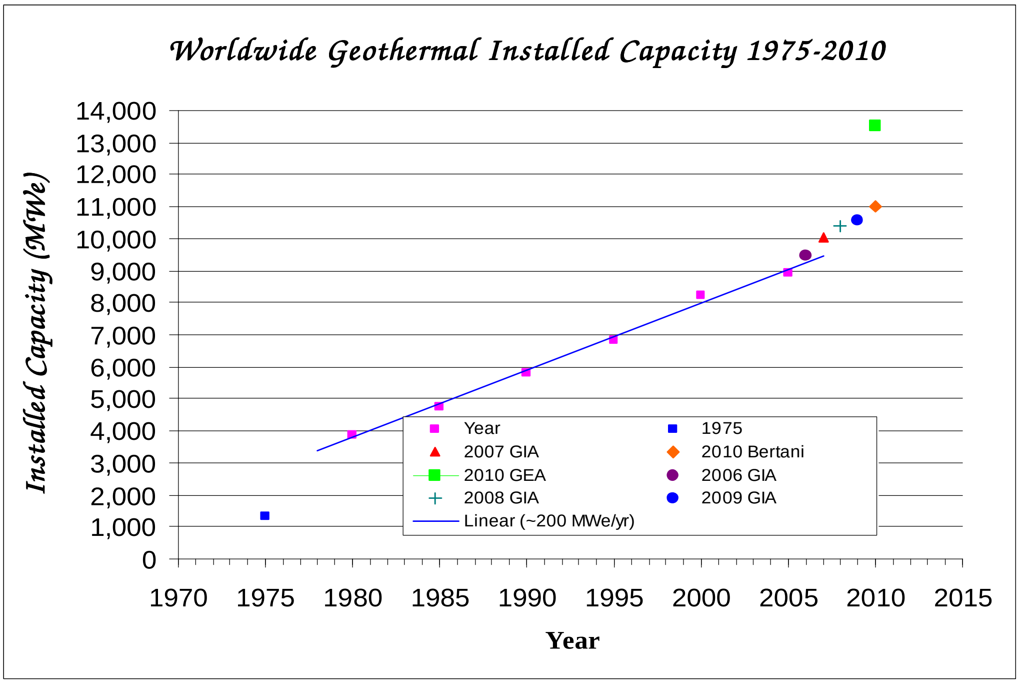

Figure ES1 Worldwide geothermal installed capacity for the period 1975-2010. The 2006 data [star] includes GIA data for 2006 and data for 16 other countries (Bertani, 2005). The 2007 [triangle], 2008 [cross] and 2009 [blue dot] data include 2007, 2008 and 2009 GIA data and data for 15 other countries (Bertani, 2007). The trendline was calculated using data for 1980-2005 and has a slope of 200 MW_e/yr; the 2010 estimates are from Bertani (2007) [diamond] and GEA (2007) [green square].

During the period 1980-2005, the worldwide geothermal installed capacity increased by a factor of about 2.3, at a very uniform rate of ~200 MW_e/yr (Figure ES1). However, since 2005, an increase in geothermal development has become evident, with a linear trend of about 420 MW_e/yr to the end of 2009. The capacity increase in GIA Member Countries was: 2009 (6,735 MW_e) - 2005 (5,449 MW_e) ~ 1,286 MW_e, or about 24% (6%/yr). Table ES1 presents the 2009 data for GIA Member Countries, and 2007 capacity and 2005 generation data for many of the other 15 countries (Bertani, 2007; 2005). Table ES2 illustrates the growth in installed capacity (1995-2009) and generation (1995-2009), with 2006, 2007, 2008 and 2009 representing minimum estimates.

Table ES1 Geothermal power installed capacity and electricity generation for GIA Member Countries in 2009, plus 2007 installed capacity data for 15 other countries (Bertani, 2007) and 2005 generation data for the 15 non-GIA countries (Bertani, 2005).

Country	Installed Capacity (2009) [MW_e]	Annual Electricity Generated (GIA- 2009) (Others- 2005) [GWh/yr]	% of National Capacity	% of National Energy
Australia*	***0.12***	***1.9***	***Negligible***	***Negligible***
Austria	1.1	3.2	Negligible	Negligible
China (Tibet)	28	95.7	30	30
Costa Rica	163	1,145	8.4	15
El Salvador	204	967	14	24
Ethiopia	7	na	1	n/a
France* ***(Guadeloupe Island)*** ***(Soultz-sous-Forêts)***	***15*** ***2.2***	***89*** ***0#***	***~9 (for Island[c])***	***~9 (for Island[c])***
Germany*	***6.6***	***19.0***	***Negligible***	***Negligible***
Guatemala	53	212	1.7	3
Iceland*	***575***	***4,553***	***22.3***	***27.0***
Indonesia	992	6,085	2.2	6.7
Italy*	***842.5***	***5,200***	***1.0***	***1.6***
Japan*	***535.26***	***2,765***	***<0.2***	***<1.1***
Kenya	129	1,088	11.2	19.2
Mexico*	***958***	***6,740***	***1.9***	***2.9***
New Zealand*	***632***	***4,542***	***7.0***	***11.4***
Nicaragua	87	270.7	11.2	9.8
Papua New Guinea (Lihir Island)	56	17	10.9	n/a
Philippines	1,970	9,419	12.7	19.1
Portugal (San Miguel Island)	23	90	25	n/a
Russia	79	85	Negligible	Negligible
Thailand	0.3	1.8	Negligible	Negligible
Turkey	38	105	Negligible	Negligible
USA*	***3,168***	***15,000***	***0.31***	***0.38***
Total	**10,565**	**58,494**	**9.4****	**12.2****
Total GIA Countries	***6,735***	***38,910***	***<6.0*****	***<7.7*****

* GIA Member Country (includes Guadeloupe Island); [c] % from Bertani (2007)
# Not operating in 2009; n/a = not available
** Average values exclude negligible contributions, but include Guadeloupe, Lihir and San Miguel Islands since this is the procedure for World Geothermal Congresses

As shown in Table ES1, geothermal energy provides a major contribution to the national capacity and national generation for several countries. For eight countries (including Lihir and San Miguel Islands), the geothermal installed capacity now exceeds 10% of national capacity, and six of these obtain 15-30% of their electricity from geothermal. In 2009, the average contribution to national installed capacity for GIA Member Countries with *non-negligible* installation/generation was about 6%, with an average contribution to national generation of about 7.7%. The corresponding worldwide values were 9.4% and 12.2%, respectively (Table ES1).

Table ES2 Worldwide installed geothermal capacity (1975-2009) and electricity generation (1995-2009). The generation changes for 2006-2009 only include changes in GIA Member Countries.

Year	1975	1980	1985	1990	1995	2000	2005	2006	2007	2008	2009
Geothermal Installed Generating Capacity (MW_e)	1,300	3,887	4,764	5,832	6,798	7,974	8,930	9,452	10,026[☾]	10,405[☾]	10,565[☾]
Electricity Generation (GWh/yr)	-	-	-	-	37,744	49,261	53,649	55,209[#]	56,782[#]	57,957[#]	58,494[#]

[☾] Includes 2007 installed capacity data for 15 countries from Bertani (2007) with updates for GIA countries for 2007, 2008 and 2009
[#] Generation data is from 2005 (Bertani, 2005) with updates for GIA countries for 2006, 2007, 2008 and 2009

Table ES3 Installed capacity, electricity generation and contribution efficiency for renewable resources in OECD Countries for 2006 (data from IEA (2008c)) and Wind and GIA for 2009.

Resource	**Installed Capacity** (MW_e)	**Generation** (GWh)	**Contribution Efficiency** (GWh/MW_e)
Geothermal			
GIA Members 2009	***6,735***	***38,910****	***5.8****
OECD 2006	5,400	38,100	7.1
Solid Biomass (2006)	22,500	115,900	5.2
Hydro (2006)	344,600	1,286,300	3.7
Wind (2009)**	111,000	207,000	1.9
Tide, Wave, Ocean (2006)	300	550	1.8
Solar PV (2006)	4,100	2,626	0.6

* The new installed capacity for 2009 has not been operational for the whole of the 2009 year; hence, the generation and contribution efficiency are low
** IEA Wind Annual Report (2009)

The total GIA geothermal generation of 38,910 GWh/yr is equivalent to a savings of about 9.8 Mtoe (using GIA conversion (Mongillo, 2005)) and avoided CO_2 emissions of 31.8 Mt. The equivalent savings for the worldwide total generation of 58,494 GWh/yr is about 14.8 Mtoe and avoided CO_2 emissions of some 47.8 Mt (*ibid.*).

A good indicator of the contributions that renewable energy resources make is the ratio of the amount of power they provide to the given installed capacity, here called the *contribution efficiency*. This ratio takes into account the amount of time that the renewable generator actually produces power, i.e. the *availability factor*. For geothermal, this can be divided into resource availability (usually sustained by make-up drilling), plant availability (affected by repairs and maintenance), and transmission or load-following constraints. As shown in Table ES3, the contribution efficiencies for the various renewables in the 30 OECD countries in 2007 were: 7.1 GWh/MW_e for geothermal (5.8 GWh/MW_e for GIA Member Countries in 2009), 5.2 GWh/MW_e for solid biomass, 3.7 GWh/MW_e for hydro, 1.9 GWh/MW_e for wind (data from 2009 IEA Wind Annual Report), 1.8 GWh/MW_e for tide/wave/ocean, and 0.6 GWh/MW_e for solar PV (IEA 2008b). Geothermal's very high availability factor makes it valuable for baseload generation. It should be noted that the *contribution efficiency* for the GIA Countries in 2009 is a minimum value because the new installed capacity was not operating for the entire year.

Significant effort is made to collect and report worldwide geothermal direct use statistics every five years for the World Geothermal Congresses (as for electricity generation), and this will next be done in 2010. Therefore, for 2009, the most current estimates available are based upon data reported by Lund, *et al.* (2005), updated using information for Europe provided by Antics and Sanner (2007) plus data contributed by GIA member countries (this annual report).

In 2005, 72 countries were utilizing geothermal energy for direct heat applications, including: geothermal heat pumps (GHPs); space, greenhouse and aquaculture pond heating; agricultural drying; industrial uses; bathing and swimming; cooling; and snow melting (Lund *et al.*, 2005). The total installed capacity at the end of 2009 was estimated to be about 36,950 MW_{th}, by incorporating 2009 GIA updates with the data of Lund et al. (2005) and Antics and Sanner (2007) (Table ES4). The total thermal energy usage for 2009 was similarly estimated to be about 348,455 TJ/yr (Table ES4). In 2009, the 12 GIA Member Countries had a total installed thermal power capacity of approximately 21,927 MW_{th} and utilized 173,745 TJ/yr (Table ES6). It is estimated that some 2 million GHP units are installed globally. Lack of data precludes reasonable heat pump estimates being made for 2009.

Table ES4 Worldwide direct use categories and their development 1995-2005 (from Lund, et al., 2005), with 2007 updates from Antics and Sanner (2007) and 2007, 2008 and 2009 updates for GIA Country Members.

Category	Capacity (MW_{th})						Utilization (TJ/yr)					
	1995	2000	2005	2007	2008	2009*	1995	2000	2005	2007	2008	2009*
Geothermal heat pumps	1,854	5,275	15,384	19,010	-	-	14,617	23,275	87,503	105,000	-	-
Space heating	2,579	3,263	4,366	-	-	-	38,230	42,926	55,256	-	-	-
Greenhouse heating	1,085	1,246	1,404	-	-	-	15,742	17,864	20,661	-	-	-
Aquaculture pond heating	1,097	605	616	-	-	-	13,493	11,733	10,976	-	-	-
Agricultural drying	67	74	157	-	-	-	1,124	1,038	2,013	-	-	-
Industrial uses	544	474	484	-	-	-	10,120	10,220	10,868	-	-	-
Bathing and swimming	1,085	3,957	5,401	-	-	-	15,742	79,546	83,018	-	-	-
Cooling/snow melting	115	114	371	-	-	-	1,124	1,063	2,032	-	-	-
Others	238	137	86	-	-	-	2,249	3,034	1,045	-	-	-
Total	**8,664**	**15,145**	**28,269**	**35,570**	**36,023**	**>36,950**	**112,441**	**190,699**	**273,372**	**329,270**	**329,880**	**>348,455**
Total GIA Countries	**-**	**-**	**-**	***20,547***	**21,000**	**>21,927**	**-**	**-**	**-**	***154,560***	***155,170***	**>173,745**

* Estimates indicating "greater than" result from lack of 2009 data from some GIA Country Members.

Worldwide direct use installed capacity has nearly doubled every 5 years between 1995 and 2005, and this high growth trend continued through 2007 (Table ES4). The estimated 2007 direct energy use increased by about 20% since 2005. However, as shown in Table ES4, both installed capacity and utilization appear to have increased only slightly (4% and 6%, respectively) between 2007 and 2009. The total use of about 348,455 TJ/yr is equivalent to an annual savings of about 12.3 Mtoe in fuel oil and 39.6 Mt in avoided CO_2 emissions (GIA conversions, Mongillo (2005)).

The IEA-GIA- an Overview

The IEA-GIA, founded in 1997, was in the 3rd year of its 3rd 5-year term (2007-2012) of operation at the end of 2009. The GIA provides a flexible framework for wide-ranging international cooperation in geothermal R&D by bringing together national and industry programmes for exploration, development and utilization of geothermal resources, with a focus on enhancing effectiveness through establishing direct cooperative links among geothermal experts in the participating countries and industries. The GIA's general scope of activity consists of international scientific collaborative efforts to: compile and exchange improved information on worldwide geothermal energy R&D concerning existing and potential technologies and practices, develop improved technologies for geothermal energy utilization, and improve the understanding of the environmental benefits of geothermal energy and ways to avoid or minimize its environmental impacts. GIA collaboration provides researchers with opportunities for information exchange via meetings, workshops and networking. Members can also participate in R&D projects and develop databases, models and handbooks. Policy and decision makers can obtain an international perspective on geothermal issues, opportunities and environmentally-appropriate development strategies. New studies and activities are implemented when needs are established.

The GIA's 3rd Term Mission is:

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

To accomplish this Mission, six Strategic Objectives target GIA's activities:

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

Activities, called Tasks, are defined and organized in broad topics termed Annexes. Participants must take part in at least one Annex. Annex titles, status, leadership and participation are provided in Table 1.2, Chapter 1. An Executive Committee (ExCo) supervises the GIA and its decisions are binding on all Members. The ExCo consists of one voting Member from each Member Country and Sponsor (industry/industry organization).

Since the GIA's commencement, the Annexes have operated under the task-sharing finance mode, whereby participants allocate specified resources and personnel to conduct their portion of the work at their own expense. Total Annex work performed under the auspices of the GIA has been estimated to be well over US$ 310,000/yr, plus several man-years (GIA, 2006a).

In March 2003, the ExCo established a GIA Secretariat to provide it with administrative and other assistance. The Secretariat is funded through cost-sharing, with all GIA Members contributing to a Common Fund according to a "share" allocation defined by the ExCo.

At the end of 2009, there were 19 IEA-GIA Members: the European Commission; 12 countries: Australia, France, Germany, Iceland, Italy, Japan, Mexico, New Zealand, the Republic of Korea, Spain, Switzerland and the United States; 4 industry Sponsors: Geodynamics, GreenRock Energy, ORMAT Technologies and ORME Jeotermal; and 2 organization Sponsors: the Canadian Geothermal Energy Association (CanGEA) and the Geothermal Group of the Spanish Renewable Energy Association (GG-APPA).

Collaborative Activities

The Annexes

In 2009, GIA participants worked on four broad research topics, specified in the following Annexes:

- Annex I- Environmental Impacts of Geothermal Energy Development
- Annex III- Enhanced Geothermal Systems
- Annex VII- Advanced Geothermal Drilling Techniques
- Annex VIII- Direct Use of Geothermal Energy
- Annex X- Data for Geothermal Applications (new)

Annexes I and III have been operating since the original implementing agreement was initiated in 1997, and have continued programmes into the current term. In October 2009, Annexes I, III and VII were extended by the ExCo for a further 4 years, to 2013. Annex VIII, which officially started in 2003, completed its first term of operation in 2007, and was unanimously continued by the ExCo for another 4 years to 2011. Annex X is a new Annex initiated in October 2009. Four other Annexes have been drafted since the start of the organization, with II- Shallow Geothermal Resources and IX- Geothermal Market Acceleration subsequently closed. The possibility remains for draft Annexes V- Sustainability of Geothermal Energy Utilization and VI- Geothermal Power Generation Cycles to be initiated if sufficient interest arises. The status of the Annexes is presented in Table 1.2, Chapter 1 of this report.

A brief discussion of some of the GIA's activities and major highlights for the Annexes active in 2009 is presented below. Details are available in Chapter 1 and in the Annex Reports included in Chapters 2-5 below.

IEA-GIA ExCo and Annex Meetings in 2009

In 2009, the IEA-GIA ExCo held its 21st ExCo Meeting in Madrid, Spain and its and 22nd in Reno, USA. Attendance remained at its usually high level, with ~30 participants at each meeting. Brief reviews of these meetings are presented in Chapter 1.

The four GIA Annexes held technical meetings in association with the 22nd ExCo Meeting held in Reno, USA, in October 2009. The GIA's 2-day joint IEA-GIA~IGA Workshop held in May 2009 in conjunction with the Madrid, Spain, ExCo meeting precluded the holding of associated Annex meetings. The Annex meetings are typically ~2 hours long and provide the opportunity for detailed discussions and assessments of current and planned activities. Important issues related to annex activities that have arisen during the year, e.g. induced seismicity, sustainability, etc. are also examined. Annex reports describing the status of activities, achievements, challenges, etc. are also presented at both of the annual ExCo meetings.

Joint IEA-GIA~IGA Workshop on Global Geothermal Potential and Climate Change

The workshop ***Geothermal Energy- Its Global Development Potential and Contribution to Mitigation of Climate Change***, held in Madrid, Spain, on 5-6 May 2009, was organized jointly by the IEA-GIA and the International Geothermal Association (IGA), and hosted by IEA-GIA Members: The Institute for

Diversification and Saving Energy (IDAE), Spain, with assistance from the Geothermal Group of the Spanish Renewable Energy Association (GG-APPA). The motivation for holding this workshop was the recognized need to have more accurate information on the global geothermal development potential and its possible contribution to mitigating climate change, the opportunity to provide such information to the geothermal chapter of the IPCC special report; and the desire for both major international organizations to work together to contribute. This effort proved very worthwhile, allowing over 50 participants from 17 countries to meet, debate and provide information and data that led to valuable insight into how geothermal might contribute to future energy needs and impact on CO_2 emissions. Results will certainly be used in the preparation of the geothermal chapter of the IPCC Special Report on renewable energy and its contribution to the mitigation of climate change. Presentations are available on the IEA-GIA website (Presentations) and proceedings will be produced and published on both the GIA and IGA websites.

Geothermal Resources Council (GRC) Annual Meeting 2009, Reno, USA

The GIA participated at the 33rd Annual Meeting of the GRC (theme: Geothermal 2009: "Making Renewable Energy Hot!") in Reno, Nevada, USA, in conjunction with the 22nd ExCo Meeting. The GRC Meetings are significant annual international geothermal events, and GIA paper: ***IEA-GIA International Geothermal Cooperation: Going from Strength to Strength*** (Mongillo, Bromley and Rybach, 2009 [pdf, 83 kB]) was presented by GIA-Chair, Chris Bromley. A brief review of the IEA, and the GIA and its activities, achievements, future directions and prospects were presented in light of the current global energy situation.

Launch of GIA Proposal Initiative

At the 21st ExCo Meeting, the GIA ExCo unanimously approved a proposal by Chair Chris Bromley that a mechanism for providing funding for approved supplementary activities related to ExCo initiatives or Annex Task activities carried out by IEA-GIA participants be provided from the IEA-GIA Common Fund. The objective of this proposal is to stimulate more joint activity by participants, and create more tangible products to help fulfil the geothermal educational, outreach, and research objectives of the IEA-GIA, particularly those activities that would otherwise be stifled by lack of funding from any other source. Procedures for determining the budget available each year, describing proposal format and assessment, and typical level of proposal funding were described. The ExCo also unanimously agreed to fund the first proposal submitted in this initiative (see below).

Two Successful GIA Proposals in 2009

- ***Geothermics*** **Special Issue on Sustainable Utilization of Geothermal Energy**
- **IEA Energy Technology Roadmap "Geothermal Energy"**

The first successful proposal (see above) submitted for ExCo approval provided US$ 5 k over a 2-year period for the GIA Secretary to act as a Guest Editor, with Guðni Axelsson (Leader of Task E Sustainable Utilization Strategies), for a ***Geothermics*** **Special Issue on Sustainable Utilization of Geothermal Energy**, scheduled for publication in December 2010. This effort will complete a significant public output from the 2008 Annex I Task E international Sustainability Modelling Workshop held in Taupo, New Zealand, in association with the 50th Anniversary of the Wairakei Geothermal Power Station.

The second successful proposal in 2009 was for a contribution of US$ 10 k towards the creation of an IEA Geothermal Roadmap, if the IEA Energy Technology division agrees to produce it. Unfunded time from GIA participants to assist with the formulation of the Roadmap would also be required. The IEA initiated the Geothermal Roadmap process in early 2010.

Preparations for the World Geothermal Congress 2010, Bali, Indonesia

The World Geothermal Congress, held every 5 years, is the premiere international geothermal event, and the next one will be on 25-30 April 2010, in Bali, Indonesia. Well over 1,000 official participants present papers, posters, sponsor exhibition booths, hold seminars, etc. The GIA will have significant involvement, with several papers accepted for presentation from the Annexes plus a general one which has been chosen as a keynote address (***IEA Geothermal Implementing Agreement- International Efforts to Promote Global Sustainable Geothermal Development and Help Mitigate Climate Change*** by Mongillo, Bromley and Rybach (2010)). The GIA will also have an exhibition booth, at which general GIA activities and those of the Annexes, and Country and Sponsor Members will be presented by posters and handout documents and reports. A range of IEA material will also be displayed and distributed.

GIA Participation in IEA Activities

In 2009, the GIA continued its active participation in IEA workshops and meetings, and by providing information and comments on IEA reports.

The GIA provided information and comments on the geothermal content of the ***IEA Cities, Towns & Renewable Energy- Yes in My Front Yard*** book, and also contributed material for the GIA portion of the ***IEA Energy Technology Initiatives*** book (2010). In addition, a draft version of the ***IEA Renewable Energy Essentials: Geothermal*** brochure was completed.

Use of Geothermal Energy and the Environment (Annex I)

Energy utilization may cause a variety of environmental impacts which can be of concern on the global scale. Though geothermal is a relatively benign renewable energy source, with important advantages over fossil fuels, e.g. significantly less carbon emissions, there are some environmental effects associated with its use that require attention. Annex I- Environmental Impacts of Geothermal Energy Development encourages the sustainable development of geothermal resources in an economic and environmentally responsible manner, while identifying and quantifying possible adverse and beneficial environmental impacts, and determining ways to avoid, remedy or minimize the adverse ones, while encouraging the beneficial.

The sustainable utilization of geothermal resources is globally an important goal. Case histories and modelling of long term reservoir behaviour are being undertaken to identify optimum future development strategies. Results on improved environmental sustainability strategies and monitoring methods were presented at several international meetings, including the 2009 New Zealand Geothermal Workshop, the 2009 Stanford Geothermal Reservoir Workshop and the 2009 GRC Annual Meeting. Major interest in sustainability issues led to the commencement of a special issue of ***Geothermics*** journal on this topic.

Annex I participants are taking part in the preparation of a geothermal chapter for the IPCC renewable energy report for the mitigation of climate change.

Annex I participants also took part in discussions at the joint IEA-GIA~IGA "Geothermal Energy- Its Global Development Potential and Contribution to the Mitigation of Climate Change Workshop held in Madrid, Spain, in May 2009.

Accessing Geothermal Resources Using Enhancement Techniques (Annex III)

Huge heat resources consisting of high temperature, water-poor rock are available within current drilling depths (>3 km) almost anywhere on earth. To utilize the enormous amount of geothermal energy in this hot rock, Annex III- Enhanced Geothermal Systems (EGS) is investigating the development of new and improved technologies to artificially stimulate these resources (e.g. hydraulically fracture the rock) to enable commercial heat extraction for electricity production and, in some cases, co-generation of heat for direct use applications. These techniques can also be used to help sustain and enhance energy production at existing conventional hydrothermal developments through increasing permeability and via reinjection. The successful development of EGS is presently one of the major challenges facing the international geothermal community.

Revision and restructuring continued in several of the Annex's activities, including those related to economic modelling; data acquisition and processing; and reservoir evaluation and field studies. The current lack of developing and operating EGS projects around the world has slowed the efforts of this Annex. However, increased EGS effort in the USA, Australia and Germany should begin to provide data in the near future. The adverse publicity arising from the issue of induced seismicity has also slowed progress. Good news is that the EGS plant at Soultz-sous-Forêts, France, is expected to begin operation once the feed-in tariff value is confirmed.

Reducing Geothermal Drilling Costs (Annex VII)

One of the most expensive and essential parts of geothermal exploration, development and utilization is the drilling of wells; with subsequent logging and completion also expensive. Reducing well drilling, logging and completion costs can bring major benefits, since these can amount to up to about 50% of the capital cost of a geothermal power project. Annex VII- Advanced Geothermal Drilling and Logging Technology, is working to identify, develop and promote ways to reduce the costs of drilling, logging and completing geothermal wells.

Collection of information for the geothermal well drilling cost and performance database continues and development of a well cost calculator based on this information is expected in the near future. An update on geothermal well costs was presented at the GRC 2009 Annual Meeting and a paper describing the Annex's activities has been accepted for presentation at the World Geothermal Congress in 2010.

Preparation of a "best practices" handbook for geothermal drilling is proceeding and plans are to complete a full draft of the handbook in 2010.

Direct Use of Geothermal Heat (Annex VIII)

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

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

Annex VIII held a meeting, in association with the 22nd ExCo Meeting, Reno, USA, in October 2009. Significant new information has been obtained and compiled from a revised questionnaire on barriers and opportunities for direct use and analysis has begun. Efforts continue in the development of a method to present direct use data on the web using Goggle Earth.

A resource characterization paper presented at the RE2008 Busan, Korea, will be published in ***Current Applied Physics***, and several papers were prepared and accepted for presentation at the WGC 2010.

National Activities

The geothermal programmes of the GIA Country Members provide the basis for the cooperative IEA geothermal activities. These programmes focus on the exploration, development and utilization of geothermal resources. A comprehensive description of the current status of geothermal activities for each of the participating countries and the EC is provided in the 2008 GIA Annual Report (Chapters 6-18).

In 2009, Contracting Parties from 12 countries and the European Commission (EC) participated in the IEA-GIA. The Member Countries were: Australia, France, Germany, Iceland, Italy, Japan, Mexico, New Zealand, the Republic of Korea, Spain, Switzerland and the United States.

Contributions of GIA Members to Power Generation and Direct Use

In 2009, the 12 GIA Member Countries with geothermal generation had an installed capacity of about 6,735 MW_e, or about 64% of the total global geothermal capacity of 10,565 MW_e; and generated 38,910 GWh/yr, or about 67% of the total geothermal generation of 58,494 GWh/yr (Tables ES1 and ES5). The United States was by far the largest producer, generating about 15,000 GWh/yr, with Mexico second with 6,740 GWh/yr and Italy third with 5,200 GWh/yr. The percent of national installed capacity provided by geothermal in the 7 IEA-GIA Member Countries with non-negligible power development ranged from <0.2% for Japan to 22.3% for Iceland, with an average of about 6.0%. The contribution of geothermal to national generation in Member Countries ranged from 0.38% for the USA to 27.0% for Iceland, with an average of 7.7%.

Table ES5 Total geothermal installed capacity, electricity generation and direct use in GIA Member Countries in 2009.

Country	Electrical Installed Capacity (MW)	Annual Energy Generated (GWh/yr)	% of National Capacity	% of National Energy	Installed Thermal Power (MW_{th})	Annual Energy Used (TJ/yr)
GIA Member Countries	6,735	38,910	<6.0*	7.7*	>21,927	>173,745
Worldwide Total**	10,565	58,494	9.4	12.2	>36,950	>348,455
GIA % of Worldwide Total	64	67	-	-	59	50

* Average % of 7 GIA Member Countries with non-negliglble generation, including Guadeloupe Island (France).

** For sources of worldwide total data see Tables ES 1 and ES4 above.

All 12 GIA Member Countries utilized geothermal in direct applications in 2009, with a total installed capacity of >21,927 MW_{th} and total thermal energy used >173,745 TJ/yr (Table ES6). In a few cases, the data presented are from 2005 (Lund, *et al.*, 2005) or Antics and Sanner (2007), or has been estimated based on indicative rates of growth. The three largest users of geothermal heat by far were the USA (56,552 TJ/yr), Japan (25,698 TJ/yr), and Iceland (25,400 TJ/yr). However, the non-high enthalpy geothermal countries, France (12,929 TJ/yr), Germany (17,890 TJ/yr) and Switzerland (7,744 TJ/yr) also had very high utilization, mainly due to the large and growing geothermal heat pump usage.

Sponsor Activities

At the end of 2009, the GIA had 6 Sponsor Members, 4 from industry: Geodynamics Limited and Green Rock Energy Limited, from Australia; Ormat Technologies, Inc. from the USA and ORME Jeotermal from Turkey; and 2 industry organizations: the Canadian Geothermal Energy Association (CanGEA) and the Geothermal Group of the Spanish Renewable Energy Association (GG-APPA).

Table ES6 Geothermal direct use in GIA Member Countries in 2009.

Country	Installed Thermal Power (MW_{th})	Annual Energy Used (TJ/yr)
Australia	132	3,746
France	1,345	12,929
Germany	> 2,000	17,890
Iceland	1,607	25,400
Italy	[650]	10,000
Japan	1,686	25,698
Mexico	156	(1,932)
New Zealand	364	10,000
Republic of Korea	229	1,854
Spain	90	na
Switzerland	1,057	7,744
USA	12,611	56,552
Total for GIA[1]	**> 21,927**	**> 173,745**

[1] Total excludes the EC; ( ) = from Lund, *et al.* (2005); na = not available
[ ] = from Antics and Sanner (2007)

Industry Sponsors

Geodynamics Limited

Geodynamics is Australia's most advanced geothermal energy developer and specifically focuses on the economic extraction of heat from hot rocks using enhanced geothermal systems (EGS) technology. In particular, its efforts are concentrating on drilling to depths of 3.6-4.0 km below surface into hot (T ~ 280 °C at 5 km) fractured granite in the Cooper and Eromanga Basins in South Australia.

Well Savina 1 was drilled into an overpressured fracture in granite at a depth of 3,700 m. Tests showed that this was similar to the overpressure at the Habanero field 19 km east. Unfortunately, the overpressure resulted in the drill string becoming stuck and the well had to be plugged.

Another setback occurred when Habanero 3 production well failed, probably due to hydrogen embrittlement of the very shallow part of the casing, and had to be cemented. This resulted in activities on the pilot plant being deferred and a delay of further activities at Jolokia and Savina sites.

However, several important successes were had in 2009. In March 2009, Geodynamics announced that "proof-of-concept" had been attained after demonstrating its ability to extract heat from hydraulically stimulated hot fractured rock to generate power. This major achievement marked the completion of Stage 1 of the Company's business plan. In addition, the Innamincka 1 MW Pilot Plant was completed as was the power line between it and Innamincka.

Geodynamics also received further significant funding with a A$ 90 M from the Australian Government's Renewable Energy Demonstration Program which provides 30% of the funds needed for drilling 6 wells, a 25 MW power plant and its connection to the wells. Another A$ 17 M in grants were received for development of Geodynamics' Hunter Valley geothermal project in New South Wales, which provides for drilling of 2 wells and construction of a power station.

Green Rock Energy Limited

Green Rock Energy Limited is a public company listed on the Australian Securities Exchange whose focus is on developing geothermal energy in Australia and abroad.

Over the near term Green Rock plans to develop two commercial demonstration geothermal projects in sedimentary aquifers, a direct use one in Australia and a combined electricity-direct use one Hungary. The chief challenges for both types of geothermal resources proving sufficient reservoir permeability to deliver commercial energy at the surface for 20 years.

Green Rock has the first geothermal exploration permit in Western Australia, and the Company's first project is a commercial demonstration designed to utilize 80-100 °C water from sedimentary aquifers at 2,500-3,000 m depth, to air condition the University of Western Australia in Perth using geothermal powered absorption chillers. Success will lead to the larger scale deployment throughout metropolitan Perth.

In Hungary, Central European Geothermal Energy (CEGE), a joint venture of Green Rock and MOL, plan to test the production of geothermal water (T ~ 140 °C) from an existing petroleum well for electricity and direct use. Success could lead to Hungary's first commercial geothermal power generation. Green Rock also has a project that aims to generate electricity from geothermal water obtained from hot sediments in the north Perth Basin and an EGS project located at the site of a major market, the Olympic Dam mine, where successful mini-hydro fracture stimulation has been demonstrated, and further work awaits funding via a "farm-in", before beginning deep drilling, stimulation and flow testing for prove-of-concept.

Ormat Technologies, Inc.

Ormat Technologies, Inc., based in the USA, is a leading vertically integrated company engaged in the geothermal and recovered energy (i.e. from "waste heat") power business. Ormat has over 40 years experience with ORC and 25 years of its applications to geothermal development. Ormat explores, develops, designs, builds, owns and operates clean, environmentally friendly geothermal and recovered energy-based power plants. In addition, the company also designs, manufactures and sells power units and other power generating equipment for geothermal and recovered energy (RE) based electricity generation for third parties.

Ormat owns and operates 538 MW_e of geothermal and RE generation in the USA, Nicaragua, Kenya and Guatemala, including 367 MW_e of geothermal in the USA, and has deployed about 70% of all geothermal capacity in the US since 2000. In 2008 and 2009, Ormat added about 240 MW_e of gross geothermal capacity worldwide, with 120-130 MW_e under construction and 138 MW_e in various stages of development. Ormat has over 1,000 employees. It also has its own in-house drilling company, GeoDrill, with four rigs (capacity ~ 5,500 m) and over 100 staff.

Ormat is involved in the largest effort undertaken by a single company in the past 20 years, to categorize, map, sample and drill US greenfield prospects. Also, a joint project with the US DoE has validated the feasibility of using its proven ORC technology to commercially generate electricity using hot water produced during oil and gas field production, the first project of its type to provide on-site fuel-free power. Ormat is also involved in EGS projects at Desert Peak and Brady in the USA, and provided a 3.2 MW_e ORC power plant at Landau, Germany, which has been operating for over a year.

In 2009, Ormat's revenues were US$ 415 M, an increase of 20% over 2008.

ORME Jeotermal, Inc.

ORME Jeotermal, a geothermal engineering, industry and trade company based in Turkey, became an industry Sponsor Member in July 2008. ORME was founded in 1984 and became a joint-stock company in 1987.

ORME's scope of work includes: geothermal field studies; drilling, well testing, reservoir determination; feasibility, design and engineering; geothermal electricity production; district heating, greenhouse heating, and cooling systems; complete design of thermal tourist facilities; installation of geothermal district heating systems; and finance, investment and management of geothermal projects.

ORME's participation in GIA activities is currently under review.

Organization Sponsors

Canadian Geothermal Energy Association (CanGEA)

The Canadian Geothermal Energy Association (CanGEA) became an organization Sponsor Member of the GIA in October 2008. CanGEA is a non-profit association that promotes the development and use of sustainable geothermal energy in Canada. Their focus is on moderate to high temperature resources (> 70 °C) for power generation.

CanGEA had 27 members at the end of 2009, including geothermal developers, equipment manufacturers and utilities, and firms specializing in consulting, engineering, construction, financial and legal aspects of geothermal energy. The Canadian and international CanGEA members are currently involved in 76 projects worldwide, with 1,470 MW_e under development and ~2,000 MW_e of operating power plants.

CanGEA was proactive in instituting the Geothermal Code for Public Reporting to enhance investor confidence and provide requirements for reporting exploration results, and geothermal resources and reserves.

Geothermal Group- Spanish Renewable Energy Association (GG-APPA)

The Geothermal Group of the Spanish Renewable Energy Association (GG-APPA represents its geothermal members' interests in politics, civil society and the media and participates in the development of Spanish energy and environmental policy. GG-APPA currently has a high enthalpy geothermal department with 11 company members and a low enthalpy one with 18 members.

Though there are significant geothermal resources in Spain, they presently have low penetration in the energy balance. Studies show several favourable areas with potential for high temperature volcanic convective hydrothermal, conductive sedimentary and EGS systems for electricity generation. A significant number of medium/low temperature resources have also been identified across Spain and will be useful for direct heat applications, including district heating (Barcelona and Madrid); and geothermal heat pumps are applicable everywhere.

Work continues in 2009 to complete the new 2011-2020 Spanish Renewable Energy Plan (PER) and the new National Renewable Energy Action Plan (PANER), the latter required by the EU for each of its members. GG-APPA is working to influence the Government to include geothermal objectives in both, which are to be published in 2010. The APPA Low Enthalpy Geothermal Department bases its efforts on analyses of the problems hindering development of low enthalpy use, including: barriers to exploiting resources; and economic, technical and regulatory barriers. The APPA High Enthalpy Geothermal Department has appointed two companies to study the status of geothermal resources in Spain and investigate support mechanisms to stimulate the Spanish geothermal industry in order to make considerable contribution to Spain's climate goals by 2020; the report is to be published in 2010.

In addition, the Spanish Geothermal Technology Platform (GEOPLAT), which aims to identify and develop sustainable strategies for the promotion and marketing of geothermal energy in Spain, was officially launched in May 2009.

Plans for 2010 and Beyond

The end of 2009 sees the GIA nearly half-way through its 3rd Term, having made good progress towards meeting its Mission and Strategic Objectives. The GIA has held ExCo meetings in Spain and the USA; held a joint GIA-IGA international workshop on global geothermal potential and contribution to the mitigation of climate change in Madrid, Spain; participated at the international 2009 GRC Annual Meeting conference in the USA; prepared several papers describing its activities and outputs for the World Geothermal Congress 2010; provided up-to-date geothermal information to several IEA publications; instituted a funding programme for assisting GIA activities; and initiated the publication of a special issue of the international geothermal journal ***Geothermics*** on the topic of sustainable geothermal use.

The GIA anticipates continued growth in its efforts and its membership in 2010, and onwards. The GIA has committed to participate at the important World Geothermal Congress in 2010 by submitting several papers and sponsoring an exhibition booth. The Proceedings of the joint international GIA-IGA (International Geothermal Association) Workshop mentioned above will be published; and significant effort will be made to complete a Special Issue of ***Geothermics*** on Sustainable Geothermal Utilization in December 2010. The GIA will continue its strong support of the IEA by providing current geothermal data/information, contributing to their publications, including providing an article for the IEA OPEN Bulletin (distribution of >12,000 subscribers) and completion of the ***IEA Technology Essentials: Geothermal*** brochure. Assuming the strong financial position of the GIA continues, the substantial balance of the Common Fund will allow continued funding of successful proposals to support special GIA efforts and Annex related activities to increase/enhance the organization's outputs and its international status. In addition, the GIA will continue to pursue new membership in order to extend its base and expand its expertise.

The global financial and economic crisis that began at the end of 2008 is still a concern to the geothermal community, though there is some optimism buoyed by a continuing growth in global geothermal development that became evident in 2007. US President Obama's commitment to the development of renewable energy is also still providing a very positive influence in the geothermal sphere. Geothermal energy can make a considerable contribution to providing sustainable renewable energy for future global energy needs, and the GIA sees its activities continuing and growing to make this a reality.

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Chapter 1

The Implementing Agreement

Galena II of 20 MW_e, last addition (2008) to the Steamboat (Nevada, USA) Complex of 84 MW_e which supplies the electricity consumption of all households in Reno, Nevada.
(Photo courtesy of Ormat Technologies, Inc, USA)

1.0 The IEA Geothermal Research and Technology Programme

IEA involvement in geothermal energy began in 1978 with the initiation of two 3-year long studies that were completed in 1981. Following a 16-year hiatus, 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. Currently, the GIA is in its 3rd 5-year term of operation, which continues to 28 February 2013.

The GIA provides a versatile framework for extensive international cooperation in geothermal research, development and deployment by bringing together national and industry programmes for exploration, development and utilization of geothermal resources. It focuses on increasing effectiveness through establishing direct cooperative links among geothermal experts in the participating countries, industries and organizations.

The GIA's general scope of activities, defined in Article 1 of its Implementing Agreement, provides 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 minimize its environmental impacts.

The GIA's present efforts assist with coordination of ongoing national programmes, with contributions from industry (Sponsor) and organization members. Activities include a range of geothermal topics from "conventional" power generation and direct use of heat, to cutting-edge technologies pertinent to enhanced geothermal systems (EGS), advanced geothermal drilling techniques, sustainable utilization strategies and presentation of data via the Web. New studies are also encouraged and implemented when the needs are established.

As of December 2009, the IEA-GIA had 19 Members: 12 Contracting Parties from 11 countries: Australia, France, Germany, Iceland, Italy, Japan, Mexico, New Zealand, the Republic of Korea, Spain, Switzerland, the United States, and the European Commission (EC); and six industry Sponsor Members: the Canadian Geothermal Energy Association, Geodynamics, the Geothermal Group- Spanish Renewable Energy Association, Green Rock Energy Limited, ORMAT Technologies Inc. and ORME Jeotermal. See Table 1.1 for details.

1.1 Strategy and Objectives

Geothermal energy has vast global potential and its development can contribute significantly towards meeting the growing global renewable energy demand in both developed and developing countries. Globally, geothermal development is in a rapid growth phase, and to maintain this accelerated development, it is essential to improve and develop new technologies, promote the benefits of sustainable geothermal utilization, and better educate the public, financial, and policy sectors.

The GIA's 3rd 5-year term began in April 2007 with these goals firmly in mind, aiming to use its extensive international cooperation to focus particularly on disseminating information, improving environmental outcomes, enhancing EGS prospects, reducing drilling costs, promoting direct use applications, and encouraging long-term sustainable development strategies that will also contribute to the mitigation of climate change. To these ends, the IEA-GIA set its ***3rd Term (2007-2012) Mission (GIA, 2006a):***

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, and thereby contribute to the mitigation of climate change.

To achieve this mission, the GIA developed six ***Strategic Objectives:***

- To actively promote effective cooperation on geothermal RD&D through collaborative work programmes, workshops and seminars
- To collect, improve/develop and disseminate geothermal energy RD&D policy information for IEA Member and non-Member countries
- To identify geothermal energy RD&D issues and opportunities and improve conventional and develop new geothermal energy technologies and methods to deal with them
- To increase membership in the GIA

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

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

1.2 Collaborative Activities

The GIA's programme operates through participation in collaborative activities called *Tasks*, which are specific studies included within broader *topic areas*, called *Annexes*. After approval by the ExCo, detailed descriptions of new Tasks, or of new Annexes, are appended to the IA (Chapters 2-5). Each Annex, referred to by its annex number, is managed by an Operating Agent organization from one of the Member Countries or industry/organization Sponsor Members.

In 2009, participants worked in four broad research areas, specified in Annexes: I- Environmental Impacts of Geothermal Energy Development; III- Enhanced Geothermal Systems; VII- Advanced Geothermal Drilling Techniques; and Annex VIII- Direct Use of Geothermal Energy. A fifth annex, Annex X- Data for Geothermal Energy Applications, was officially opened at the end of 2009, with operational aspects to be finalized in 2010.

Annexes I and III, initiated at the start of the GIA, have continued their activities throughout 2009; as have Annexes VII (started in 2001) and VIII (begun in 2003). Annex V- Sustainability of Geothermal Energy Utilization has remained in draft form; however, a Sustainable Utilization Strategies task operates in Annex I. Annex VI- Geothermal Power Generation Cycles also remains in draft form.

A list of Annexes, Operating Agents, Annex Leaders, participants, and an indication of Annex status as of December 2009 are provided in Table 1.2. Complete descriptions of objectives, results for 2009 and work planned for 2010 for the active Annexes are presented in the Annex Reports included in Chapters 2-5. Brief summaries of the current draft and the closed Annexes are given in Table 1.3.

GIA Participants must take part in at least one Annex, with their involvement determined by their current interests, and research and development programmes. Not all Participants are necessarily active in all Tasks in those Annexes in which they participate. However, all GIA Members will participate in Annex X since this annex will deal with the collection and analysis of Member's geothermal data. GIA Member Annex involvement is shown in Table 1.1.

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

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

The geothermal status, activities and achievements of each Member Country and a company and organization profile and description of activities for each Sponsor (industry/organization)

Table 1.1 Contracting Parties, Sponsors, funding sources and periods of operation for the Annexes active to the end of December 2009.

Annex		I	III	VII	VIII	X
Country/Industry	**Contracting Party/Sponsor**	**Environmental Impacts of Geothermal Development**	**Enhanced Geothermal Systems**	**Advanced Geothermal Drilling Techniques**	**Direct Use of Geothermal Energy**	**Data for Geothermal Energy Applications**
Australia	Primary Industries & Resources-South Australia (PIRSA)	G	G	G		G
Canadian Geothermal Energy Association (CanGEA)	CanGEA, Canada		IO	IO	IO	IO
European Commission (EC)	The Commission of the European Communities, Belgium	G	G	G		G
France	Bureau de recherches géologiques et miniéres (BRGM)	G	G		G	
Geothermal Group of Spanish Renewable Energy Association (GG-APPA)	GG-APPA, Spain		IO		IO	IO
Germany	Forschungszentrum Jülich GmbH		G			OA, G
Geodynamics	Geodynamics Limited, Australia		OA, I			I
Green Rock Energy	Green Rock Energy Limited, Australia		I			I
Iceland	Orkustofnun	G, I		G	OA, G	G
Italy	ENEL Produzione	I	I			I
Japan	National Institute of Advanced Industrial Science and Technology (AIST)	R	R		R	R
Mexico	Instituto de Investigaciones Electricas (IIE)	G		G		G
New Zealand	GNS Science	OA, R, I		I	R	R
ORMAT Technologies	ORMAT Technologies, Inc, United States		I			I
ORME Jeotermal	ORME Jeotermal, Turkey				I	I
Republic of Korea	Korea Institute of Geoscience & Mineral Resources (KIGAM)		R		R	R
Spain	Institute for Diversification and Saving Energy (IDAE)		G		G	G
Switzerland	Swiss Federal Office of Energy	G	G		G	OA, G
USA	United States Department of Energy (US DOE)	N	N	OA, N	U	N
Annex Start Date		1997	1997	2001	2003	2009
Date Current Term of Annex Continues To		2009	2009	2009	2011	2013
End Date*		Ongoing	Ongoing	Ongoing	Ongoing	Ongoing

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

Member are provided in the Country and Sponsor Reports making-up Chapters 6-18 and 19-23, respectively.

Further information about the GIA and its activities may be obtained by contacting the GIA Secretary at: mongillom@reap.org.nz or by visiting the GIA website: **www.iea-gia.org**.

Table 1.2 Annex Title, Operating Agent and Status of GIA Annexes at December 2009.

Annex Number	**Title** **Operating Agent (OA)** **Annex Leader (AL); Affiliation; Contact E-mail** **Participants**	**Status**
I	**Environmental Impacts of Geothermal Development** OA: GNS Science (GNS), New Zealand AL: Chris Bromley; GNS, New Zealand; c.bromley@gns.cri.nz Participants: Australia, France, EC, Iceland, Italy, Japan, Mexico, New Zealand, Switzerland, USA	Active since 1997, Continuing through 2009
II	Shallow Geothermal Resources	Closed
III	**Enhanced Geothermal Systems** OA: Geodynamics Limited, Australia ALs: Roy Baria; MIL-TECH UK (for Geodynamics); roybaria@onetel.com and Doone Wyborn; Geodynamics, Australia; dwyborn@geodynamics.com.au Participants: Australia, CanGEA, EC, France, Geodynamics, Germany, GG-APPA, Green Rock Energy, Italy, Japan, ORMAT, Spain, Switzerland, USA	Active since 1997, Continuing through 2009
IV	**Deep Geothermal Resources**	Closed September 2006
V	**Sustainability of Geothermal Energy Utilization**	Draft
VI	**Geothermal Power Generation Cycles**	Draft
VII	**Advanced Geothermal Drilling Techniques** OA: Sandia National Laboratories, United States AL: Steven Bauer; Sandia National Laboratories, USA; sjbauer@sandia.gov Participants: Australia, CanGEA, EC, Iceland, Mexico, New Zealand, USA	Active since 2001, Continuing through 2009
VIII	**Direct Use of Geothermal Energy** OA: The Federation of Icelandic Energy and Waterworks, Iceland AL: Einar Gunnlaugsson; The Federation of Icelandic Energy and Waterworks, Iceland; einar.gunnlaugsson@or.is Participants: CanGEA, France, GG-APPA, Iceland, Japan, New Zealand, Republic of Korea, Spain, Switzerland, USA	Active since 2003, Continuing through 2011
IX	**Geothermal Market Acceleration**	Closed
X	**Data for Geothermal Energy Applications** OA: Projekttraeger Juelich, PTJ EEN Germany; Geothermal Energy Research Program ; Federal Office of Energy (BFE) AL: Lothar Wissing; Projekttraeger Juelich, PTJ EEN, Germany; l.wissing@fz-juelich.de and Rudolf Minder; Swiss Federal Office of Energy, Switzerland; ruldof.minder@bluewin.ch Participants: Australia, CanGEA, EC, France, Geodynamics, GG-APPA, Germany, Green Rock Energy, Iceland, Italy, Japan, Mexico, New Zealand, Ormat, ORME Jeotermal, Republic of Korea, Spain, Switzerland, USA	Opened 2009, Continuing through 2012

Table 1.3 Annex number, name, description and status for draft and completed Annexes as of December 2009.

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 may be revised if interest in the topic grows.	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

1.3 Structure of the GIA

The GIA is managed by an Executive Committee (ExCo), which consists of one Member and one Alternate Member designated by each Contracting Party and each Sponsor. There is currently one Contracting Party for each GIA country member, which is a government department or agency, or independent company (industry). The ExCo meets twice each year to exchange information, discuss activities and progress in each of the Annexes and in each of the participating countries, industries and organizations, and to plan future activities of the organization. Non-financial decisions are made by majority vote (unless otherwise specified in the Implementing Agreement), with financial decisions requiring a ***unanimous*** vote; with each Contracting Party and each Sponsor allowed one vote. In 2002, the GIA ExCo decided to increase its scope of activities, and as a result, created a dedicated Secretariat, which began operations in March 2003, and is funded by a cost-shared Common Fund.

GIA research and activity results are extensively disseminated through participation at international geothermal and renewable energy conferences and workshops, and publication in scientific and technical journals and conference proceedings (details in Chapters 2-5). In addition, information is made widely available on the GIA's public website, through promotional material produced by the GIA Secretariat, and via IEA publications and workshops, and the IEA website (www.iea.org).

In 2009, 12 countries, the EC, two international organizations and three industries formally participated in this programme (Table 1.1). One of the new industries, which became a Member in mid-2008, has been unable to participate or attend meetings, and will probably withdraw from the GIA.

1.4 The Executive Committee

Officers

In 2009, Chris Bromley (New Zealand) was re-elected Chairman. Dr Ladislaus Rybach (Switzerland) was also re-elected to serve as Vice-Chairs for Policy, and Jonas Ketilsson (Iceland) was elected as Vice-Chair for Administration.

Membership

There were many changes in the ExCo composition in 2009: Laurent Le Bel replaced Fabrice Boissier as Member for France; Erich Nägele replaced Andreas Piontek as Member for the EC; Ed Wall replaced Jay Nathwani as Member for the USA, with Jay Nathwani becoming Alternate Member; Nilgun Bakir replaced Tevfik Kaya as Alternate Member for ORME Jeotermal; Ezra Zemach was appointed as Alternate Member for Ormat Technologies, replacing Zvi Krieger; Betina Bendall replaced Tony Hill as Australian Alternate Member; and David Gowland replaced Craig Dunn as Alternate Member for CanGEA.

The list of ExCo Members and Alternates as at December 2009 is provided in Appendix C.

ExCo Meetings

The ExCo held two Meetings in 2009 to conduct its operations, which included discussing and reviewing ongoing tasks and the planning of future activities.

21st ExCo Meeting, 7-8 May 2009, Madrid, Spain

The 21st ExCo Meeting was held on 7-8 May 2009, at the Hotel Tryp Ambassador in Madrid, Spain, with the kind support of the Institute for Diversification and Saving Energy (IDAE), Spain. There were 29 attendees, including 11 ExCo Members and 4 Alternate Members; 12 Observers, including the GIA Secretary; and 2 invited Guests. Of the Invited Guests present, two represented Norway, a prospective GIA Member. The GIA's two newest Members, the Sponsors Geothermal Group of the Spanish Renewable Energy Association (GG-APPA) and the Canadian Geothermal Energy Association (CanGEA) were represented and extended a special welcome. This was a very good turnout considering the effects of the global swine-flu epidemic on international travel.

A joint 2-day IEA-GIA~IGA (International Geothermal Association) Workshop on Geothermal Energy Global Development Potential and Contribution to Mitigation of Climate Change (5-6 May 2009) was held in Madrid on 5-6 May, in association with the ExCo Meeting and IGA Board Meeting. This first formal cooperation between the GIA and IGA proved very successful (see discussion below) and is expected to lead to continued cooperation between the two organizations. The outcomes of this Workshop provided input for the Geothermal Chapter of the Intergovernmental Panel on Climate Change (IPCC) Renewable Energy Special Report.

Though no Annex meetings were held due to time constraints arising from the joint GIA-IGA Workshop, the four active Annexes reported on their activities at the ExCo meeting, as did 10 Country Members and 4 Sponsor (industry/organization) Members. Three Guest Reports were also presented, two by representatives of prospective GIA Member Norway; and the third on GeotIS, the Geothermal Information System for Germany.

The ExCo unanimously re-elected Chris Bromley (New Zealand) as Chair, and Jonas Ketilsson (Iceland) and Ladislaus Rybach (Switzerland) as Vice-Chairs.

GIA's membership has grown significantly in the past few years, and further good prospects being pursued included: Ireland, the Philippines and Norway.

The GIA's current excellent financial position led to the ExCo unanimously accepting a proposal to formalize a mechanism for funding approved supplementary activities related to ExCo initiatives or Annex Task activities carried out by IEA-GIA participants from the GIA Common Fund. The ExCo also unanimously supported the first successful proposal to fund a portion of the Secretary's time to act as one of two Guest Editors of a ***Geothermics*** Special Issue on Sustainable Geothermal Utilization, including the co-authoring of the introductory paper.

The Secretary reported on the operation (work accomplished and budgets) of the Secretariat for the 2008-year and the 2009-year to 31 March 2009, presented a work plan and revised budget for the remainder of 2009, and gave an update on the Common Fund. The GIA planned to participate in the 2009 Geothermal Resources Council Annual Meeting (Reno, USA), and the Secretary would be contributing to a paper with the ExCo Officers describing the GIA activities. A Proceedings for the joint IEA-GIA~IGA Madrid Workshop would be prepared and the GIA's participation at the WGC 2010 arranged, including co-authoring a GIA paper.

The IEA Secretariat report was presented by Takatsune Ito, who reviewed the IEA's recent activities and publications, including the GREMPP and the Renewable Energy in Cities reports to which the GIA was contributing. The IEA series of concise (4-page) brochures on renewable energies was described, noting the GIA was working with the IEA on the geothermal issue.

Plans for GIA participation at the World Geothermal Congress (WGC) 2010, to be held in Bali, Indonesia, on 25-30 April 2010, were discussed; and the ExCo agreed to hold its 23rd ExCo

Meeting in Bali on 22-23 April, with Annex Meetings on 21 April, to support GIA participation at the WGC 2010.

The ExCo had previously agreed to hold the 22nd ExCo Meeting in Reno, Nevada, USA, on 1-2 October 2009, in association with the 2009 Geothermal Resources Council (GRC) Annual Meeting, with Annex Meetings on 30 September, to encourage GIA participation at the GRC Meeting.

22nd ExCo Meeting 1-2 October 2009, Reno, Nevada, USA

The 22nd ExCo Meeting was hosted by Ormat Technologies Inc. and held at the Peppermill Resort in Reno, Nevada, USA, on 1-2 October 2009. The meeting was held in conjunction with the 2009 Geothermal Resources Council (GRC) Annual Meeting, providing GIA meeting participants the opportunity to take part; and several GIA papers were presented. Thirty-three people attended the ExCo Meeting, including: 13 ExCo Members, 4 Alternate Members and 16 Observers, including the GIA Secretary. Ormat also hosted a fieldtrip to their new (2008) Galena II 20 MW plant addition to the Steamboat (Nevada) Complex.

The periods of operation for three Annexes: I- Environmental Impacts, III- Enhanced Geothermal Systems (EGS) and VII- Advanced Geothermal Drilling and Logging Technologies, whose current terms ended in 2009, were extended for a further 4 years.

GIA's participation at the WGC 2010, as part of its efforts to disseminate information about geothermal energy and promote the IEA-GIA, was discussed. The GIA will be sponsoring an exhibition booth at which general GIA, Annex and Member posters would be exhibited, and GIA and IEA documents and other material distributed. Several papers by GIA participants had also been accepted for presentation: two from Annex I, one from Annex VII, three from Annex VIII, and a general one about the GIA and its efforts to promote sustainable geothermal development.

Production of an IEA geothermal roadmap was discussed and its importance stressed. Financial contributions from several GIA Members would be needed to support this effort and a proposal to obtain a contribution from the GIA Common Fund would be submitted.

The ExCo continued its efforts in the pursuit of new membership, especially targeting the two major geothermal countries not yet members- Indonesia and the Philippines. China and Russia membership were recognized as important, but GIA efforts so far have been unsuccessful. Prospects for Norway's GIA Membership looked very good.

Annexes I, III, VII and VIII held meetings on 30 September 2009. The ExCo voted unanimously to open new Annex X- Data Collection and Information; with the final details to be developed and submitted.

Progress reports from Annexes I, III, VII and VIII, and 10 Country and 4 Sponsor reports were presented and discussed. A separate report on Annex I Task E- Sustainable Utilization Strategies highlighted the GIA's effort in promoting sustainable geothermal use. The Secretary reviewed activities since the 21st ExCo Meeting and submitted work plans and budgets for the remainder of 2009 and for 2010 along with the Common Fund report, and these were unanimously accepted by the ExCo. Good progress was being made on the ***Geothermics*** Special Issue on Sustainable Geothermal Utilization.

The recent availability of funding for GIA-related activities from the GIA Common Fund was attracting interest, with eight proposals for support discussed. These are to be distributed to the ExCo for consideration and prioritization after this meeting.

The Secretary presented the IEA Secretariat report, reviewing the IEA's major activities and publications and highlighting the GIA's contributions to them. The GIA had significant input with completing the final draft of the *IEA Renewable Energy Essentials: Geothermal* brochure, and contributed to the *IEA Cutting Edge 2009* and *Renewable Energy in Cities* documents.

The ExCo earlier agreed to hold the 23rd ExCo Meeting in Bali, Indonesia, in association with the World Geothermal Congress 2010, with Annex meetings on 21 April and the ExCo Meeting on 22-23 April 2010.

1.5 GIA Participation in IEA Activities in 2009

The GIA continued its active involvement with the IEA in 2009. The GIA had major input to the ***IEA Renewable Energy Essentials: Geothermal*** brochure; provided significant information for the geothermal sections of the **IEA Renewable Energies in Cities** report; and responded to several requests for information/input on materials requirements for geothermal development, geothermal costs and the IEA Cutting Edge 2009 report.

1.6 Other GIA Activities

The GIA and IGA (International Geothermal Association) jointly organized an international workshop on *Geothermal Energy- Its Global Development Potential and Contribution to Mitigation of Climate Change*, which was held on 5-6 May 2009, in Madrid, Spain, with significant support of The Institute for Diversification and Saving Energy (IDAE), Spain, and assistance from the Geothermal Group of the Spanish Renewable Energy Association (GG-APPA). There were over 50 attendees, with 40 official participants from 17 countries. A comprehensive proceedings is in draft form and will be published and made available on the GIA in early 2010.

The GIA participated at the Geothermal Resources Council (GRC) 2009 Annual Meeting, Reno, Nevada, USA, with presentation of an IEA-GIA paper by Mongillo, Bromley and Rybach: *IEA-GIA- International Geothermal Cooperation Going from Strength to Strength.*

The GIA also initiated the publication of a special issue of an international geothermal journal: ***Geothermics Special Issue on Sustainable Geothermal Utilization***, with M.A. Mongillo (GIA Secretary) and Guðni Axelsson (GIA Annex I Task E Leader) as Guest Editors; to be published at the end of 2010.

In addition, the GIA has made a major commitment to participate at the World Geothermal Congress 2010, Bali, Indonesia, to be held on 25-30 April 2010. Six Annex papers have been accepted for publication and presentation at the Congress, with a general GIA paper by Mongillo, Bromley and Rybach: *The IEA Geothermal Implementing Agreement- International Efforts to Promote Global Sustainable Geothermal Development and Help Mitigate Climate Change* to be a keynote address. The GIA will also be sponsoring an exhibition booth at which general GIA, Annex and Member posters will be exhibited, and GIA and IEA publications distributed.

The GIA's public website (www.iea-gia.org) remains an important source for information dissemination and discussion.

1.7 Costs of the Agreement

The IEA-GIA Secretariat is currently located in New Zealand. It is supported by a part-time Secretary, who handles the administration, assists with the management of the organization and provides a major part of the information dissemination, including the preparation of GIA documents and publications, the GIA annual reports and maintenance of the GIA website.

Table 1.4 *Common fund share apportionment among the GIA Members as of December 2009.*

Australia	2	Spain	2
European Commission	4	Switzerland	2
France	4	United States	4
Germany	4	CanGEA	1
Iceland	1	Geodynamics	1
Italy	2	GG-APPA	1
Japan	4	Green Rock Energy	1
Mexico	1	ORMAT	2
New Zealand	1	ORME Jeotermal	1
Republic of Korea	2	-	-
Total = 40 shares			

The expenses for operating the GIA Secretariat, including the Secretary's salary and travel, website hosting, and other common costs of the ExCo, are met from a GIA Common Fund. In 2009, these costs amounted to a total of US$ 94,700, including a funded proposal contribution of US$ 3,800 for the Secretary's effort as Guest Editor of the ***Geothermics Special Issue on Sustainable Geothermal Utilization***. The Common 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 each new Member is determined by the unanimous agreement of the ExCo. The apportionment for the current GIA Membership is shown in Table 1.4.

The cost per Common Fund share, set by unanimous ExCo decision, was US$ 3,500/yr in 2009. Contributions are made annually on a calendar year basis.

1.8 References

GIA, 2006a. IEA-GIA Strategic Plan 2007-2012, 9 November 2006, 23 p.

GIA, 2006b. IEA-GIA End of Term Report 2002-2007, 30 October 2006, 36 p.

Mongillo, M.A. Bromley, C.J. and Rybach, L., 2009. IEA-GIA- International Geothermal Cooperation Going from Strength to Strength. Transactions GRC 2009 Annual Meeting (CD-Rom), 8p.

IEA Geothermal R & D Programme

Chapter 2

Annex I- Environmental Impacts of Geothermal Energy Development

Figure 2.3 *El Tatio geyser field (Chile), the subject of international environmental lobbying, policy review, and eventual protection from possible development effects by government decree. (Photo courtesy of Chris Bromley)*

2.0 Introduction

Geothermal is mostly environmentally-benign, is a renewable energy source, has significant benefits relative to fossil fuels with respect to global carbon-dioxide emissions, and therefore has significant potential for reducing global warming effects. There are, however, some local environmental problems associated with its utilization. To further the use of geothermal energy, possible adverse and beneficial environmental effects are identified, and measures devised and adopted to avoid or minimize adverse impacts, while encouraging the benefits.

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

Participants in Annex I include: Australia, European Commission, Iceland, Italy, Japan, Mexico, New Zealand, Switzerland and the United States.

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

2.1 Tasks of Annex I

Annex I has five Tasks, described below.

2.1.1 Task A - Impacts on Natural Features

(Task Leader: Chris Bromley, GNS Science, New Zealand)

Impacts of geothermal developments on natural geothermal features such as geysers, hot springs and fumaroles are documented. Methods are devised to accurately monitor changes and to avoid or mitigate the adverse impacts of development on these geothermal features, which often have significant economic value for tourism and cultural value for indigenous peoples.

Figure 2.1 *Monitoring steaming ground and thermal vegetation at Tauhara, New Zealand (increased steam discharge due to effects of Wairakei liquid pressure drawdown). (Photo courtesy of Chris Bromley)*

2.1.2 Task B - Discharge and Reinjection Problems

(Task Leaders: Trevor Hunt and Robert Reeves, GNS Science, New Zealand)

Better methods of overcoming any adverse impacts of geothermal developments on other aspects of the environment are also developed. These include the effects of gas emissions from geothermal power plants on air quality; the effects of toxic chemicals in waste fluid that may be discharged into the ground or into rivers; and the effects of ground subsidence resulting from pressure decline. Projects examine the problems associated with disposal of waste geothermal fluids and the effects of CO_2, Hg and H_2S gas emissions, along with mechanisms and mitigation options, using injection, for ground subsidence.

2.1.3 Task C - Methods of Impact Mitigation and Environmental Procedures

(Task Leader: Chris Bromley, GNS Science, New Zealand)

By developing an effective, standard, environmental analysis process, the objective of this task is to reduce the risks of adverse effects, reduce the costs of environmental compliance, and stream-line the process for project consenting, thereby contributing to the responsible and timely deployment of future geothermal energy projects. Field management strategies that result in improved environmental outcomes are identified and publicized. Successful mitigation schemes that provide developers and regulators with options for compensating unavoidable effects are also identified, documented and publicized.

Figure 2.2 *Thermal wetland centred at Otumuheke Spring, situated within an accumulated 3m deep geothermal subsidence bowl at Spa Valley, Tauhara, New Zealand. (Photo courtesy of Chris Bromley)*

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

(Task Leaders: Ernie Majer, Lawrence Berkeley National Laboratories, USA; and Roy Baria, MIL-TECH, United Kingdom)

The purpose of this task is to investigate the occurrences of felt induced seismic events, particularly in connection with high pressure fracture stimulation, and their effects on the local population. The objective is to obtain a better understanding of why these events occur so that they can either be avoided or mitigated. Additional objectives are to assess and generate appropriate source parameter models, and test the models in relation to the hydraulic injection history, temperature gradients, stress field and the tectonic/geological background, using stress modelling, and rock mechanics. Once various mechanisms of the events are understood, the injection process to fracture stimulate a geothermal reservoir may be modified to reduce or eliminate the occurrence of large events. This task is complementary to a similar research objective under Annex III (for EGS), and from 2011 both tasks will be transferred to a new specially created Annex (XI) lead by Ernie Majer.

2.1.5 Task E - Sustainable Utilization Strategies

(Task Leader: Guðni Axelsson, Geological Survey (ISOR), Iceland)

Case histories of reservoir models of geothermal developments are studied to see what strategies have been successful. Additional modelling of long term reservoir behaviour is undertaken to select optimum future strategies given different recharge and resource size scenarios. Different sustainable development scenarios are compared to determine relative environmental and economic benefits. Different conceptual and hypothetical reservoir model predictions are compared using long-term scenarios. Long-term reservoir behaviour, recharge factors, recovery times, and optimised cyclic or staged operation strategies are investigated.

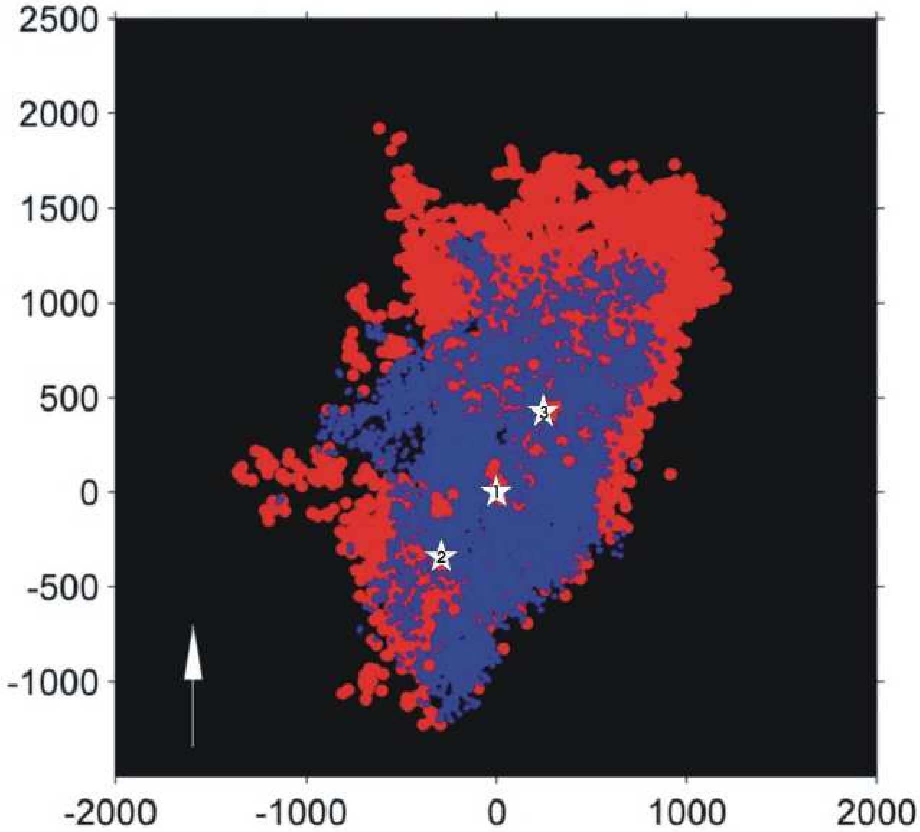

Figure 2.4 Reservoir-creating induced-seismicity events, in plan view, at Habanero, Cooper Basin, Australia, from different injection stimulation events (blue then red) surrounding deep wells HB1 to HB3 (stars). (Figure courtesy of Doone Wyborn, Geodynamics)

2.2 Work Performed in 2009

Several participants in Annex I (Chris Bromley, New Zealand; Barry Goldstein, Australia; Hirofumi Muraoka, Japan), along with other geothermal specialists from the GIA participating countries (Mexico, USA, Iceland, Germany, and Italy; Figure 2.6) met twice during 2009 (in Sao Paulo, Brazil and in Oslo, Norway) to prepare a draft of the geothermal energy chapter of the IPCC Special Report on Renewable Sources (SRREN). This major effort involved a voluntary contribution totalling many man-months by the participants. The chapter includes a section on environmental issues, and projections of technical and deployment potential for geothermal energy out to 2050 and beyond. This highlighted geothermal's important future role in the mitigation of climate change effects by substituting for fossil fuels. The final version of the report, after intensive international review during 2010, is due to be published in 2011.

Figure 2.5 *Blue Lagoon and Svartsengi "resource park" – sustainably-managed, integrated power station, hot water supply and thermal spa (Iceland). (Photo courtesy of Chris Bromley)*

Figure 2.6 *IPCC SRREN Geothermal chapter Lead Author participants. (Photo courtesy of Chris Bromley)*

2.2.1 Task A - Impacts on Natural Features

Meetings of task participants were held at Madrid, Spain, in April and Reno, USA, in October 2009. Changes observed in thermal features caused by geothermal developments were further discussed. Strategies to mitigate, recover or enhance thermal features using targeted injection and strategic production were presented. Policies were refined to help regulators to monitor and manage effects on thermal features in a practical manner. Results were discussed at geothermal workshops in New Zealand and the USA.

2.2.2 Task B - Discharge and Reinjection Problems

Environmental issues specific to EGS projects were canvassed; these included water management, noise, hazards and visual impact. Optimum injection strategies, including scaling treatment and avoidance, methods of reduction of CO_2 emissions by injection, and arsenic reduction through silica precipitation were further investigated. Injection/production management using an adaptive approach to reverse or avoid adverse effects on surface features and on reservoir sustainability were advocated. Basic research into the transient behaviour of fluid-rock-gas interactions was initiated to better explain scaling, dissolution, deposition and acid alteration processes.

Mechanisms of subsidence/ground inflation in geothermal fields in New Zealand and Iceland were investigated in more detail and methods to improve predictive tools using coupled reservoir and subsidence models were further developed. Some results were published at international geothermal workshops.

2.2.3 Task C - Methods of Impact Mitigation and Environmental Procedures

Feedback on draft geothermal policy and best-practice planning guidelines were canvassed at international meetings. Tables of effects and avoidance strategies were further developed. Examples of successful mitigation strategies were collated and discussed at the two Annex I meetings. Barriers to accelerated development such as lobbying against large scale power development by hot spring associations (in Japan), land access constraints imposed by National Park status in remote volcanic settings, and water allocation in arid areas, were discussed.

Discussion also covered the possible integration of social and economic "sustainability assessment protocol" issues (e.g., aspects and scores), from an Icelandic study, with EIA risk issues identified in the tables of effects.

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

Collaboration between participants involved in EGS projects and geothermal researchers with experience of induced seismicity continued in order to advance understanding of induced seismicity mechanisms. Methods to address the issue of large induced earthquakes from injection/production activities were discussed from the perspective of vibration amplitude and frequency. Suggested improvements to the induced seismicity protocol (posted on IEA-GIA website) were discussed. Improved seismic monitoring and processing methods were also discussed.

An additional issue raised for discussion was that of the length of time needed to establish a baseline for background seismicity before commencing a deep drilling and stimulation project. Improved collaboration between induced seismicity researchers and the availability of datasets were also discussed.

2.2.5 Task E- Sustainable Utilization Strategies

An outcome of the international workshop held at Taupo, New Zealand (November 2008) to address reservoir modelling issues concerning long-term sustainability was the commitment to produce a special issue of the international geothermal journal, ***Geothermics,*** on this topic, with joint editors Mike Mongillo and Guðni Axelsson.

Issues of long-term reservoir performance and potential constraints were discussed during Annex I meetings. The results showed that resources that are depleted in pressure and temperature are generally recoverable (i.e., renewable) over time frames comparable in duration to the initial period of draw-down. Adopting long-term cyclic or rotational approaches to energy extraction was suggested as an optimal strategy. The importance of cost-benefit analysis of make-up drilling late in a project extraction cycle was stressed, along with the benefits of staged development to reduce the risk of over-utilisation. Highlights of this work were posted on the IEA-GIA website.

Collaboration with the International Geothermal Association (IGA) through a jointly sponsored seminar on Global Development Potential and Contribution to the Mitigation of Climate Change was held in Madrid, Spain, in April 2009. The resources-reserves definition task to enable better comparison of heat recovery factors was a major topic discussed.

2.3 Highlights of Annex I Programme Work for 2009

The highlights for the 2009-year were:

- Interest in sustainability issues led to commencement of a special issue of Geothermics journal on this topic
- Papers were presented by participants and work colleagues on environmental research, improved environmental sustainability strategies and monitoring methods at the 2009 New Zealand Geothermal Workshop, the 2009 Stanford Geothermal Reservoir Workshop, and the 2009 GRC Annual Meeting
- Improved methods to monitor and avoid or mitigate environmental effects such as subsidence, gas and heat emissions, and induced seismicity were developed
- Annex participants took part in preparing a draft geothermal chapter for the IPCC SRREN report for mitigation of climate change
- Annex participants took part in discussions at a joint IEA-GIA~IGA workshop "Geothermal Energy– its Global Development Potential and Contribution to the Mitigation of Climate Change" held in Madrid, Spain (April) as well as at an Annex meeting in Reno, USA (October)

2.4 Work Planned for 2010 and Beyond

2.4.1 Task A

- 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

- Geothermal CO_2 capture for horticulture and bottling
- CO_2 sequestration by injection or chemical fixing

- Arsenic and boron removal from waste water by bio- or chemical- processing
- Protection of potable water aquifers from out-field reinjection effects
- Improved prediction of subsidence and effects avoidance or mitigation

2.4.3 Task C

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

2.4.4 Task D

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

2.4.5 Task E

- Complete ***Geothermics*** special issue on sustainability of geothermal resource utilisation
- Compare simulations of >100 years continuous and periodic (30-50 year interval) production/injection scenarios. What are the optimum strategies? Establish funding source for PhD work in this area?
- How rapidly and effectively do geothermal systems recover during breaks after periods of excessive production?
- What factors are most significant in controlling long-term behaviour/capacity; boundary conditions, inflow/recharge, reinjection, etc.?
- How significant and far-reaching are long-term production pressure drawdown and injection cooling effects, i.e., how significant is interference between adjacent geothermal areas?

- Using case histories, what is the reliability of long term predictions of reservoir behaviour using various methods (stored heat, simple analytical models, complex 3-D models, etc.)?
- What information should be collected at pre-exploitation and early development stages to significantly reduce uncertainties in long-term resource sustainability assessments?

All environmental tasks would benefit from supportive funding. Specific examples are:

- Preparation of an international geothermal environmental protocol document (improve on existing documents)
- Induced seismicity and sustainability workshops and publishing costs
- Field trials using targeted shallow reinjection of hot fluids to recover/enhance thermal features
- Field trials of injection as a means of suppressing subsidence
- Field trials of gas injection in geothermal wells
- Field trials of injection/production methods to influence the rate of induced seismicity
- Field trials of water treatment to remove toxic elements

2.5 Outputs for 2009

Majer, E., Baria, R., Stark, M., Bromley, C., Cumming, W., Jelacic, A., Rybach, L., 2009. Protocol for induced seismicity associated with enhanced geothermal systems. IEA-GIA Executive Committee approved publication on IEA-GIA website:
http://www.iea-gia.org/documents/ProtocolforInducedSeismicityEGS-GIADoc25Feb09.pdf

Papers submitted to the ***Geothermics*** special issue on sustainability (to be published in late 2010).

Significant effort by Annex I participants in 2009 was also directed to preparation of papers for publication and presentation at WGC2010 which was held in Bali, Indonesia, in April 2010 (to be included in 2010 GIA Annual Report).

GIA Annex I publications:

Allis, R., Bromley, C.J., 2009. Unravelling the subsidence at Wairakei, New Zealand. Transactions Geothermal Resources Council 33, 299-302, GRC2009.

Boothroyd, I., 2009. Restoring geothermal ecosystems: perspectives in the colonisation process of geothermally influenced streams. Abstract in handbook of New Zealand Geothermal Workshop 16-18 November 2009, Rotorua, New Zealand.

Bromley, C.J., 2009. Geophysical monitoring: deformation (subsidence), surface thermal features and heat losses. Presentation at NZ Geothermal Association Monitoring Seminar (Wairakei Resort, Taupo, 19 August 2009).

Bromley, C.J., 2009. Improving long-term utilisation strategies and promoting beneficial environmental effects. Proceedings (on CD) and presentation at PNOC-EDC 30th Annual Geothermal Conference, March 11-12 2009, Manila, Philippines.

2.6 Websites Related to Annex I Work

- IEA Geothermal Implementing Agreement hosting seismicity protocol, sustainability reference list, etc.: www.iea-gia.org
- Website hosting the results of three IEA-GIA convened induced seismicity workshops, containing presentations and links to sources of information and data: http://esd.lbl.gov/EGS/
- GEISER induced seismicity research collaboration: www.geiser-fp7.eu

Figure 2.7 The author sharing a bathing experience in Puritama Hot Springs, on route to El Tatio, Chile, with indigenous people (Atacameños), and skin-nibbling tropical fish. (Photo courtesy of Chris Bromley)

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Chapter 3

Annex III- Enhanced Geothermal Systems (EGS)

Part of the ORC plant at the Soultz-sous-Forêts geothermal power plant, Alsace, France (from: Innovation Through Research, 2008 Annual Report on Research Funding in the Renewable Energies Sector, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Germany).

3.0 Introduction

International energy policy-makers are gradually recognising the potential and the importance of the development of Enhanced or Engineered Geothermal Systems (EGS). EGS are strategic resources with potential for supplying continuous base load power, and potentially could accommodate peaks in power demand as well. Recent economic evaluation indicates that the combination of heat and power is more attractive in an industrialised world due to the increasing cost of hydrocarbon energy sources for both applications. The relatively low visual and carbon dioxide impacts are also helping EGS to be recognised as one of the attractive energy resources of the future. This is reflected in the increasing membership of the IEA-GIA by countries who wish to cooperatively develop EGS technology. The IEA-GIA is the appropriate vehicle to promote international cooperation and share technological development.

The importance of EGS technology is also gaining momentum internationally as the IEA is preparing a geothermal roadmap for the G8 which incorporates EGS; and additionally, will include EGS in their future *Energy Technology Perspectives* reports. The IEA has clearly recognized that one of the most important greenhouse gas mitigation opportunities lies in the increasing use of renewable energy. The *Energy Technology Perspectives 2008* report concluded that if we are to reduce energy related CO_2 emissions by 50% from today's level by 2050, 21% of the necessary greenhouse gas emissions reductions will have to come from renewable energy production. Owing to the recent accelerated annual growth in installed capacity for geothermal power generation and the significant progress achieved in EGS development in Europe, Australia and North America, the IEA envisions geothermal energy to make a significant contribution to the growth of the renewable portfolio. However, a significant number of technology development and demonstration, legal and regulatory, and public policy issues must be addressed if the potential of geothermal energy is to be unlocked.

With the above background, the IEA is working in collaboration with the IEA Geothermal Implementing Agreement (GIA) to develop a roadmap for electricity generation and direct heat use utilizing geothermal resources. To start this project, the IEA conducted the first workshop focusing on the technology state of the art, prospects, innovation and R&D issues and priorities. The goal of the Roadmap is to provide guidance to government and industry decision makers as they set priorities and accelerate efforts to develop and deploy technologies that will enlarge the contribution of geothermal power and direct heat use in the energy mix.

With this in mind, the objective of the EGS Annex is to address new and improved technologies via international collaboration so that the huge heat resources present in the majority of the continental land masses can be accessed by developing engineered heat exchangers at depth, and at commercially viable costs. Further, application of EGS techniques at existing hydrothermal fields is also helping to increase energy extraction and improve sustainability.

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

The countries and organizations that participated in Annex III in 2009 were: Australia, the European Commission (EC), France, Germany, Italy, Japan, Norway, Republic of Korea, Switzerland, USA, Geodynamics Ltd., Green Rock Energy Ltd. and ORMAT Technologies Inc.

The Operating Agent for Annex III is Geodynamics Ltd., located at Level 3, 19 Long Parade, Milton QLD 4064, Australia. The two Annex Leaders are Roy Baria (MIL-TECH, UK) and Doone Wyborn, of Geodynamics Ltd., Australia.

3.1 Tasks of Annex III

Annex III has five Tasks, described below. Many of these Tasks were revised during 2009.

3.1.1 Task A- Economic Modelling

(Task Leader: Adrian Williams; Geodynamics)

Task A, which originally involved the evaluation of the economics of EGS systems, was successfully completed in 2001 and numerical models were developed by the US and other countries. However, this task was re-activated in 2007 in order to incorporate the quantification and definition of EGS resources in a form that can be internationally accepted. Additionally, many commercially funded projects have commenced and will require a common terminology to make them comparable. It is becoming apparent that the development of EGS is moving from fundamental research to demonstration and application. New EGS projects are taking place on different continents, with varying geological conditions and stress regimes, and *the knowledge gained in the past will need to be applied to new conditions.* It is important for the success of

EGS that the processes developed through international research and cooperation are applicable in different stress regimes and geological settings. With this in mind, details of this Task are being reassessed and implementation sought. It is also becoming apparent that the flow of information is decreasing as privately funded projects regard the knowledge they obtain as the intellectual property rights associated with their investment.

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

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

Some of the important parameters to be defined are: life-cycle of an EGS system, separation between the wells, production flow rate, flow impedance, water loss, thermal drawdown, contact surface area and reservoir rock volume. These factors will be defined and updated based on experience gained.

3.1.2 Task B- Application of Conventional Geothermal Technology to EGS

(Task Leader: Joel Renner, Idaho National laboratory, USA)

This Task is aimed to modify conventional hydrothermal development technology, such as horizontal drilling, fracture detecting and mapping, and pumping, for application to EGS energy development. A set of coordinated actions related to what was prepared to see how these technologies could help the development of EGS. The list was circulated and discussions are continuing to see what is feasible within existing budgets.

3.1.3 Task C- Data Acquisition and Processing

(Task Leader: To be appointed, Switzerland)

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

Access to past data and reports from various projects has always been difficult. The US DoE developed the "Legacy Project", which provides access to some of the reports from previous EGS projects. This scheme needs reinforcing with the addition of missing reports and a better search engine (refinement of the existing one, or its replacement). Alterative means are being considered to address this data and information access problem, such as via financial support from the GIA Common Fund, or the full program being funded by an organisation, joint consortium of partners, etc.

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

- ***In-situ data:*** geology, stress profile, temperature with depth, *in-situ* fluid composition and pressure, joint network and orientation, *etc*.

- ***Hydraulic data:*** all hydraulic testing, stimulations and circulations of the wells

- ***Microseismic data:*** both located events and raw data

- ***Reports and papers***

3.1.4 Task D- Reservoir Evaluation

(Task Leader: Doone Wyborn, Geodynamics Limited, Australia)

The overall object of Task D is to compile and make clear what kind of methods, techniques, and tools are effective for reservoir evaluation; and then establish the evaluation methods best applied to develop a new EGS site. Creation of an economically viable reservoir is the single most important item in EGS technology. Methods used for evaluation of the data have developed from past EGS projects and others are borrowed from the oil and gas industry. The plan is to define agreed procedures to test and evaluate the reservoir parameters so that they can be compared. Initial work has started and it will be developed further in 2010.

Some of the parameters have been defined for discussion and are presented below. The work has progressed slowly but additional support is being considered and investigated.

Some of the procedures that could be standardized are:

- Well testing models
  - ***Before stimulation***: for the assessment of undisturbed in-situ permeability which can then be compared to that of after stimulation; near wellbore, and if possible, far field
  - ***For stimulation:*** for the assessment of enhanced permeability following stimulation to see how successful was the stimulation; near wellbore and far field
  - ***For circulation:*** for the assessment of the further enhancement of permeability due to cooling and precipitation and dissolution processes, i.e. is the reservoir improving or degrading; both near and far field.

- Borehole measurements
  - ***Wellbore images:*** wellbore images are necessary to identify joint network and flow exits. Borehole imaging tools such as BHTV, FMI, etc. are commonly used for this purpose. Higher temperatures can make the use of existing tools/methods impractical; although, cooling of wells and use of heat shields can allow them to work for a limited time.
  - ***Temperature:*** Temperature is a very important heat resource and flow exit/inlet identification tool. Analogue and digital tools are available to work at up to 200 °C. Higher temperature tools can be attained using heat shield technology. Temperature sensors with low thermal mass are preferable because they respond faster to changes in temperature for identifying small flow exits.
  - ***Flow:*** Impeller flow meters are preferred as they are a simpler device and very sensitive to flow. The larger the diameter of the impeller the higher the sensitivity. For higher temperature, the impeller can be made of Teflon and Teflon coated bearings are used to reduce friction and corrosion. Standardised methods for flow measurement and interpretation would be useful.

- ***Pressure:*** Studies to be continued.

- Water management
  - ***Open system:*** The characterisation of the *in-situ* condition of rock mass is essential to plan stimulations, well trajectories and water requirement/management. One of the tests used for assessing an open or closed system is a shut in test after the stimulation. In an open system the pressure decays rapidly and microseismicity generation slows down rapidly giving an indication of the likely far-field water leak off.
  - ***Closed system:*** The requirements and tests are the same as those for the open system but here the pressure decays very slowly (microseismicity generation decays slowly as well) and gives an indication of the likely low far-field water leak off and therefore the constraint of circulation pressure may be necessary to limit further growth of a reservoir. Again, a preferred method and procedure may be useful to compare sites in terms of economic viability and stability of a reservoir.
  - ***Over-pressured system:*** Where the fracture network is over-pressured special conditions exist during drilling since permeable fractures at different depths cannot be in connection with a wellbore fluid at the same time when the pressure is controlled by mud weight. No pump is required in a production well under these conditions. It is not yet clear how widespread these conditions are in the Earth's crust.

- Review of numerical methods
  - ***Flac 3D***
  - ***uDec and 3Dec***
  - ***Geocrack***
  - ***FRIP***
  - ***Feflow***
  - ***Kappa***
  - ***Tough (various)***
  - ***Fracod***
  - ***Others***

- Microseismic measurements
  - ***Design of network and errors:*** One of the main reasons for the use of a microseismic system is the need to track fluid pressure during stimulation for the creation of an EGS reservoir. The design has to take into consideration the layout of the sensors to optimise errors in the location of these events. This entails the layout of the sensors with respect to the proposed stimulation volume, the local environmental situation for background noise, transmission of the data to the base station, the local geology where the seismic stations will be positioned, the sensitivity and the bandwidth of the seismic sensors etc. It is also important to get a good handle on the in-situ velocity model (P and S wave) for improving the location of seismic events.
  - ***Automatic location of data:*** Automatic location of microseismic events is very helpful during the creation of the reservoir to assess the growth and the direction of the reservoir. There are a number of location algorithms available and each has it's advantages and disadvantages. Commercial software is available to do automatic locations and also to help interpret the data.
  - ***Interpretation of data:*** This, like any other interpretation requires knowledge and experience. As mentioned above there are software available to be able to process the microseismic data for Fault Plane Solutions, source parameters, collapsing methods, moment tensors etc. It is important and a good practice to integrate all

the other information such as the hydraulic history, joint network, stress regime, geology and other in-situ parameters to obtain meaningful interpretation of the data.

- *Quantification of stimulated area and heat transfer volume:* Both of these parameters are needed to assess the life of an EGS system under operating conditions. This is difficult and still in a development stage. Information from microseismic, tracers, joint network, numerical modelling and geology is used to calculate the heat transfer area and heat transfer volume. Work is continuing on these topics. One of the problems is that there are not enough EGS reservoirs in a circulation mode to carry out experiments to assess and confirm the data.

- Tracer studies
  - *Selection of tracers:* Quite a lot of work has been done on this topic to select the right tracer for a specific task. The work is in the process of being written up.
  - *Sampling, breakthrough time and modal volume:* Although procedures for specific tests have been established, the interpretation needs to be better defined with the help of numerical models.
  - *Heat transfer area:* This is a difficult parameter to assess because of the dependence on the nature of the system, i.e., open or closed.
  - *Life of a reservoir:* This is an important parameter to define the return on investment. Some numerical models are available which rely on the hydraulic, tracer, microseismic and geochemical data but it is difficult to give supporting evidence due to the lack of any circulating EGS system for a prolonged period. Results from task 3.1.5 (below) will be very helpful in defining the procedure and interpretation on this task.

3.1.5 Task E- Field Studies of EGS

(Task Leaders: Peter Rose, EGI University of Utah, USA and Albert Genter, EEIG and EC)

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

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

3.2 Review of EGS Field Studies in 2008

3.2.1 July-August 2008 Circulation Test

The deeper reservoir between wells GPK2 and GPK3 was circulated in July-August 2008 while the power plant was being commissioned. A line shaft pump (LSP) was installed at 350 m depth in GPK2 and GPK4 was shut-in. Following the earlier circulation test in 2005, the injection well GPK3 was subjected to further acid stimulation in 2007 to improve permeability but without success. GPK4 had been subject to three different types of acidization treatments with some success. Circulation began at the beginning of July 2008 and lasted until mid-August 2008. During this period, the pump-assisted production from GPK2 was around 25 l/s with a backpressure of 2 MPa. The production fluid temperature at the surface reached 163 °C. The heat was extracted using a heat exchanger before being re-injected in GPK3. The wellhead injection pressure in GPK3 started at 6 MPa and increased faster initially but then slowed down and settled at 7 MPa during the last week of the test. The reinjection temperature varied from 40 °C to 110 °C, depending on the cooling capacities. Approximately 190 microseismic events were located during this test and the event rate was comparable to that observed in the 2005 circulation test. They also occurred in much the same locations as the earlier events, just below the GPK3 and GPK4 but the magnitudes did not exceed ML 1.4, compared to those generated in 2005 which included events in excess of ML 2.0. This may reflect differences between the two tests. In 2005, using the buoyancy effect in the production well the circulation test lasted for 6 months compared to 2008 where circulation was assisted by the use of a line shaft pump in the production well during a period of only 2 months.

3.2.2 November-December 2008 Circulation Test

The circulation test of November-December 2008 was performed after the installation of the second production pump (ESP - Electro-Submersible Pump) into GPK4 and the re-installation of the LSP into GPK2. The ESP (GPK4) was started on 17 November first, followed by the LSP (GPK2) one week later. Unfortunately, the LSP encountered problems and had to be stopped. It was restarted on 1 December 2008, and the circulation test (which involved all three deep wells) continued until 17 December, when the test had to be stopped due to technical problems. The production flow in GPK2 was around 17 l/s with a surface temperature of 163 °C at the end of the test. Production from GPK4 started at around 17 l/s and quickly deceased to a steady value of around 12 l/s with a final production temperature of about 155 °C. Wellhead pressure in both wells was maintained at 2 MPa in order to prevent scaling. At the beginning of the test, that is when only GPK4 was producing, the re-injection into GPK3 was at around 17 l/s, then declined to about 12 l/s as the wellhead pressure increased to 2.8 MPa. When the second well (GPK2) was put in production, the reinjection flow rate rose to 27 l/s and the wellhead pressure was increased up to 8.6 MPa.

Work is continuing on the analysis of the data and the interpretation of the results.

3.3 Work Performed in 2009

Many of the Task activities were revised during 2009. As a consequence of reduced funding from various participating organizations, efforts on Task projects were much reduced. It is expected that this will pick up in 2010 as more funding becomes available.

3.3.1 Task A- Economic Modelling

The major effort in this Task involved its re-establishment with new objectives (see Section 3.1.1 above). The work on redefining economic related parameters has started and is continuing.

3.3.2 Task B- Application of Conventional Geothermal Technology to EGS

The US Department of Energy continues to fund research projects bridging hydrothermal technology and technology that is more specific to Enhanced Geothermal Systems development. Results of these projects are summarized in "EGS Program Review" (http://www1.eere.energy.gov/geothermal/egs_prog_review.html), and described in the EGS sessions of the GRC (2007) and the SGERW (2007). Further discussion and plans are being prepared to see how recent experiences from hydrothermal projects can be adapted to help EGS.

3.3.3 Task C- Data Acquisition and Processing

During 2009 no specific work was conducted within this Task. However, a handbook that facilitates the planning of specific EGS project steps and provides an overview to the state of art of commercially available services, which was completed in 2005: Enhanced Geothermal System Project Management Decision Assistant or EGS-PMDA (see IEA-GIA website under http://www.iea-gia.org/geothermal_information.asp) is still being distributed at a cost only to cover reproduction and postage.

Various avenues are being considered to reactivate this Task due to its long-term importance. Both public and private sectors are being contacted to fulfil this important task. The Task is much larger than expected and needs to involve long-term commitment from an organisation that will have to do the archiving and website maintenance.

3.3.4 Task D- Reservoir Evaluation

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

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

3.3.5 Task E- Field Studies of EGS Reservoir Performance

As stated above, this Task was being re-designed during 2007 and the task has been re-defined and some circulation tests were carried out in 2008/2009. During and following the installation of the power plant at Soultz in 2008, two short term circulation tests were carried out (reported above) but long term circulation is being planned for 2009/10 as the power plant has been installed and minor engineering problems have been rectified. Reservoir characterisation such as tracer breakthrough time, modal volume, etc., will be carried out to evaluate the reservoir parameters.

3.4 Work Planned for 2010

The lack of many developing or operating EGS projects in the world has slowed down many of the Task efforts in this Annex, but it is anticipated that the activities will increase as US, Australian and German funding begin to bring new EGS projects on-line. Additionally, these Tasks have been slow in progressing because of adverse publicly associated with the generation of larger microseismic events in EGS reservoirs, the difficulty with obtaining funding (private and public) due to the financial crisis, and the lack of willingness of privately funded EGS projects to disclose much of the information gained, as it is considered confidential for commercial reasons. It is anticipated that further EGS projects will come on-line by the latter part of 2011, and they will help to correct this situation.

3.5 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 (discontinued)
- Deep Heat Mining, Switzerland: http://www.dhm.ch (discontinued)
- 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 (discontinued)
- Soultz European HDR Project: http://www.soultz.net/

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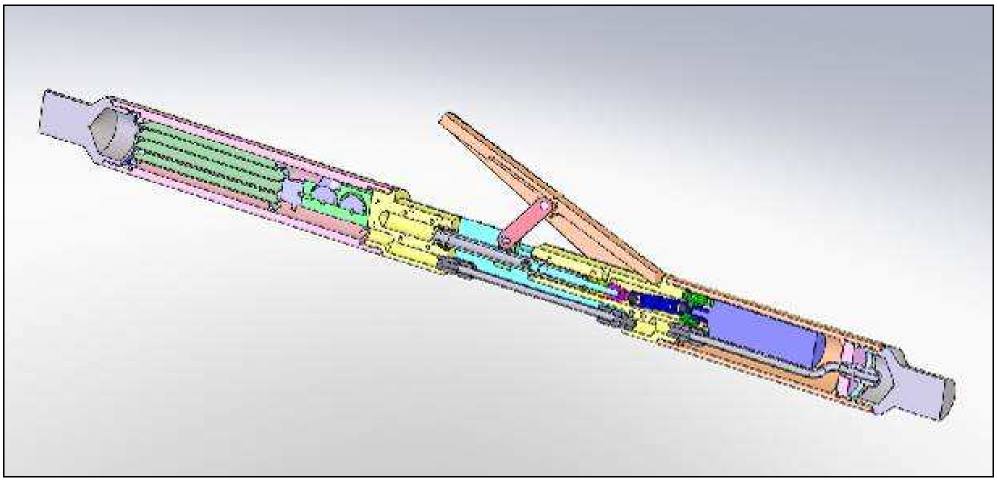
Chapter 4

Annex VII- Advanced Geothermal Drilling Technology



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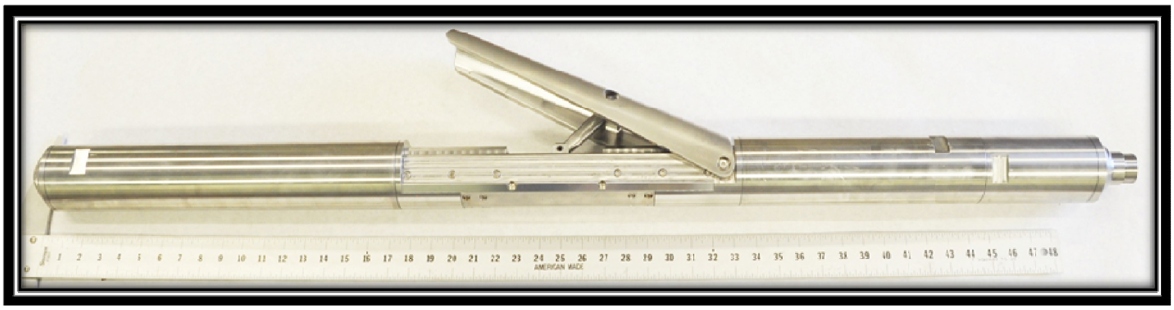

As Built

Figure 4.1 *Sandia high temperature seismic tool.*
(Figure and photo courtesy of Joe Henfling, Sandia National Laboratories, USA)

4.0 Introduction

The objective of advanced drilling and logging technologies 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 and logging 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 and Logging Technologies Annex will address aspects of geothermal well construction, which include:

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

The objectives of Advanced Geothermal Drilling and Logging Technologies 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 and logging technologies

Annex VII of the Geothermal Implementing Agreement has been developed to pursue advanced geothermal drilling and logging research that will address all aspects of geothermal well construction. Participants in this Annex are: Australia, Mexico, Iceland, the European Commission, New Zealand, and the United States.

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

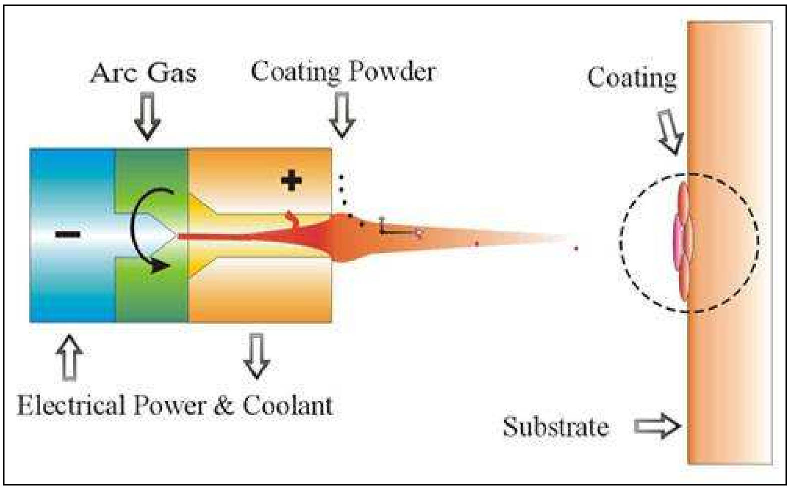

Figure 4.2 *Evaluation of thermal spray coatings as a pressure seal.*
(Figure courtesy of Joe Henfling, Sandia National Laboratories, USA)

4.1 Tasks of Annex VII

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

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

(Task Leader: Stephen Bauer, Sandia National Laboratories, USA).

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

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

(Task Leader: Stephen Bauer, Sandia National Laboratories, USA).

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

4.1.3 Task C- Advanced Drilling and Logging Collaboration

(Task Leader: Stephen Bauer, Sandia National Laboratories, USA).

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

4.2 Work Performed in 2009

4.2.1 General

Provided reports to the 21st and 22nd ExCo meetings, completed written Annex VII reports, and provided Annex VII revised descriptions for the revised GIA Document.

The Annex VII participants met in May 2009, in Madrid, Spain; and in October, in Reno, Nevada, USA, in association with the GIA ExCo Meetings.

The following is an update of Annex VII activities presented and discussed at those meetings, and which took place in the past 12 months.

Key Points from the Annex Meetings:

- Each of the six active participants in the Annex was represented at both meetings: Australia, Iceland, Mexico, New Zealand, European Commission, and the United States.

- ➢ Each Task was discussed, with a view towards maintaining a substantive path forward

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

No new well data was added to the database in 2009.

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

Work on the Drilling Handbook was reinitiated. The US DoE authorized work through Sandia National Laboratories. A detailed outline for the Handbook was developed and it was fleshed out, and text for the handbook was developed.

4.2.3 Task C- Advanced Drilling and Logging Collaboration

Requests for collaboration were received, discussed, and information exchanged between principal investigators. Potential for technology sharing continued.

At the October 2009 Annex VII meeting, Joe Henfling, Task Leader for HT Geothermal Tool Development, Sandia National Laboratories, made a presentation: *Sandia/DoE recent successes and plans for the immediate future for downhole tools.*

4.3 Highlights of Annex Programme Work for 2009

The effort to re-invigorate the Drilling Handbook was significant and led to measurable progress on the draft.

4.4 Work Planned for 2010

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

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

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

Output: A more comprehensive compilation of cost data received.

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

Plans are to complete a full draft of the Handbook for review and comment by a limited set of reviewers.

Output: Status reports to Executive Committee.

4.4.3 Task C- Advanced Drilling and Logging Collaboration

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

Output: Reports to Executive Committee.

5. Outputs for 2009

Published Papers

Mansure, A.J., Blankenship, D.A., 2009. Geothermal Well Cost Update 2008. Sandia National Laboratories. Transactions Geothermal Resources Council, September, 2009, Reno, Nevada.

Henfling, J., 2009. Development of an Integrated Power Controller Based on HT SOI and SiC. Presentation at: HiTEN (High Temperature Electronics Network). 13-16 September 2009, St. Catherine's College, Oxford, UK.

Henfling, J., Greving,J., Maldonado, F., Chavira, D., Uhl, J., 2009. Development of a high temperature seismic downhole tool. World Geothermal Congress 2010 (submitted abstract).

Bauer, S.J., Blankenship, D.A., Nathwani, J., 2009. Geothermal Implementing Agreement, Annex VII: Advanced Geothermal Drilling Technology. World Geothermal Congress 2010 (submitted abstract).

6. Websites Related to Annex Work

- http://www.sandia.gov/geothermal
- http://www.nrel.gov/geothermal/
- http://engine.brgm.fr/

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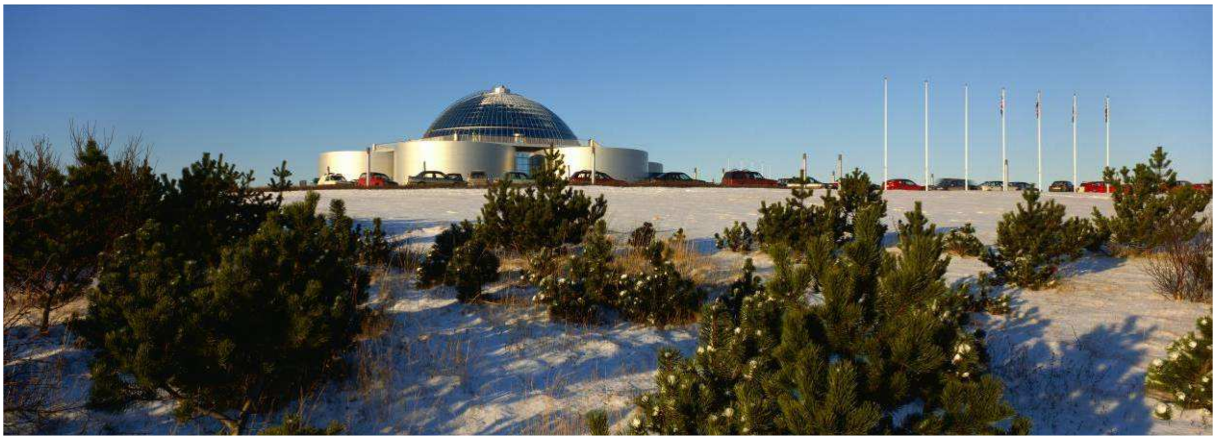
Chapter 5

Annex VIII- Direct Use of Geothermal Energy



The Pearl in Reykjavik. Hot water storage tanks with a restaurant on the top. Picture taken during the winter. (Photo courtesy of Einar Gunnlaugsson)

5.0 Introduction

For thousands of years geothermal water has been used for various applications. In earlier times the hot water was only used where geothermal water was present in surface springs. It was used for bathing, cooking and for therapeutic purposes. During the last decades, direct use of geothermal water has increased significantly; and today, direct use of geothermal energy is possible everywhere as the use of geothermal heat pumps has proven. Today, geothermal water is used for different applications that require heat, such as: heating buildings, individually or for whole towns; raising plants in greenhouses; drying crops; heating water at fish farms; snow melting; bathing and for therapeutic purposes and several industrial processes.

To promote further direct use of geothermal water and to learn from each other, IEA-GIA decided to establish an Annex on this subject. The Direct Use of Geothermal Energy Annex was initiated in 2003, when the agreement entered into force.

The objectives of Annex VIII are to:

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

Participants of this Annex in 2009 are: France, Iceland, Japan, Korea, New Zealand, Spain, APPA (Spain), Switzerland and USA.

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

5.1 Tasks of Annex VIII

Six tasks have been defined for this Annex, and work has started for five of these tasks.

5.1.1 Task A- Resource Characterization

(Task Leader: Hirofumi Muraoka, National Institute of Advanced Industrial Science and Technology (AIST), Japan)

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

5.1.2 Task B- Cost and Performance Database

(Task Leader: Yoonho Song, Korea Institute of Geoscience and Mineral Resources (KIGAM), Republic of Korea)

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

5.1.3 Task C- Barrier and Opportunity Identification

(Task Leader: Yoonho Song, Korea Institute of Geoscience and Mineral Resources (KIGAM), Republic of Korea)

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

5.1.4 Task D- Equipment Performance Validation

(Task Leader: To be appointed)

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

5.1.5 Task E- Design Configuration and Engineering Standards

(Task Leader: Ladsi Rybach, Geowatt, Switzerland)

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

5.1.6 Task F- Publication and Geographical Presentation on the Web

(Task Leader: Einar Gunnlaugsson, Orkuveita Reykjavikur, Iceland)

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

5.1.7 Expected Results

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

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

5.2 Work Performed in 2009

An Annex VIII meeting was held in 2009, in connection with the ExCo meeting held in Reno, USA, in October 2009.

5.2.1 Task A- Resource Characterization (Temperature and Chemistry)

Evaluation of data on the temperature and chemistry of the geothermal manifestations from Korea, Iceland, Japan and USA has been made. The results show that differences in chemistry are related to the different rock types and geological environments. The paper presented at the Renewable Energy 2008 conference in Busan was accepted to be published in ***Current: Applied Physics***.

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

The Questionnaire for Direct Use of Geothermal Energy was first developed in 2006. It has been revised and sent to more countries than the first one. The revision was focused on barrier and opportunity identification. Answers from twelve countries have been received and compilation and analyses have been made.

5.2.3 Task E- Design Configuration (Engineering Standards)

The collection of available information has begun and a list of references regarding published material is available. The first compilation shows that some data is available from the participants' countries but further compilation and collection is needed.

5.2.4 Task F- Publication and Geographical Presentation on the Web

The aim of this task is to define a suitable form to present data on direct use of geothermal water geographically on the web. Tests have been made to present data in files which can be opened on the web through Google Earth. This method looks promising and future work will be to develop this method further. Minimum data which have to be collected to be able to show data in graphical information systems was listed for various applications.

5.3 Work Planned for 2010

5.3.1 Task A- Resource Characterization (Temperature and Chemistry)

Proposed next steps:

- Prepare a paper to be submitted to WGC2010 in Bali, Indonesia
- Define how resource characteristics are affecting direct use of the recourses
- An output for Task A at the end of the third term is to publish ***An Atlas of World Hydrothermal Systems*** that contains a variety of diagrams and maps

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

Proposed next steps:

- Prepare a paper to be submitted to WGC2010 in Bali
- Define suggestions to remove barriers

5.3.3 Task E- Design Configuration (Engineering Standards)

Proposed next steps:

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

5.3.4 Task F- Publication and Geographical Presentation on the Web

Proposed next steps:

- Guidelines regarding files for Google Earth and other geographical information systems
- Find best option to open web-page for the work regarding Annex VIII
- Try to get webpage on material selection related to the chemistry of water translated to English (Website: http://www.lagnaval.is)

5.3.5 Expected Outputs for 2010

- A simple standardized database will be identified that can be used to show the direct use applications by each of the participating countries
- Several papers will be presented at the World Geothermal Congress 2010, Bali, Indonesia

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National Activities

Chapter 6

Australia

Weatherford rig 828 on site at the Paralana Geothermal Project, drilling the first well into the Paralana resource, northern Flinders Ranges, South Australia. (Photo courtesy of Petratherm Ltd.)

6.0 Introduction

The use of geothermal energy for electricity generation and direct use applications is new technology to Australia and requires successful technical and commercial demonstration before gaining widespread acceptance. Nonetheless, in the nine years since the first Geothermal Exploration Licence (GEL) was granted in Australia, interest and activity in the geothermal sector has increased at a tremendous pace.

Nationally, to the end of 2009, 54 companies have applied for 403 licence areas (covering 475,000 km^2) to progress proof-of-concept amagmatic Enhanced Geothermal Systems (EGS) and Hot Sedimentary Aquifer (HSA) projects (Figure 6.1). This represents a 32% increase in applications from 2008, but leaves vast prospective areas still to be licensed for geothermal exploration (Figure 6.2). From 2002 to 2009, more than AU$ 454 million (US$ 409 million) has been spent on studies, geophysical surveys, drilling, reservoir stimulation and flow tests which comprise the work programs required to sustain tenure in geothermal licence areas.

Geothermal resources with considerable potential to enable power generation in Australia generally fall into two categories: EGS and HSA plays (i.e., hot groundwater resources in sedimentary basins). However, at present, the sector remains in a pre-competitive phase with the only geothermal energy currently produced in Australia being from a 120 kW plant located in Birdsville, Queensland. This plant is operated by Ergon Energy (see Section 6.3.1) and sources medium temperature hydrothermal waters at relatively shallow depths from the Great Artesian (Eromanga) Basin.

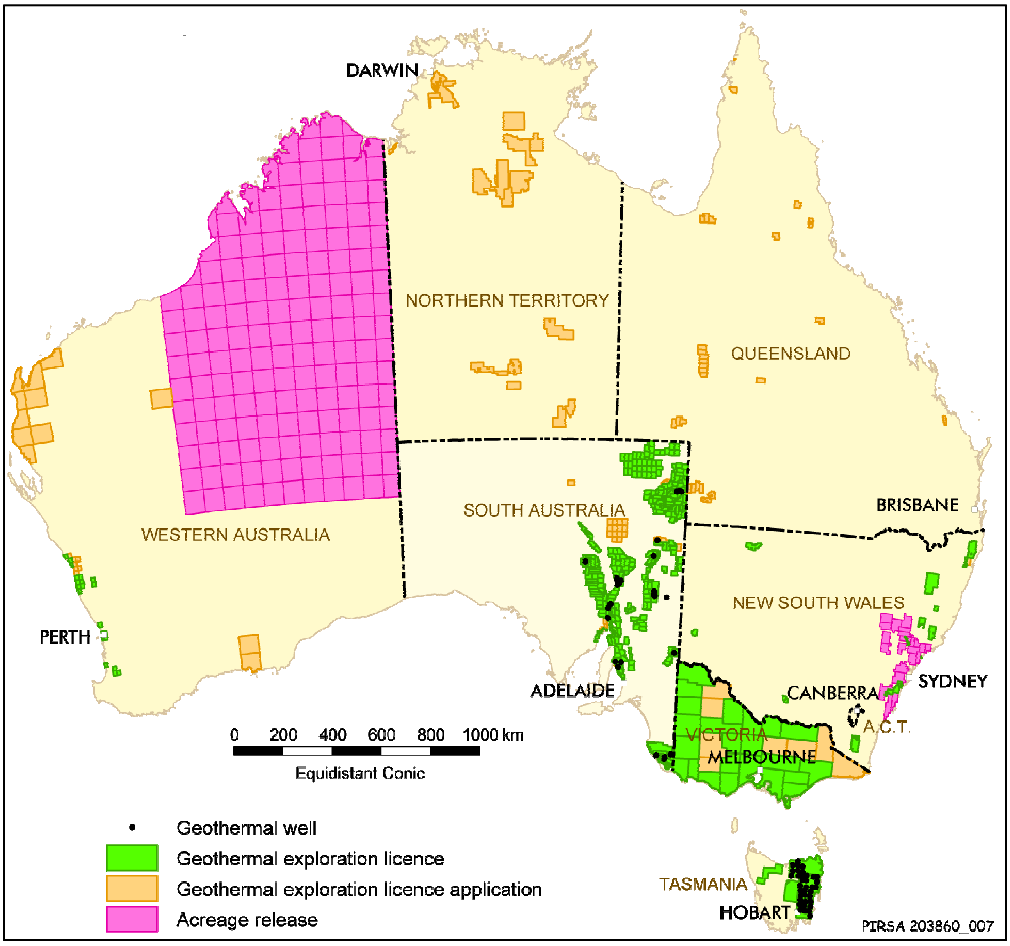

Figure 6.1 Geothermal licences, applications and gazettal areas as at 31 December 2009.

6.1 Highlights and Achievements for 2009

- The Australian Government amended the Renewable Energy Target, aiming for a substantially increased target of 20% of national electricity supply to be sourced from renewable sources by 2020. In concert, new and additional funding strategies were introduced under the AU$ 4.5 billion [US$ 4.1 billion] Clean Energy Initiative, to support the research, development and demonstration of low emission energy technologies.
- A total of AU$ 230 million (US$ 207 million) in grants were awarded during 2009 by the Australian and state governments for geothermal research and exploration projects. Government grants awarded to the geothermal sector from 2000 to 2009 now total AU$ 291 million (US$ 261 million).
- Petratherm Ltd drilled its first well to reservoir depths (>3000 m) to test their EGS resource at the Paralana Geothermal Project site in South Australia. Early stage exploration drilling was also undertaken by Geothermal Resources, Deep Energy and Torrens Energy. Synopses of operating Australian geothermal companies and their activities for 2009 are provided in Appendix 6A.
- At 31 December 2009, a total of AU$ 2,960 million (US$ 2,664 million) in work program investment is forecast for the period 2002 to 2014. An estimated AU$ 455 million (US$ 409 million) of this forecast was invested in the term 2002 to 2009. These forecasts are based upon current proposed exploration work programs and

exclude capital expenditure associated with demonstration power plants. However, not all projects may continue to the completion of their tenure.

6.2 National Policy

6.2.1 Strategy

In 2009, substantial changes were made to the Australian Government's existing set of policies and programs aimed at supporting the development of affordable and efficient low-emission and renewable energy technologies and reducing Australia's greenhouse gas emissions.

Through the expanded Renewable Energy Target (RET), the Australian Government's goal is to source at least 20% of Australia's electricity supply from renewable energy sources by 2020. This will provide a cross-subsidy to the renewable energy industry worth billions of dollars. The Australian Government's modelling shows that by 2020, geothermal projects could take up one fifth of the target, or around 10,000 GWh.

The RET scheme was initially supported by two funds: the AU$ 500 million (US$ 450 million) Renewable Energy Fund and the AU$ 150 million (US$ 135 million) Energy Innovation Fund, which were expected to stimulate over AU$ 1.5 billion (US$ 1.35 billion) investment in renewable energy generation. These funding mechanisms have been built upon, and additional initiatives implemented, with the May 2009 Budget announcement of the AU$ 4.5 billion (US$ 4.1 billion) Clean Energy Initiative (CEI), which is specifically designed to support the research, development, and demonstration of low emission energy technologies (see Sections 6.2.3 and 6.2.4 for further detail on this initiative).

6.2.2 Legislation and Regulation (including acreage releases)

In Australia, legislation and regulation of geothermal exploration and development is state and territory government responsibility. To the end of 2009, each of the six states (New South Wales, Queensland, South Australia, Tasmania, Victoria and Western Australia) and one territory (Northern Territory legislation commenced operation on 1 December 2009) had legislation in place to regulate geothermal exploration and development. Relevant legislation is summarised in Table 6.1.

6.2.3 Progress Toward National Targets for Renewable Energy and Emissions

The Australian Government has pledged that by 2020, 20% of Australia's electricity supply will come from renewable sources. To this end, in 2009, the Australian Parliament passed legislation to expand the national Renewable Energy Target (RET) from 9,500 GWh to 45,000 GWh by 2020 (see Section 6.4.1).

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

The expanded Renewable Energy Target (RET) provides a strong incentive to accelerate the uptake of Australia's abundant renewable energy resources (discussed in section 6.4.1). However, significant increases in renewable energy technologies and various commercial challenges facing the renewable energy industry cannot solely be addressed by implementation of the RET. Resolving these challenges requires supporting legislation and funding structures to encourage research, development and demonstration of these renewable energy technologies.

Table 6.1 Summation of the applicable legislation currently governing geothermal exploration activities in the various Australian states.

State or Territory Government	Applicable legislation for geothermal exploration	Description
South Australia	*Petroleum and Geothermal Energy Act 2000*	Regulates licensing and activity approvals for upstream petroleum, geothermal, gas storage and petroleum pipeline projects. An "over the counter" system, where explorers can apply for those areas desired. Licences can co-exist with existing or future minerals and petroleum exploration titles.
Victoria	*Geothermal Energy Resources Act 2005*	Regulates large-scale commercial and sustainable exploration and extraction of geothermal energy resources.
New South Wales	*Mining Act 1992*	Governs geothermal exploration, which is considered as Group 8- Geothermal Substances. Application for a Group 8 geothermal exploration licence requires the Minister's consent.
Queensland	*Geothermal Exploration Act 2004*	Applies a competitive permit system to encourage and facilitate efficient and responsible exploration.
Tasmania	*Mineral Resources Development Act 1995*	Geothermal tenements are granted as a Category 6 mineral "Special Exploration Licence" (SEL). An "over the counter" system, where explorers can apply for those areas wanted for exploration. Licences can co-exist with existing or future minerals and petroleum exploration titles.
Western Australia	*Petroleum and Geothermal Energy Resources Act 1967*	Provides legislative coverage for the exploration and recovery of both conventional (hydrothermal) geothermal energy and EGS (hot dry rock) geothermal energy. Does not cover non-commercial uses or heat pumps.
Northern Territory	*Geothermal Energy Act 2009*	Provides for "over-the-counter" application for geothermal authorities over most of the Territory. Intent is to reserve a relatively small region around the Katherine area for later tendered release.

The AU$ 4.5 billion Clean Energy Initiative (CEI), announced in May 2009, is a key platform for achieving this objective. The CEI comprises three elements which provide a targeted framework for research and development support. These are:

- Carbon Capture and Storage Flagships Program (AU$ 2.425 billion over nine years)
- Solar Flagships Program (AU$ 1.6 billion over six years)
- Australian Centre for Renewable Energy (ACRE) (AU$ 465 million).

The Australian geothermal sector benefits most directly from targeted programs administered under ACRE. ACRE's objectives are to promote the development, commercialisation and deployment of renewable energy and enabling technologies to a point where they can be on a competitive footing with existing energy technologies. ACRE therefore acts as a central agency for Australian renewable energy businesses, consolidating various new and legacy programs including:

- Renewable Energy Demonstration Program
- AU$ 15 million Second Generation Biofuels Research and Development Program
- AU$ 50 million Geothermal Drilling Program

- AU$ 20 million Advanced Electricity Storage Technologies Program
- AU$ 14 million Wind Energy Forecasting Capability Program
- AU$ 18 million Renewable Energy Equity Fund.

Programs under ACRE that have direct relevance to the Australian geothermal sector are:

- Geothermal Drilling Program (GDP)– The GDP supports companies with the cost of drilling for proof-of-concept geothermal projects. In 2009, seven recipients were awarded grants of AU$ 7 million each (US$ 6.3 million), including: Hot Rock Ltd– Otway Basin, Victoria; Geodynamics– Hunter Valley, New South Wales; GRE Geothermal WA1 Pty Ltd– Perth, Western Australia; Greenearth Energy Ltd– Geelong, Victoria; Torrens Energy Ltd– Parachilna, South Australia; Petratherm Ltd– Paralana, South Australia; and Panax Geothermal Ltd– Limestone Coast, South Australia.
- Renewable Energy Demonstration Program (REDP)– REDP accelerates the commercialisation and deployment of new renewable energy technologies for power generation in Australia by assisting the demonstration of these technologies on a commercial scale by providing grants on a 2:1 matched funding basis for eligible demonstration projects. Two geothermal projects were awarded REDP grants: Geodynamics Ltd (AU$ 90 million) for its Cooper Basin project and Petratherm Ltd (AU$ 62.7 million) for its Paralana project.

Australia's Onshore Energy Security Program- In addition to the CEI, part of the Australian Government's AU$ 58.9 million (US$ 53 million) funding over five years for the Onshore Energy Security Program (OESP) will be directed towards the advancement of geothermal energy projects (see Section 6.7.2). Approximately AU$ 1.3 million (US$ 1.16 million) from this program has been spent directly on geothermal projects (including salaries) up until December 2009.

State and Territory Government Initiatives- Growth and activity in the Australian geothermal sector has benefited from targeted policy and legislative frameworks and generous grant funding from the Australian state and territory governments. Australia's 2007 and 2008 GIA Annual Reports outline previous and continuing Australian, state and territory government programs and initiatives, including the Geothermal Industry Development Framework (GIDF) (DRET, 2008a) and Council of Australian Governments' (CoAG) Technology Roadmap (DRET, 2008b). Current government programs supporting geothermal energy research and development are summarised in Table 6.2.

South Australia (SA)- Launched in 2004 by the South Australian Government, the AU$ 22.5 million (US$ 20 million) Plan for Accelerating Exploration (PACE) initiative includes funding for collaborative exploration programs that address critical uncertainties in mineral, petroleum and geothermal exploration.

To the end of 2009, a total of AU$ 4.7 million (US$ 4.2 million) in PACE and other research grants has been provided to underpin the advancement of geothermal energy projects and to establish the South Australian Centre for Geothermal Energy Research (SACGER). In addition, the South Australian Government continues to provide the secretariat for the AGEG and is the Contracting Party to the IEA GIA for Australia. For details of successful projects supported by PACE funding, see: http://www.pir.sa.gov.au/minerals/pace/theme_2. Research supported by the South Australian Government is discussed further in Section 6.7.2 and Appendix 6B.

Western Australia (WA)- Government research and development is carried out by the Geological Survey of Western Australia (GSWA), within the Department of Mines and Petroleum. Total research and development expenditure on geothermal in 2009 by GSWA was AU$ 187,077.

In March 2008, the Western Australian Government committed AU$ 2.3 million (US$ 2 million) to establish the Western Australian Geothermal Centre of Excellence (WAGCOE), a partnership between the University of WA, Curtin University and the CSIRO, to foster geothermal research into low-grade (up to 130 °C) heat in permeable sedimentary settings such as the Perth Basin. For more information, see section 6.7.2 and Appendix 6B.

Queensland- Under its Renewable Energy Plan, the Queensland Government has taken a number of steps in 2009 that support the wider use of geothermal energy. Most notable is the implementation of the AU$ 5 million (US$ 4.5 million) Coastal Geothermal Energy Initiative (CGEI), to investigate additional sources of EGS geothermal energy close to existing population centres and transmission lines.

New South Wales (NSW)- The NSW Climate Change Fund was established in July 2007 and incorporates the Renewable Energy Development Grant (RED), which provides AU$ 40 million (US$ 36 million) over five years to support projects which are expected to lead to large scale greenhouse gas emission savings in NSW by demonstrating renewable energy technologies and supporting the early commercialisation of renewable energy technologies.

Round One of the RED program focussed on funding renewable energy projects that will generate electricity or displace grid electricity use for stationary energy purposes. Under this program, Geodynamics Limited were awarded AU$ 10 million (US$ 9 million) for their Hunter Valley Geothermal Project.

In addition, as part of its New Frontiers Initiative, the NSW Government initiated a project focused on mapping and identification of prospective geothermal energy systems. A suite of scientific data such as: granite geochemistry, potential field data, heat flow units, bottom-hole temperatures from petroleum wells are being compiled and will be presented as geothermal data packages.

Victoria- In 2009, the Victorian Department of Primary Industries (DPI) initiated a AU$ 500,000 (US$ 450,000) study to collect and compile datasets on heat flow and thermal conductivity across the state. This fundamental geothermal data will be compiled into a state-wide heat flow map and database.

The Rediscover Victoria Drilling program has also offered several Victorian explorers a total of AU$ 250,000 (US$ 225,000) to co-fund shallow heat flow exploration drilling in their permits to help fill gaps in current knowledge.

The Energy Technology Innovation Strategy group within DPI granted Greenearth Energy AU$ 5 million (US$ 4.5 million) for deep appraisal drilling, to be followed by AU$ 20 million (US$ 18 million) for a demonstration power plant if the drilling is successful.

In addition, the four year 3D Victoria project building a full crustal 3D model of Victoria is well underway. This AU$ 2.5 million (US$ 2.25 million) project incorporates and reconciles potential field data such as gravity, magnetics and seismic into the model. Attribution of the geothermal data into this model will allow regional scale modelling of geothermal potential across the state.

Table 6.2 An overview of grants currently available to the Australian geothermal sector and their relationship to the stages of individual project development. All currency values in Australian Dollars (AU$) and million expressed as 'M' throughout the document AU$ 1 = US$ 0.90.

Agency	Research & pre-drill	Shallow drilling & early exploration	Deep drilling to resource depth	Proof of Concept	Pre-competitive Production demonstration	Production
Australian Government (federal)	Geoscience Australia (GA) data		Energy Technology Innovation Strategy ~AU$ 5M awarded to date		Renewable Energy Future Fund (REF)	Renewable Energy Credits (RECs)
			REDI ~AU$ 100 M total, available at AU$ 5M per well	REDI ~AU$ 100M total, at AU$ 50,000- 5 M per proposal	REDI~AU$ 100M total, at AU$ 50,000 – 5 M per proposal	
			GDP~ AU$ 50 M total, available at AU$ 7 M per well		REDP~ AU$435M Total, available at $50 – 100 M per proposal	
				Energy Innovation Fund ~AU$ 50 M total	Energy Innovation Fund ~AU$ 50 M total	
South Australian Government	SA PACE ~ AU$ 1.6 M total, at up to $ 100,000 per proposal	SA PACE ~ AU$1.6 M total at up to $ 100,000 per well			Regional Development Infrastructure Fund	
Victorian Government		Rediscover Victoria AU$ 250,000 total	Energy Technology Innovation Strategy	Energy Technology Innovation Strategy	Renewable Energy Support Fund	
Western Australian Government	Exploration Incentive Scheme ~AU$ 81 M total, available at up to AU$ 200,000 per proposal					
New South Wales Government				NSW Climate Change Fund ~AU$ 40 M total	NSW Climate Change Fund ~AU$ 40 M total	
Queensland Government		QLD Collaborative Drilling Initiative				QLD Renewable Energy Plan AU$ 4.3 M

6.2.5 Industry Expenditure on Geothermal R&D

Australian geothermal sector field expenditure is considered as research and totalled AU$ 133 million (US$ 119.7 million) in 2009. This represents a 103% increase, or AU$ 59 million (US$ 53 million), on the previous year. A 156% increase to AU$ 197 million ($US 177 million) is forecast to be expended in 2010. Historical, current and projected expenditure for 2009 are highlighted in Figure 6.2.

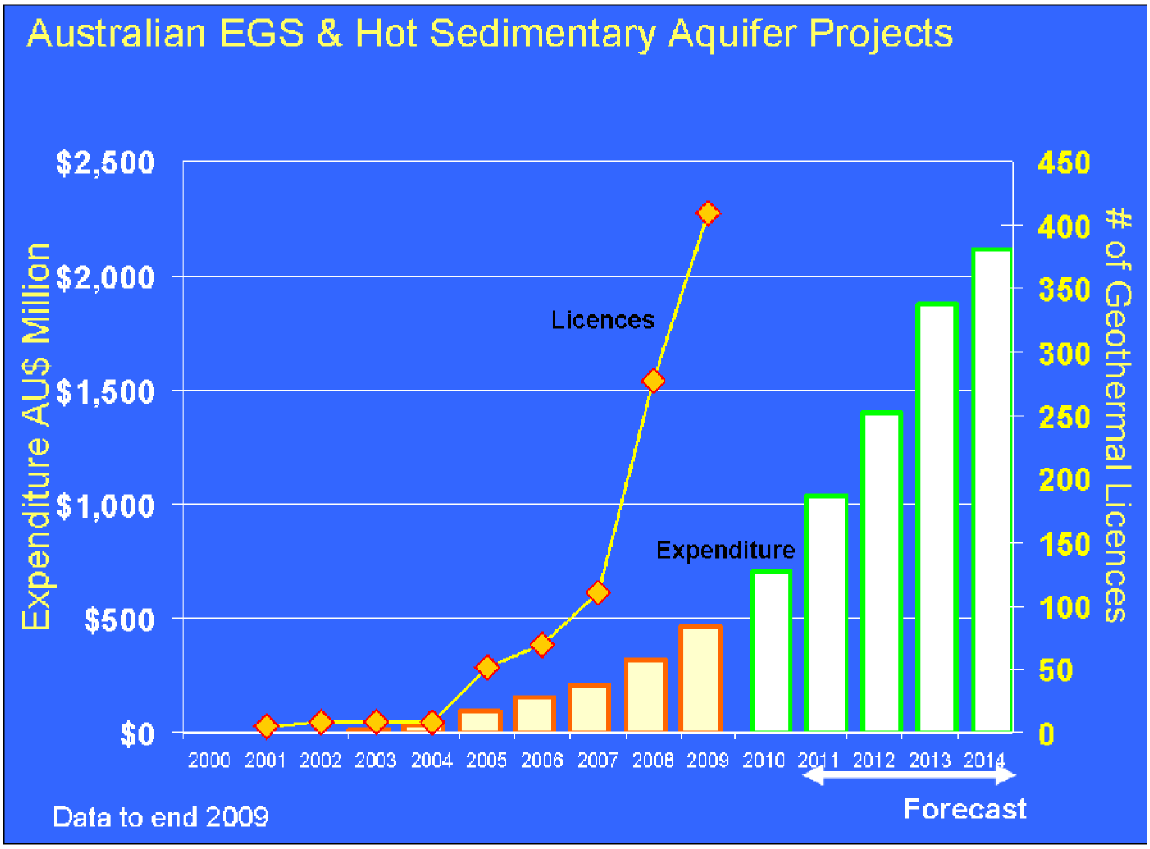

Figure 6.2 Growth in Australian EGS and Hot Sedimentary Aquifer projects since 2000, indicating the cumulative increases in exploration expenditure and geothermal licence applications actuals 2000 to 2009 and the forecast for 2010. (source: PIRSA)

6.3 Current Status of Geothermal Energy Use In 2009

6.3.1 Electricity Generation

Geothermal energy is currently produced at one small binary power station at Birdsville, Queensland, which is supplemented by diesel powered generators. The fluid has a temperature of 98 °C and derives from the Great Artesian Basin (also referred to as the Eromanga Basin) which overlies the Cooper Basin. The water is run through a gas-filled Organic Rankine Cycle heat exchanger and the partly cooled water is channelled into a pond for further cooling and reticulation into the town's water supply and lagoon. The gross capacity of the plant is 120 kW and the plant power consumption is 40 kW, equating to a net output of 80 kW. Total exported power generation in 2009 was 1,885,606 kWh, of which 597,240 kWh was provided by the geothermal power plant. This equates to 32% of total exported power output, which reduced diesel consumption by about 130,000 litres and saved about 375 tonnes of greenhouse gas emissions through the year.

Ergon Energy, who operate the plant, have completed a feasibility study into whether Birdsville's entire power requirements can be provided by geothermal energy, relegating the existing LPG and diesel-fuelled generators to back-up use at peak times. In response, the Queensland Government has committed AU$4.3 million (US$3.8 million) in funding to replace the aging plant. Discussions between Ergon Energy and the Queensland Government continued throughout 2009, addressing the need to increase Ergon's water allocation licence from the Great Artesian Basin for this purpose.

6.3.2 Direct Use

6.3.2.1 Installed Thermal Power

Australia's total installed capacity in direct geothermal applications is estimated to be 132 MW_{th}. This is up from the 2005 estimate of 109.5 MW_{th} (Lund et al., 2005).

6.3.2.2 Thermal Energy Used (including capacity factor)

Following Lund et al. (2005) with a capacity factor of 0.9, the thermal energy used is estimated to be 3746 TJ/yr, up from the 2005 estimate of 2968 TJ/yr.

6.3.2.3 Category Use (space heating, bathing, heat pumps, etc)

District heating (space heating) constitutes the majority with an estimated 98 MW_{th}. Bathing and swimming installations total 8 MW_{th}. Ground source heat pumps (GSHPs) constitute the remaining 26 MW_{th}.

6.3.3 Energy Savings (Direct Use)

6.3.3.1 Fossil Fuel Savings/Replacement

The estimated fossil fuel saving is 89,201 tonnes of oil equivalent (toe, 1 toe = 42 GJ).

6.3.3.2 Reduced/Avoided CO_2 Emissions (tonne/yr)

Using the DTI/Carbon Trust/DEFRA/Ofgem recommended figure of 0.43 kg CO_2 per kWh saved, yields avoided emissions of CO_2 of 447 tonne/yr.

6.4 Market Development and Stimulation

6.4.1 Support Initiatives and Market Stimulation Incentives

The Australian Government's Renewable Energy Target (RET) scheme was initiated to stimulate investment and growth in Australia's renewable energy industry, including the geothermal sector. Key goals of the RET scheme are:

- To promote additional generation of electricity from renewable energy sources with a declared target of 20% of national electricity supply from renewables by 2020
- To achieve reductions in greenhouse gas emissions in the electricity sector

RET is implemented via the *Renewable Energy (Electricity) Act 2000* and the *Renewable Energy (Electricity) (Charge) Act 2000*. This legislation facilitates the achievement of RET objectives by: placing a liability on wholesale electricity purchasers to proportionally contribute an additional 45,000 GWh of renewable energy per year by 2020; and setting the framework for both the supply and demand of Renewable Energy Certificates (RECs) via a REC market.

RECs are an electronic form of currency created on the REC Registry and able to be transferred between eligible parties (recognised renewable energy generators) and liable parties (wholesale purchasers of electricity) for a negotiated price. Compliance with the RET is encouraged by a shortfall charge being levied against liable parties who do not meet obligations to purchase RECs.

During the course of 2009, amendments to the legislation and expansion of the RET scheme were developed, with two amendment bills being passed by Australian Parliament. Amendments included an increase in the renewable energy target to 45,000 GWh and an increase in the shortfall charge.

RET does not provide a rebate or feed-in tariff.

6.4.2 Development Cost Trends

There is no data available as yet to assess development cost trends.

6.5 Development Constraints

Whilst geothermal energy resources in Australia have vast potential, geothermal power generation is not yet price-competitive, particularly in the absence of a carbon price.

6.6 Economics

6.6.1 Trends in Geothermal Investment

Over the past three years, the Australian Government has committed AU$ 203 million (US$ 182 million) to the geothermal energy sector with the approval of seven applications under the Geothermal Drilling Program (GDP) and AU$ 153 million (US$ 137 million) with the approval of two grants under the Renewable Energy Demonstration Program (REDP). Approximately AU$ 12 million (US$ 10.8 million) of these funds have been released to companies thus far, as recipients are required to achieve certain milestones prior to payment. As such, the sector has developed to its current stage primarily on the back of private sector investment.

No additional companies listed on the Australian Securities Exchange (ASX) in 2009, although equity markets continued their support of the geothermal sector by participating in capital raisings undertaken, despite the impacts of the global financial crisis (GFC). The combination of the GFC and limited activity in the sector has made further capital raisings difficult, although equity markets have indicated support for the technology and willingness to invest further when certainty improves.

6.6.2 Trends in Cost of Energy

The Australian Geothermal Energy Association (AGEA) sponsored work by MMA Associates on the benefits to the market of accelerating the introduction of geothermal from South Australia. They estimated this benefit at AU$ 2.7 billion (US$ 2.4 billion); highlighting the cost competitiveness of geothermal against other low emission energy technologies across Australia (Table 6.3; McLennan Magasanik Assoc., 2009).

The Australian Energy Markets Commission (AEMC) has proposed changes to the National Electricity Market (NEM) rules which assist transmission companies develop Scale Efficient Network Extensions (SENE), to help accelerate the connection of remote renewable projects, including geothermal energy.

Table 6.3 *Comparison of long run marginal costs of generation technologies, AU$/MWh, mid 2008 dollar terms. (After McLennan Magasanik Assoc., 2009)*

	2020	2030
Coal Options		
Supercritical coal (dry-cooling)	97	117
IGCC	99	110
IGCC with CC	101	98
Supercritical coal with oxyfiring and CC	107	109
Post-combustion capture	149	174
Natural Gas Options		
CCGT - small	97	104
CCGT - large	88	95
Cogeneration	76	80
CCGT with CC	104	102
Renewable Energy Options		
Wind	102	96
Biomass - Steam	110	108
Biomass - Gasification	109	105
Solar Thermal	250	229
Solar Hot Water	157	150
Geothermal – Hydrothermal**	75	72
Geothermal - Hot Rocks (EGS)	99	95
Geothermal - Hot Sedimentary Rocks (HSR)	97	93
Geothermal – Direct Heat*	105	100
Concentrating PV	271	259
Roof Top PV	507	397

Calculated assuming 10.2% discount rate. Calculated at a notional regional reference node in the NEM (common basis for comparing technology costs in the wholesale market) by assuming marginal loss factors i the range from 3% to 10%, with higher losses applying to technologies likely to be located in remote region Assumes carbon prices as per Treasury's CPRS -5 scenario. Capital costs sourced from AGEA, IEA, Sun an Wind Power Journal, Gas Turbine World and US DOE. Assume de-escalation rates for capital as pe assumptions used in MMA's analysis of CPRS for Federal Treasury (including the assumption that the suppl shortage and material cost factors that increased costs of all generation options dissipates by 2012). Costs d not include transmission costs other than modest connection charges. Costs are accurate to +/- 20% fo mature technologies and +/- 50% for immature or as yet developed technologies.

* The direct heat option, on a displaced electricity cost basis, will be competing on a delivered electricity co basis (not at the regional reference node) as in this table. At the estimated long run marginal costs in this tabl (which assumes heat loads are located close to the heat source), the delivered energy cost for this technolog will be significantly lower than current average retail tariffs for commercial customer classes (current averaging above $130/MWh) and some less energy intensive (low voltage level) industrial customer classe (where current retail tariffs are above $100/MWh).

** The opportunity for this technology is limited in Australia.

6.7 Research Activities

6.7.1 Focus Topics

Australian research continues to focus primarily on the various technical challenges faced by explorers and developers of EGS, and those challenges held in common with development of HSA resources. Research topics include, but are not limited to: drilling technologies for deep, high pressure and temperature environments; environmental impacts (such as induced seismicity and efficient water use); pre-drill prediction and characterisation of geothermal reservoir potential; and innovative power generation solutions.

Although EGS focused research is most applicable to the Australian context, considerable alignment exists between identified Australian research priorities (DRET, 2008) and international research imperatives (e.g., DoE, 2008; ENGINE, 2008; IPGT, 2008) including the GIA Research Annexes (see http://www.iea-gia.org/research_tasks.asp). The Australian geothermal sector recognises that coordinating local research efforts with those of the wider international geothermal community is important, and to this end supported the creation of the Australian Geothermal Energy Group (AGEG), comprised of members from industry, government and academia, including key research institutions. The role and structure of AGEG is further discussed in section 6.9.1.

6.7.2 Government Funded Research

Geoscience Australia- In 2009, as part of the Australian Government's five year (2006-2011) Onshore Energy Security Program, key activities of Geoscience Australia's geothermal energy project included: preliminary design work on a heat flow database; refining the geological datasets used in the Austherm05 dataset of Chopra and Holgate (2005) (Figure 6.3); and commissioning a

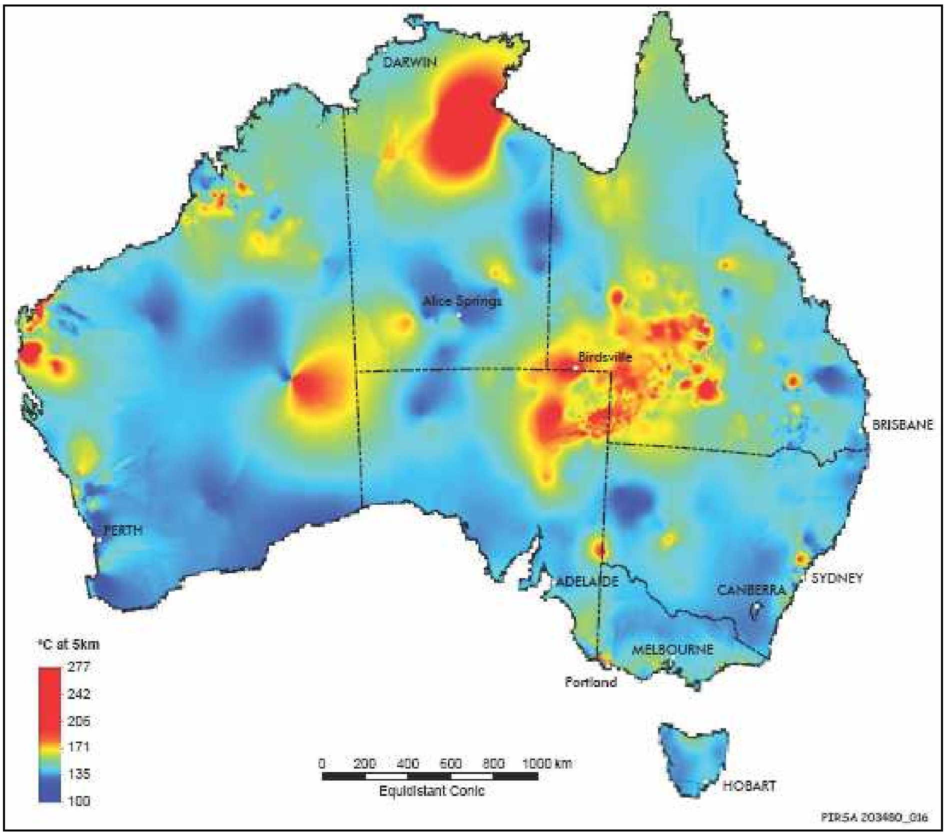

Figure 6.3 Map of estimated crustal temperature at 5 km derived from the Austherm database of Chopra & Holgate (2005). Image is 2007; Dr Prame Chopra, Earthinsite.com Pty Ltd.; © Geoscience Australia. Note: map is based on available (in places sparse) data and it is likely additional areas of relatively high temperature (> 200 °C above 5 km) will be identified in areas not yet depicted.

heat flow measurement capability comprising downhole temperature logging and thermal conductivity measurement equipment. Acquisition of seismic, MT, gravity, magnetics and geochemistry data continued in areas with energy potential.

Commonwealth Scientific and Industrial Research Organisation (CSIRO)- CSIRO's research capabilities in the geothermal arena are broad, due to the organisation's research diversity and ability to integrate multidisciplinary skills. The primary focus of CSIRO's activities in geothermal has been through its contribution to WAGCOE (see below). CSIRO's contributions to the WAGCOE are mainly in the geological, geophysical, ground water, and reservoir engineering aspects of the Perth Basin Assessment research program. CSIRO also has research expertise in hydraulic fracturing, reservoir engineering, well bore stability, rock petrophysics and microseismic monitoring. For more information, visit www.csiro.au/org/geothermal.

South Australia (SA)- Since 2005, the South Australian Government has provided AU$ 4.7 million (US$ 4.2 million) in grants for geothermal projects and research. This sum includes the first project funded by the SA Government's Renewable Energy Fund- the establishment of the South Australian Centre for Geothermal Energy Research (SACGER) via an AU$ 1.6 million (US$ 1.4 million) grant over two years from July 2009. Based at the University of Adelaide, the Centre is also supported by a grant of AU$ 400,000 from the university over the same period. In 2009, seven individual projects conducted at the Centre received supporting grants of AU$ 269,000 from the Primary Industries and Resources South Australia (PIRSA). The SACGER research program will focus on investigating subsurface factors in EGS resources such as reservoir characterisation and modelling and complement research programs of other national centres. The research program is currently being developed in consultation with the geothermal sector. For more information see Appendix 6B.

A further AU$ 750,000 grant was awarded by the SA Government to the innovative Heliotherm project, a joint initiative between the University of Adelaide's Centre for Energy Technology and Petratherm Ltd, to design and develop an integrated solar, geothermal and combustion system able to achieve high efficiency base load power generation.

Western Australia (WA)- The Western Australian Geothermal Centre of Excellence (WAGCOE) is a collaborative venture between three of Western Australia's leading research institutions: CSIRO, the University of Western Australia, and Curtin University of Technology. The Centre was established in February 2009, with a AU$ 2.3 million (US$ 2 million) grant over three years from the WA Government and substantial in-kind and cash contributions from the Centre's members.

WAGCOE is charged with leading the exploration and exploitation of geothermal energy in Western Australia, and is focussing initially on direct heat use technologies (e.g., geothermal powered air conditioning and desalination) for use in population centres where there is shallow groundwater of moderate temperature. For more information, visit: http://www.geothermal.org.au/ and Appendix 6B.

Queensland- The Queensland Geothermal Energy Centre of Excellence (QGECE) is based at the University of Queensland and was established with a AU$ 15 million (US$ 13.5 million) grant from the Queensland Government and AU$ 3.3 million (US$ 2.9 million) of in-kind support from the university. The Centre commenced operations in January 2009 with a five year program designed to fill gaps in the national and international geothermal research effort. The Centre's focus is on new tools for precompetitive exploration of high heat producing granites and above ground technologies, with the aim of accelerating large-scale utilisation of geothermal energy in Australia. For more information, visit: www.uq.edu.au/geothermal and Appendix 6B.

New South Wales (NSW)- Geothermal research at the University of Newcastle focuses on novel power generation cycles and the concept of CO_2 thermosiphon concept for Engineered Geothermal Systems (EGS). The study of power cycles is regarded as a key area for major technological improvements since many of the problems associated with power generation from geothermal sources are underpinned by inefficient, and often unsuitable, heat exchange processes within power cycles. This is partly due to the fact that most power cycles currently in use were originally designed for large-scale power production from fossil fuels, where higher temperature sources are available for heat exchange. For more information see Appendix 6B.

Victoria- The Melbourne Energy Institute, located at the University of Melbourne, has a number of geothermal projects including the Victorian Geothermal Assessment Report, which intends to address critical issues for the successful development of geothermal power capability in Victoria. For more information, visit: www.energy.unimelb.edu.au.

6.8 Geothermal Education and Conferences

6.8.1 Postgraduate Education

A Master's level course in Advanced Energy Systems was introduced in 2009 at the University of Newcastle to cover a range of topics including geothermal power generation.

6.8.2 Australian Geothermal Energy Conference (AGEC)

The 2nd Australian Geothermal Energy Conference (AGEC) was held in Brisbane, Queensland, from 10-13 November 2009. This annual national conference is jointly presented by the Australian Geothermal Energy Association (AGEA- the industry representative body for Australian geothermal companies) and the Australian Geothermal Energy Group (AGEG- representing the wider Australian geothermal energy community including industry, government and academia).

Building on the success of the 2008 inaugural conference in Melbourne, the AGEC has now cemented its position as the premier national conference dedicated to geothermal energy. The 2009 conference was strongly supported, with attendance of over 370 delegates from the geothermal sector, business and government. Over 100 papers were presented on a range of key technical and commercial topics. Concurrent with the AGEC, a pre-conference technical seminar on joint geophysical methods for geothermal exploration was held, facilitated by the Institute of Earth Science and Engineering, University of Auckland and the New Zealand Geothermal Association (NZGA).

6.8.3 WGC2015

Australia and New Zealand submitted a joint bid to host the 2015 IGA World Geothermal Congress in Melbourne, Australia. Success of the bid was announced in November 2009 and planning for the event is underway. The 2015 WGC will be jointly organised and supported by the Australian Geothermal Energy Association (AGEA), the Australian Geothermal Energy Group (AGEG) and the New Zealand Geothermal Association (NZGA). For more information, visit: http://www.pir.sa.gov.au/__data/assets/pdf_file/0005/90590/WGC_2015_screen.pdf.

6.9 International Cooperative Activities

Australia is a member of the IEA Geothermal Implementing Agreement, and participates in Annexes I (Environmental Impacts of Geothermal Development), III (Enhanced Geothermal

Systems) which is led by Australian-based company Geodynamics Ltd., VII (Advanced Geothermal Drilling and Logging Techniques), Annex VIII (Direct Use of Geothermal Energy), Annex X (Data for Geothermal Energy Applications) and Annex XI (Induced Seismicity) . Geodynamics Ltd and Green Rock Energy (both listed on the Australian Securities Exchange) are Australian corporate sponsors of the IEA Geothermal Implementing Agreement.

Australia is also a founding member of the International Partnership for Geothermal Technology (IPGT) with Iceland and the United States. For more information, visit: http://www.internationalgeothermal.org.

6.9.1 Australian Geothermal Energy Group (AGEG)

The Australian Geothermal Energy Group (AGEG) is the Australian whole-of-sector body for industry, research and government organisations interested in the use of geothermal energy. The AGEG provides financial and intellectual support for Australia's membership in the IEA-GIA.

In 2009, the AGEG increased to 101 member organisations including: Australian geothermal licence holders and licence applicants and service companies; 11 Australian universities with geothermal research programs; and all Australian, state and territory government agencies responsible for providing geoscientific information, attracting investment, and regulating licences for the geothermal sector.

The organisational structure of the AGEG and its 12 Technical Interest Groups (TIGs) (Figure 6.4) are designed to facilitate coordination of Australia's research effort, and foster national and international sharing of information, expertise and research into improved technologies and techniques. The TIGs have active organisational links to the IEA-GIA's research annexes, and to the IPGT's working groups and have also been active in coordinating technical workshops and short courses on topics associated with their individual Terms of Reference. For more information, visit: http://www.pir.sa.gov.au/geothermal/ageg and see Appendix 6B.

Australian Geothermal Energy Group (AGEG) Technical Interest Groups (TIGs)											
Communication & Community Issues				**Geothermal Technologies**							
TIG 1 Sustainability	TIG 2 Reserves & Resources	TIG 3 Induced Seismicity	TIG 4 Outreach	TIG 5 Economic Modelling/ Novel Use	TIG 6 Power Plants	TIG 7 Direct Use	TIG 8 Information & Data	TIG 9 Reservoir Development & Engineering	TIG 10 Exploration & Logging Technologies	TIG 11 Drilling & Well Construction	TIG 12 Direct Use
Licensing requirements; emissions; water & effluent management; environmental impacts	Forum for contributions and discussion on the Australian Geothermal Reporting Code	Focussing on the need for technical research and informed public communication on induced seismicity.	Includes conferences & web-content	Includes economic models, cost benchmarks & novel uses.	Improving geothermal power plant efficiency e.g. cycle type & fluids, heat exchanger efficiencies & cooling processes	Investigate direct use geothermal applications including both circulating hot water & geothermal heat pumps.	Data availability, usefulness & exchange via standards, database design, content & development of interpretive tools.	Reservoir characterisation, reservoir modelling, geochemistry & reservoir stimulation	Foci include geophysical methods, pre-drill resource prediction & logging	Foci include; lower cost Drilling, zonal isolation & packers, temporary sealing of fractures, reducing exploration drilling costs.	Industry short courses, Tertiary curricula & internat'l post-grad exchange
Related Linked IEA GIA Research Annexes and IPGT Working Groups											
IEA GIA: Annex I		IEA GIA: Annex I & III		IEA GIA: Annex III	IEA GIA: Annex VI (Proposed)	IEA GIA: Annex VIII	IEA GIA: Annex III	IEA GIA: Annex III IPGT: Stimulation procedures & modelling	IPGT: Exploration Technologies	IEA GIA: Annex VII IPGT: lower cost drilling & zonal isolation	

Figure 6.4 The organisational structure for the Australian Geothermal Energy Group (AGEG) and its Technical Interest Groups are designed to foster national and international sharing of information.

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Acknowledgements

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National Activities

Chapter 7

European Commission

7.0 Introduction

The EU is supporting geothermal energy through its Framework Programmes for Research and Innovation. The current 7th Framework Programme (FP7) has regular calls for proposals in the area of geothermal energy. On the political side, the EU has launched the Strategic Energy Technology Plan (SET-Plan), designed to be the technological pillar of EU energy policy.

7.1 Major Highlights and Achievements for 2009

In the FP7 ENERGY 2009 call, a topic on mitigation of seismic risk was opened. A large international proposal was submitted and approved. Negotiations were completed in 2009 and the GEISER project officially started 1 January 2010 (Coordinator: GFZ, Germany, contact: David Bruhn, dbruhn@gfz-potsdam.de). The FP6-projects GROUND-HIT (Co-ordinator: CRES, Greece, contact: Kostas Karytsas, kkari@cres.gr) in the domain of shallow geothermal and LOW-BIN (Co-ordinator: CRES, Greece, contact: Kostas Karytsas), related to deep geothermal power generation were terminated in 2009.

In 2009, ongoing projects were EGS-PILOT PLANT (Co-ordinator: GEIE, France, contact: Albert Genter, genter@soultz.net) dealing with the pilot plant at Soultz-sous-Forêts, France; and I-GET (Co-ordinator: GFZ, Germany, contact: David Bruhn) dealing with geophysical exploration of reservoirs. In the projects GROUND MED (Co-ordinator: CRES, Greece, contact: Dimitri Mendrinos, dmendrin@cres.gr) and TERRA THERMA (Co-ordinator: Pera, UK, contact: Zoe Wanstall, zoe.wanstall@pera.com) ambient heat stored at shallow depths represents the essential component of energy-efficient heating and cooling systems in buildings. The past decade has seen a very steep increase in the deployment of heat pumps. Today, there is a real need for improved buildings integration of low temperature heating andcooling, and the EC intend to cover these issues through Private Public Partnerships.

The new European Technology Platform for Renewable Heating and Cooling (RHC-ETP) was endorsed by the European Commission in October 2008 and started in spring 2009. This platform gathers all main renewable heating sources and stakeholders (biomass, solar thermal and geothermal) and deals with strategic issues for growth, competitiveness and sustainability.

The structure of this platform has been approved by the board and the next important objectives are to elaborate a shared/common vision about the development of the market by 2020 - 2030 with the preparation of the related Strategic Research Agenda.

7.2 EU Policy

7.2.1 Strategy

The SET-Plan comprises 6 European Industrial Initiatives (EEI), none on geothermal energy; and the European Energy Research Alliance (EERA). Preparatory workshops were organised for designing roadmaps for the EEIs and a joint programme for the EERAs. The geothermal EERA group was particularly active and, in 2009, produced a roadmap and a complete joint programme outlining research needs for geothermal energy until 2030.

7.3 EU Expenditure on Geothermal Research and Development

EU support for geothermal energy RTD adds up to over € 7 million in FP7 to the end of 2009. In 2009, € 5.3 million were allocated. Industrial and other participation added € 1.8 million. € 1.6 million were allocated to "soft actions" close to the market, mainly for promotion and education measures on heat pumps through the Intelligent Energy Europe Programme.

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National Activities

Chapter 8

France

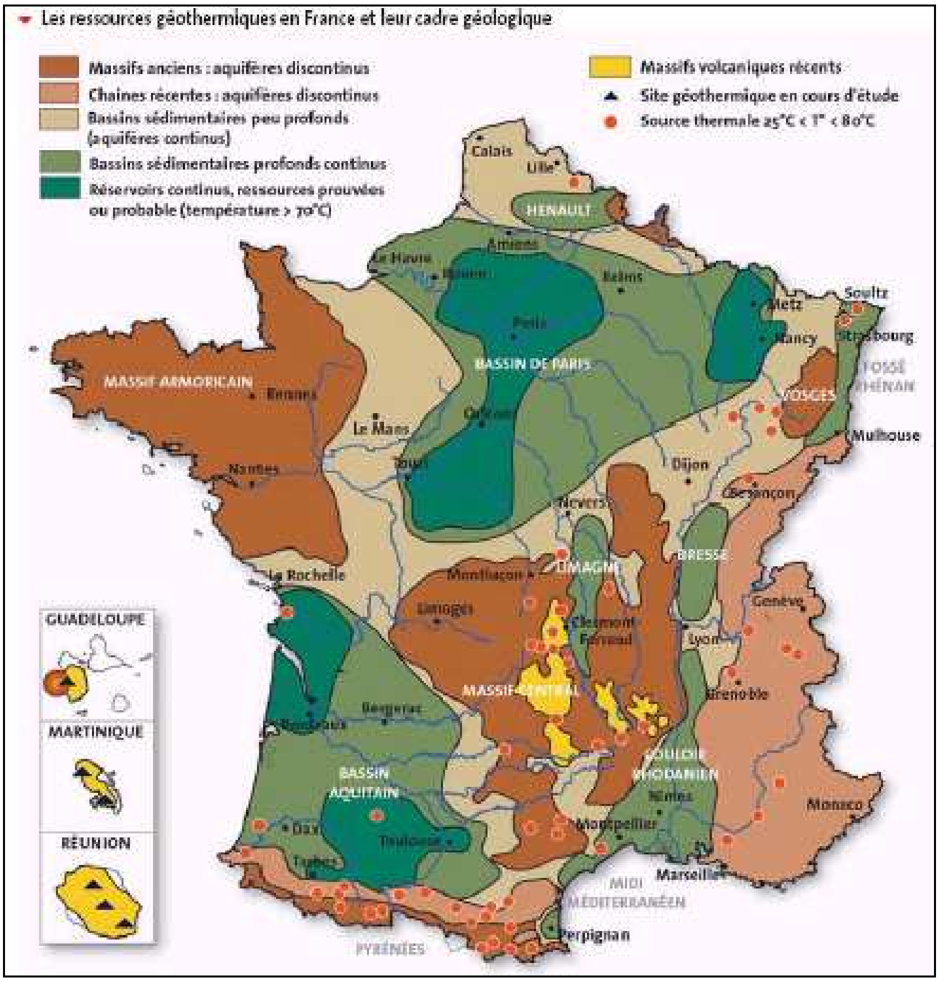

Figure 8.1 *French geothermal resources.*

8.0 Introduction

Following the implementation of the French Energy Law in 2005 and the large consulting process "Grenelle de l'environnement" launched in 2007, a strong focus has been put in France on the development of renewable energy sources. These two elements, which establish the structure for the French energy policy, assign renewable energy sources, including geothermal energy, an important role and, *a priori*, the necessary financial resources to allow their real development.

Geothermal energy benefits from an old development in France, for all kinds of geothermal energy, which gives a strong base for a renewed and rapid growth:

- Geothermal heat pumps experienced a first development in the 1980s, and, notably through the presence of French SME, the market has developed again since 2003
- Geothermal district heating already supplies heat for more than 150,000 dwellings, and new operations have been launched since 2007
- Electricity production is especially suitable in overseas departments that are not connected to the European grid. The Bouillante plant on Guadeloupe Island has an installed

capacity of 15 MW and is considering new development; and exploration works shall begin in Martinique and la Réunion

- Concerning enhanced geothermal systems, after more than 20 years of R&D works, the Soultz project is now operational and provides a worldwide reference for this technology

8.1 National Policy

8.2.1 Strategy

The French national policy towards renewable energy sources was greatly advanced with the "Grenelle de l'environnement", France's Environment Round Table. The initiative was taken by Nicolas Sarkozy when he was elected President in 2007. For the first time, the consulting process brought together the society's main bodies: unions, local authorities, industry, NGOs and administration. For three months, working groups met to propose concrete action to be implemented at national, European and international levels. In October 2007, these proposals were opened up to debate by a range of public groups. Thus began a stage looking at the technical, legal and administrative aspects, which will serve to assess how best to implement all the measures decided upon. Around thirty operational committees met to define guidelines and objectives for operational programs.

Following this process, a law proposal was presented in the Parliament in November 2008 in order to put in writing the objectives, and to provide the framework for an ambitious action plan for attaining these objectives. The law proposal was accepted with quasi-unanimity votes in Parliament and the Sénat.

Among the objectives, climate change mitigation is the main one, with the following targets in line with the European Directive on renewable energy sources: to decrease by 38% the building energy consumption, to increase by 20 Mtoe/yr the consumption of Renewable Energy (which is in line with the target of 23% of renewable energy sources in energy consumption), and to decrease by 20% GES (greenhouse gas) emissions in transport.

Within this framework, powerful tools were set up, or reinforced, in favour of renewable energies. On 17 November 2008, a declaration was made by the Minister for Ecology, Energy, Sustainable Development and Town and Country Planning for 50 measures for the development of high environmental quality renewable energies. Geothermal energy is a concern of several of them:

- A "Renewable Heating and Cooling Fund" is set up by the finance law 2009-2011 voted in November 2008. This law creates a fund for supporting renewable heating and cooling in tertiary, collective buildings or agricultural/industrial processes. This fund is dedicated to the funding of operational projects, under the following principle: to reach a renewable energy sources heat price at least 5% lower than conventional heat. For that, an economic analysis is conducted for each project in order to determine the level of subsidy. This fund is granted € 1 billion for the 2009-2011 period, and is designed to gradually reach € 800 million/yr, increasing by a large factor the public money previously dedicated to renewable energy sources for heating and cooling. Among the renewable energy sources, it is foreseen that geothermal energy projects (geothermal heat pumps and direct use) will represent around € 130 million for the 2009-2011 period.
- Tax credits are maintained until 2012 for the purchasing of heat pumps.
- R&D work on geothermal heat pumps is supported with two priorities: assessment of the potential of the superficial underground and aquifers for geothermal heat pumps, and the installation of an experimental platform devoted to R&D for geothermal heat pumps at BRGM.

- A R&D program will be launched to accompany Soultz-sous-Forêts pilot plant exploitation.
- The feed-in tariff for geothermal electricity will be raised.

8.2.2 National Targets

Following the "Grenelle de l'environnement", an operational committee devoted to renewable energy sources proposed in 2008 a burden sharing among renewable energy sources in order to reach the +20 Mtoe/yr of renewable energy sources in 2020. For geothermal energy, the following targets were set up, updating the targets set in the law on energy in 2005:

Table 8.1 *"Grenelle de l'environnement" targets for geothermal heating (in ktoe/yr).*

	2006	2012	2020
Geothermal district heating	130	195	500
Large geothermal HP	50	100	250
Individual geothermal HP	40	240	550
Total geothermal heating	**220**	**535**	**1300**

Table 8.2 *"Grenelle de l'environnement" targets for geothermal electricity production in French overseas departments, including importation from Dominica (MW installed capacity).*

	2006	2020
Guadeloupe	15	90
Martinique	0	40
La Réunion	0	60

8.3 French Geothermal Resources

France has several types of geothermal resources.

Low-energy resources, developed for thermal applications, are primarily located in the two major existing sedimentary basins: the Paris Basin (for which Paris is the geographical centre) and the Aquitaine Basin in southwest France. The resources are found at depths between 600 and 2,000 m.

Other French regions also have high potential for low-energy resources, but the geological structures are more complex and the fields much more localized (Alsace, Hainault, Bresse, Limagne, etc.).

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

Finally, the entire French territory has a good supply of superficial water-bearing strata that can be exploited using heat pumps.

Several studies have been conducted in the last years by BRGM (French Geological Survey), with the cooperation of ADEME (French Energy Agency) to update the assessment of French geothermal resources. Specific focus is now on the potential of clayed sandstone aquifers in various French sedimentary basins, which are not yet exploited.

8.4 The Development of Geothermal Heat Pumps

8.4.1 Heat Pumps for Individual Houses

After a rapid increase to 2007, the market for geothermal heat pumps for individual houses is stagnant, at around 20,000 units/yr. In parallel, we observe a boom in the selling of air-source heat pumps. The main reason for this is that the system of tax credit is largely in favour of air source heat pumps (Figure 8.2).

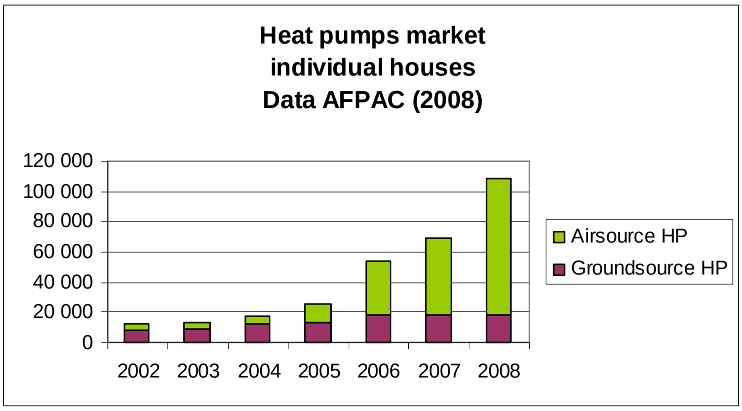

Figure 8.2 Evolution of heat pumps market for individual houses (data association française des pompes à chaleur, (AFPAC, 2008)).

There has been a slight evolution in the employed technologies: France was previously characterized by a strong market for the horizontal closed-loop ground-source type, and especially direct expansion heat pumps, with several very active SMEs. But in the last years, installations of borehole heat exchangers have grown, and the direct expansion systems are now in decline. Another important development is the rapid rise of the geothermal heat pumps in refurbished houses. Table 8.3 below clearly shows this evolution.

8.4.2 Heat Pumps for Tertiary and Collective Buildings

In the tertiary and collective buildings, the market for geothermal heat pumps is booming.

Groundwater heat pump projects, benefiting from good profitability, represent the majority of the market. No statistics are available for this market, but it is estimated at more than 100 installations/yr. The growth of this market can be illustrated by the data from the AQUAPAC guarantee (Figure 8.3). This guarantee is used only in areas where the hydrological knowledge is poor, and therefore represents a small part of the market. The evolution of the number of projects that applied for this guarantee is shown in Figure 8.3.

Table 8.3 Breakdown of the market for geothermal heat pumps for individual houses. (data AFPAC 2008)

	2005	2006	2007	% New	% Retrofit	2008	% New	% Retrofit
Direct Expansion Systems	7,800	9,600	9,600	98	2	7,900	95	5
Water or Groundwater	5,400	8,850	9,000	75	25	11,530	60	40
Total Geothermie	**13,200**	**18,500**	**18,600**	**87**	**13**	**19,430**	**74**	**26**

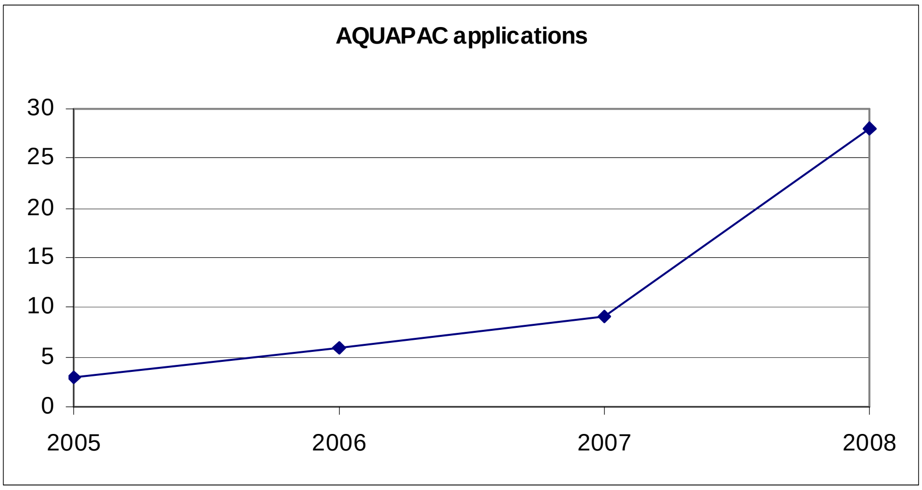

Figure 8.3 Evolution of the number of projects submitted to AQUAPAC guarantee.

The first large operations on borehole heat exchangers are emerging, but until 2008 they were not bankable with the subsidies allocated to such projects, and were therefore limited to demonstration projects. From 2009 on, with the Renewable Heating and Cooling Fund, the situation will change, and it is expected that this market will boom as well.

8.4.3 Energy and Environmental Assessment

In 2008, total geothermal heat pump installations in France represented an average annual savings of approximately 180,000 toe of fossil fuel. The number of geothermal heat pumps installed in individual houses was estimated at 122,000 units, contributing a savings of approximately 110,000 toe of fossil fuels. The geothermal heat pumps in collective and tertiary buildings contributed the remaining 70,000 toe of fossil fuel.

8.4.4 Public Programs in Favor of the Development of Geothermal Heat Pumps

Several actions were conducted by the heat pump industry and by public bodies to accompany this development. Among others, can be quoted the following:

- Initiatives to push the quality of installations: AFPAC, the French Association for Heat Pumps, has managed a quality label, QUALIPAC, for heat pump installers since 2007; BRGM, EDF and ADEME support a quality label for borehole heat exchanger drillers named QUALIFORAGE, which includes about 70 drilling companies. French standards have also been established for heat pumps (NF PAC) as for the wells.
- A geological risk guarantee, AQUAPAC, covers geological risk for large groundwater heat pump projects. This guarantee is partially funded by ADEME, allowing a low cost for the contracting body.
- Geographical information systems are being progressively developed in each French region, to assess the potential of superficial aquifers for geothermal energy.

To date, the GIS for Ile de France, Centre, Lorraine, Midi-Pyrénées regions are available online (www.geothermie-perspectives.fr).

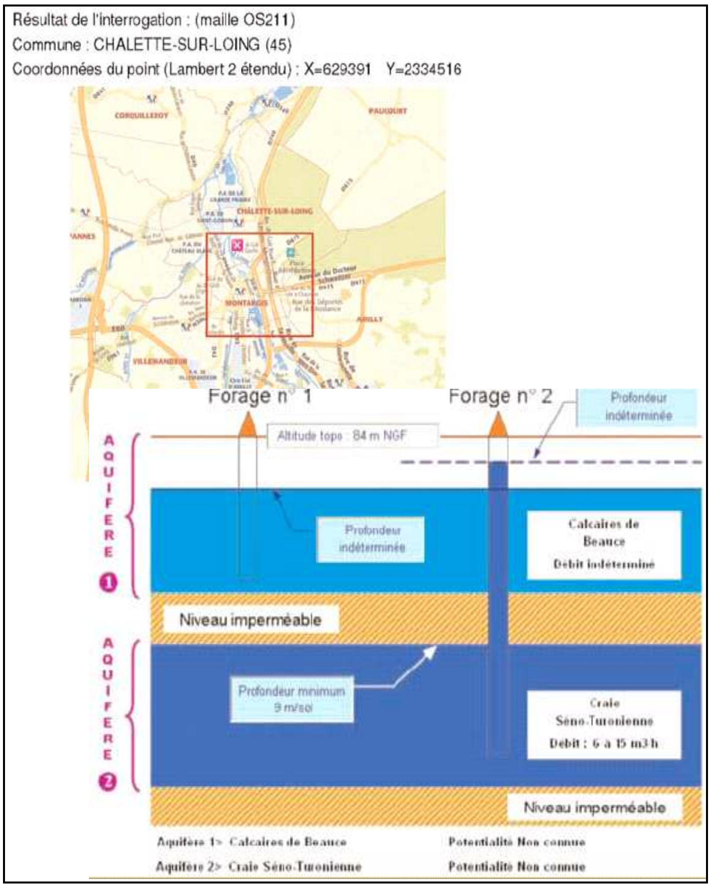

Figure 8.4 *View of the GIS potential for superficial aquifers for geothermal exploitation in Region Centre.*

- An experimental platform for geothermal heat pumps and their underground heat exchangers has been created by BRGM in Orléans, in partnership with the Région Centre.ces. This platform is aimed at a global assessment of the performances of heating systems functioning with geothermal heat pumps. Horizontal and vertical heat exchangers are driven in a controlled manner, allowing the simulation of the heat demand for any heat pump or building.

8.5 The Development of Low Energy Resources and Direct Uses

8.5.1 Current Situation and Development

The nature of the existing resources has led France to favour thermal applications of geothermal resources.

To this end, between 1961 and 2000, 112 deep exploration wells (drilled wells or rehabilitated existing wells) were created, 97 of which were brought into operation, mainly between 1980 and 1987. At present, 65 geothermal production plants (installations with single, double and triple wells) are in operation, corresponding to 60 geothermal operations *sensu stricto*. Approximately one-third of the operations were discontinued due to technical, economic or financial problems.

Most of the plants are located in the Paris Basin, with the remainder in the Aquitaine Basin.

Almost half of operations are district heat networks, which are essentially in the Paris region where they serve on average 4,000 to 5,000 LUEs (Living Unit Equivalents). Other installations provide heating systems for fish-breeding installations, horticultural greenhouses, swimming pools or aquatic leisure complexes. Table 8.4 below gives the repartition of operations for direct use in France.

Since 2007, a renewed interest in geothermal district heating was observed, especially in the Paris Region. After the drilling of a doublet replacing an old one in Orly city in 2007, 2008 was marked by:

- The drilling of one well in Sucy-en-Brie, in order to transform an old doublet into a triplet (the new well being used as production well, and the two old wells as reinjection wells).
- The preparation of a new operation for Paris city district heating, the drilling operation having successfully been performed in spring 2009.
- The preparation of a new operation in Aix en Provence, the drilling operation having successfully been performed in spring 2009.
- Several feasibility studies are in progress for operations in Paris Basin, Alsace and other regions.

Table 8.4 *Geographical breakdown of geothermal resource direct use in France in 2008.*

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

8.5.2 Energy and Environmental Assessment

Together, all these operations represent an average annual saving of approximately 130,000 toe of fossil fuel, serving about 166,000 LUEs. The annual CO_2 emission avoided is estimated at 400,000 tonnes.

8.5.3 Public Programs in Favor of the Development of Low Energy Resources

Besides the Renewable Heating and Cooling Fund that makes geothermal projects bankable, public authorities implement actions to foster the revival of low energy geothermal energy in France.

The Geological Risk Guarantee organized in the 1980s has been reactivated; it offers a low cost insurance against geological risk for drilling projects.

ADEME, ARENE (Ile de France Regional Environmental Association) and BRGM joined to organize meetings with stakeholders in 2007. Following these exchanges it was decided to develop a program for boosting geothermal energy for the Paris Basin. It covers technical and economic aspects.

A Technical Center has been created within BRGM to support geothermal stakeholders for design, realization, exploitation… This technical centre develops a pragmatic approach, based on the stakeholders' needs:

- Centralize all information, studies, data and organize public access to it in order to enhance information diffusion and access to organized data.
- Conduct specific studies on issues that the development of geothermal district heating could raise. Its role will be to coordinate the best specialists and manage dissemination of the results.
- 3 tasks have already been launched :
    - State of the art of geothermal operations (analysis of all existing options, technical (drilling, equipment), call for tender process, insurances,…)
    - Dogger aquifer management
    - Scientific works around drillings

8.6 Electricity Production in Overseas Departments

Due to their volcanic environment, the French Overseas Departments, Guadeloupe, Martinique and La Réunion, represent, for France, prime candidates for geothermal electricity production. Moreover, they are isolated islands, where electricity production by classical plants is costly and polluting.

France benefits from a successful experience in Guadeloupe, with the geothermal plant of Geothermie Bouillante. The two units, the first one, Bouillante 1, commissioned in 1984, and the second one, Bouillante 2, commissioned in 2004, have a total installed capacity of 15 MW_e. A good rate of avaibility was achieved, greater than 90%, with 95 GWh delivered to the grid in 2007.

From July 2008 on, due to a drawdown of the pressure in the field, and to avoid surface manifestations around the plant which is in an urban area, the operating capacity was decreased to 11 MW_e. The operating capacity will stay at this level until partial reinjection of the brine is implemented. The installation of the reinjection facilities will take place before the end of 2009.

Moreover, Geothermie Bouillante plans to drill exploratory wells for the extension of Bouillante plant (project "Bouillante 3"), in the northern part of Bouillante Bay (Figure 8.5). An additional capacity of 20 to 30 MW_e is expected. Drilling was authorized in December 2008 and could take place by the end of 2009.

On the other islands, no field developments have taken place to date. Nevertheless, exploration programs are planned:

- In La Réunion Island (Indian Ocean), the Regional Council plans exploratory drilling near the volcano Piton de la Fournaise. These wells could be drilled in 2010.
- In La Martinique (French West Indies), an exploration plan shall be set up in 2009 by the local authorities.

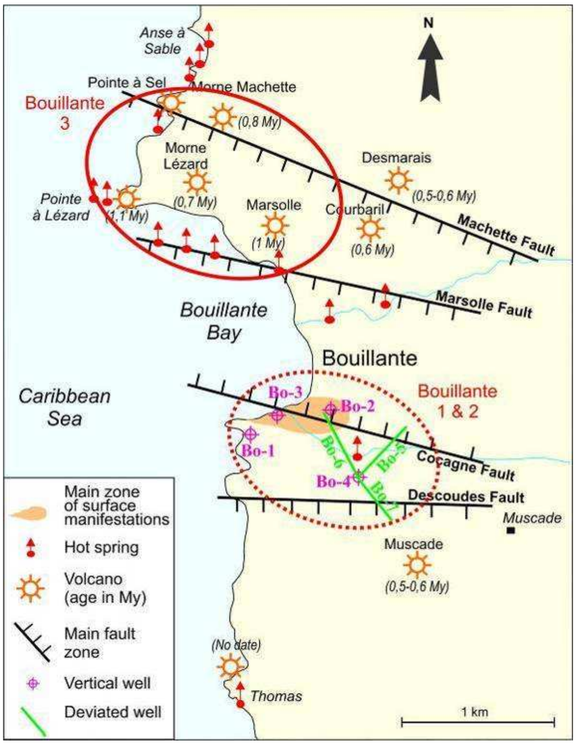

Figure 8.5 Bouillante Geothermal Field .

Geothermal energy shall contribute largely to the objective set in the Grenelle I law, to reach 50% of renewable energy in energy consumption in French Overseas Departments.

8.7 Enhanced Geothermal Systems

Since 1987, France has been committed, beside Germany and the European Union, to deep and fractured rock geothermal resources. Highly encouraging results were obtained from research conducted at Soultz-sous-Forêts (Alsace) in the east of France. This resulted, in 1999, in the decision to implement a scientific pilot plant designed to demonstrate the feasibility of the concept of deep geothermal resources.

The design of this pilot required the drilling of three wells 5,000 m deep, (2 production wells and 1 injection well), and the development of an enhanced reservoir by hydraulic and chemical stimulation of the deep fracture network. During the period 2001-2007, successful stimulation and long-term circulation testing between the wells in the deep reservoir heat exchanger were performed.

Following this phase, the construction phase of the newly-created geothermal power plant at Soultz started in autumn 2007 with the building of an ORC (Organic Rankine Cycle) plant having a net power capacity of 1.5 MW_e. During the construction phase, a lot of effort was dedicated to taking into account industrial risks such as fire due to the organic working fluid and environment issues such as noise, vibration, and visual impact. Surface equipment (turbine, air cooling system, heat exchanger) as well as two different types of down-hole pumps were installed on surface and in the production wells, respectively. The different components of the power plant have been under going testing since April 2008. Many improvements were made during the first months of operating. For example, a new lubrication system for the line shaft pump axis has been set up following damage of the shaft axis. A specific filtering system for the geothermal brine has also been improved because the first generation filter was not designed to handle the corrosive fluid. During the circulation tests done in 2008, hydraulics, induced microseismicity and corrosion were monitored continuously. In December 2008, the thermal output ranged around 12 MW_{th} for a cumulative flowrate of about 28 l/s. In 2008, the first electrical power was produced in mid-June when the power plant was officially inaugurated by the French Prime Minister.

Currently, a scientific program is set up to accompany the initial years of exploitation, with French, German and Swiss research centres participating. The main objectives will be to acquire data on the system during its exploitation and work on its long-term management.

8.8 Conclusion

Geothermal activities in France have increased significantly over recent years. The ambitious targets set during the "Grenelle de l'environnement" process put various types of geothermal energy, as other renewable energy sources, in the spotlight. The overall public awareness is getting better and better, as shown through polls conducted by ADEME in 2004 and 2008. In 2004, only 7% of the people knew about geothermal energy, whereas this figure rose to 28% in 2008. Nowadays, financial incentives give strong incentives to develop new projects. France shall thus be in a position to reach the targets for geothermal energy, provided this favourable context leads to a strong development of the supply side.

Appendices

Table A1 Present and planned electricity production.

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify)		Total	
	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr
In operation in December 2008	17	100	18300	51400	25400	68100	63100	418300	3200 800 80	5700 (wind) 5500 (biomass and waste) (solar)	110897	549100
Under construction in December 2008	0		4500		0		1600		1000 250			
Funds committed, but not yet under construction in December 2008	0											
Total projected use by 2015	50		24400		27400		64700		20200 3400 1580	(wind) (biomass and waste) (solar)		

Table A2 Utilization of geothermal energy for electric power generation as of 31 December 2009.

Locality	Power Plant Name	Year Com-missioned	No. of Units	Status[1)]	Type of Unit[2)]	Total Installed Capacity MWe	Annual Energy Produced 2008 GWh/yr	Total under Constr. or Planned MWe
Bouillante	Bouillante 1	1984	1		2F	4	10 (2008)	
Bouillante	Bouillante 2	2004	1		1F	11	79 (2008)	
Soultz-sous-Forêts		2008	1		B	2,2	0 (2008)	
Total			3			17,2	89	

Table A3 Utilization of geothermal energy for direct heat (other than heat pumps) as of 31 December 2007

Locality	Type[1)]	Maximum Utilization					Capacity[3)]	Annual Utilization (data :2007)		
		Flow Rate	Temperature (^{o}C)		Enthalpy[2)] (kJ/kg)			Ave. Flow	Energy[4)]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5)]
Bassin Parisien :										
Alfortville	D	76	73	44			9,2	41	155,4	0,53
Bonneuil sur Marne	D	78	79,3	49			9,9	23	91,9	0,29
Cachan Nord & Sud	D	100	70	46			10,0	56	176,5	0,56
Champigny sur Marne	D	78	78	45			10,8	48	210,8	0,62
Chelles	D	78	69	40			9,5	16	60,9	0,20
Chevilly Larue + L'Hay Des Roses	D	155	72,6	43			19,2	67	261,3	0,43
Clichy Sous Bois	D	50	71	44			5,6	16	56,1	0,32
Coulommiers	D	64	85	61			6,4	28	89,1	0,44
Créteil	D	84	78,9	50			10,1	53	203,3	0,64
Epinay sous Sénart	D	70	72	49			6,7	59	179,5	0,85
Fresnes	D	70	73	46			7,9	33	116,4	0,47
La Courneuve Nord	D	55	58	40			4,1	33	78,0	0,60
La Courneuve Sud	D	50	56	40			3,3	21	44,9	0,43
Le Blanc Mesnil Nord	D	49	66	40			5,3	27	91,7	0,55
Le Mée sur Seine	D	38	72	52			3,2	29	76,2	0,76
Maisons Alfort1	D	84	73	50			8,1	44	132,0	0,52
Maisons Alfort2	D	72	74	54			6,0	28	74,7	0,39
Meaux Beauval & Collinet	D	113	75	46			13,7	55	210,2	0,49
Meaux Hopital	D	36	76	51			3,8	23	74,4	0,63
Melun l'Almont	D	72	72	42			9,0	41	160,5	0,56
Montgeron	D	61	72,5	45			7,0	17	60,8	0,27
Orly 1 & 2	D	98	76	49			11,1	69	244,8	0,70
Ris Orangis	D	52	72	53			4,1	23	58,5	0,45
Sucy en Brie	D	55	77	50			6,2	35	125,1	0,64
Thiais	D	70	76	46			8,8	40	156,7	0,57
Tremblay en France	D	76	73	46			8,6	46	164,0	0,61
Vigneux sur Seine	D	67	73,2	44			8,2	31	120,9	0,47
Villeneuve Saint Georges	D	97	76	45			12,6	30	123,9	0,31
Villers le Bel	D	64	67	40			7,2	22	78,1	0,34

Table A3 *(continued)*

Locality	Type[1]	Maximum Utilization					Capacity[3]	Annual Utilization (data :2007)		
		Flow Rate	Temperature (°C)		Enthalpy[2] (kJ/kg)			Ave. Flow	Energy[4]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5]
Autres bassins:										
région Centre										
Châteauroux	D		34						53,5	
Lorraine										
Dieuze	F	31	31	20			1,4	13	18,8	0,42
Lunéville	B	42	25	15			1,8	2	3,0	0,05
Nancy1 - Thermes	B	39	45	29			2,6	5	11,3	0,14
Nancy 2 -Caserne Kellermann	D		30						22,6	
Bresse										
Montrevel en Bresse	B	17	32	20,1			0,8	4	6,9	0,26
Languedoc										
Montagnac	F	10	30	20			0,4	21	28,3	2,14
Lodève 1	G	10	30	20			0,4	24	31,6	2,40
Lodève 2	G	10	52	20			1,3	5	22,6	0,54
Pézenas	F+B	53	38	20,1			4,0	18	41,7	0,33
Limagne										
Aigueperse	G	17	43	20			1,6	14	41,4	0,80
Bassin Aquitain										
Argelouse/Sore	G	42	48	18			5,3	15	59,4	0,36
Bordeaux Benauge	B	55,5	42	30			2,8	1	1,4	0,02
Bordeaux Mériadeck	D		52						11,9	
Bordeaux Stadium	B	36	34	26			1,2	4	3,9	0,10
Gujan Mestra	B		25						7,2	
Hagetmau	B		32						10,1	
Merignac - BA 106	D	67	52	40			3,4	37	58,4	0,55
Mios le Tech	F	55,5	73	30			10,0	14	77,2	0,25
Mont-de-Marsan 1	D	70	60	54			1,8	60	47,4	0,86
Mont-de-Marsan 2	D	17	56	44			0,9	6	8,9	0,33
Pessac -Salge Formanoir	D		48						58,2	
Saint Paul les Dax 1	D+B	42	47	22			4,4	15	49,6	0,36
Saint Paul les Dax 2	H+B	8,5	60	30			1,1	4	15,5	0,46
Blagnac1	B	8,5	55	28			1,0	3	11,5	0,38
Blagnac 2	D		60						22,7	
Nogaro 2	F	50	51	27			5,0	21	66,6	0,42
Jonzac 1	D+B	8,5	60	30			1,1	5	19,8	0,59
Jonzac 2	B	17	58	26			2,3	10	43,3	0,60
TOTAL							290		4531	

Table A5 *Summary of geothermal direct heat uses as of 31 December 2008.*

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]			
District Heating [4]	300	4900	52%
Air Conditioning (Cooling)			
Greenhouse Heating	9	155	55%
Fish Farming	19	212	35%
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]			
Snow Melting			
Bathing and Swimming[7]	17	162	30%
Other Uses (specify)			
Subtotal	345	5429	
Geothermal Heat Pumps	1000	7500	24%
TOTAL	1345	12929	

Table A6 *Wells drilled for geothermal utilization (excluding heat pump wells, Including thermal gradient wells, but not ones less than 100 m deep) 2005-2009.*

Purpose	Wellhead Temperature	Number of Wells Drilled: Electric Power	Direct Use	Combined	Other (specify)	Total Depth (km)
Exploration[1]	(all)					
Production	>150° C					
	150-100° C					
	<100° C		4			6,5
Injection	(all)		3			4,5
Total			7			11

Table A8 *Total investments (US$) in geothermal in 2009*

Period	Research & Development Incl. Surface Explor. & Exploration Drilling (Million US$)	Field Development Including Production Drilling & Surface Equipment (Million US$)	Utilization: Direct (Million US$)	Utilization: Electrical (Million US$)	Funding Type: Private (%)	Funding Type: Public (%)
2005-2009	46	43	40	49	70	30

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National Activities

Chapter 9

Germany

Baker Hughes INTEQ GmbH installing a pump.
(Photo from: BMU, 2009a, p. 58)

9.0 Introduction

The positive trend in the use of geothermal energy continued in 2009. One success story is the geo thermal power plant in Unterhaching near Munich, which was awarded the European Solar Prize at the end of 2008. Unterhaching has been generating heat for the heat distribution system since late 2007 and began producing electricity in 2008. The Unterhaching model has triggered a boom in deep geothermal energy use in the Munich region. Geologically speaking, Munich is located in the Molasse basin of Bavaria, one of the most productive regions in Ger-many in terms of geothermal energy. Boreholes for geothermal systems have been drilled at a number of locations. The first systems have already begun trial operation with a view to providing electricity and heat to a number of communities.

Another region that is well placed to use geothermal energy is Oberrheingraben. Two geothermal power stations – Landau and Bruchsal – are already in operation there. Monitoring programmes record the power stations' operating parameters and their operation is being optimized. Since 2009, preparations have also been underway to operate a new plant in Insheim, to the south of Landau. Here studies are being carried out, in particular on preventing induced microseismic activity during long-term circulation. If the power station planned in Insheim can be commissioned at the end of 2010 with an electrical capacity of 4 to 5 MW, it will be the second industrially operated hydrothermal power station in the southern Palatinate region, the other being Landau.

9.1 German National Policy

9.1.1 Strategy

The 2008 lead study on renewable energies commissioned by the BMU anticipates a positive development for deep geothermal energy in Germany. The authors of the study expect the electricity generation costs of geothermal power plants to decline rapidly up until 2020. Initially, they anticipate a successful market entry for hydrothermal plants, and later for petrothermal plants. In this way, it is hoped that the installed output will rise to 100 MW by 2015 and to 280 MW by 2020, corresponding to an annual electricity production of 1.8 terawatt hours (TWh/a). Accordingly, the proportion of geothermal energy among final energy generated from renewable energies would rise to five percent by the year 2020. As well as electricity generation, the 2008 pilot study shows that the use of waste heat in corresponding district heating networks is pivotal to the success of geothermal energy.

9.1.2 Legislation and Regulation

At the end of 2009, some 15 geothermal projects were being implemented across Germany, and applications for exploration permits had been submitted for a further 150 sites. The strong market development for deep geothermal energy in Germany is primarily attributable to the Renewable Energy Sources Act which, with its scale of feed-in tariffs, creates an encouraging economic environment for the operation of geothermal plants. With the adoption of the amended Renewable Energy Sources Act on 6 June 2008, the German Bundestag (Lower House) significantly improved the conditions for geothermal energy in Germany still further. Whereas the maximum tariff had previously been 15 cents/kWh, depending on the size of the plant, under the new provisions the basic tariff from 1 January 2009 has been increased to 16 cents per kilowatt hour supplied. 10.5 cents per kilowatt hour is paid for plants with a capacity of 10 MW or higher. An additional bonus of 4 cents is payable for electricity from plants which go live up to 2015. A further bonus of 4 cents/ kWh has been introduced for petrothermal techniques (use of hot rock) to encourage the market launch of innovative technologies. Operators who use the waste heat from their plants are eligible for a further 3 cents.

9.1.3 Progress Towards National Targets

In the economic crisis year 2009, renewable energy sources (RES) proved themselves to be a stable factor. Despite exceptionally unfavorable wind conditions, in 2009 renewable energy sources supplied slightly more energy than the previous year, with around 238 billion kWh in total (previous year: 236 billion kWh). This is particularly noteworthy given that energy supply from all other sources was down on 2008 levels for economic reasons, as a result of which the share of total final energy consumption attributable to RES increased to 10.1 % (2008: 9.3 %).

A closer look at developments during 2009, particularly the rates of new construction in the various sectors, indicates yet again that Germany is well on the way to meeting its ambitious targets for the expansion of
renewable energy sources.

Table 9.1 Contribution of renewable energy sources to electricity generation in Germany 1990 – 2009.

	Hydropower [1]	Wind energy	Biomass [2]	Biogenic share of waste [3]	Photo-voltaics	Geothermal energy	Total electricity generation	Share of gross electricity consumption
	[GWh]	[GWh]	[GWh]	[GWh]	[GWh]	[GWh]	[GWh]	[%]
1990	15,580	71	222	1,213	1	0	**17,087**	**3.1**
1991	15,402	100	259	1,211	2	0	**16,973**	**3.1**
1992	18,091	275	297	1,262	3	0	**19,928**	**3.7**
1993	18,526	600	433	1,203	6	0	**20,768**	**3.9**
1994	19,501	909	570	1,306	8	0	**22,294**	**4.2**
1995	20,747	1,500	665	1,348	11	0	**24,271**	**4.5**
1996	18,340	2,032	759	1,343	16	0	**22,490**	**4.1**
1997	18,453	2,966	879	1,397	26	0	**23,721**	**4.3**
1998	18,452	4,489	1,642	1,618	32	0	**26,233**	**4.7**
1999	20,686	5,528	1,847	1,740	42	0	**29,843**	**5.4**
2000	24,867	7,550	2,893	1,844	64	0	**37,217**	**6.4**
2001	23,241	10,509	3,348	1,859	76	0	**39,033**	**6.7**
2002	23,662	15,786	4,089	1,949	162	0	**45,647**	**7.8**
2003	17,722	18,713	6,085	2,161	313	0	**44,993**	**7.5**
2004	19,910	25,509	7,960	2,117	556	0.2	**56,052**	**9.2**
2005	19,576	27,229	10,979	3,047	1,282	0.2	**62,112**	**10.1**
2006	20,042	30,710	14,840	3,675	2,220	0.4	**71,487**	**11.6**
2007	21,249	39,713	19,430	4,130	3,075	0.4	**87,597**	**14.2**
2008	20,446	40,574	22,872	4,940	4,420	17.6	**93,269**	**15.2**
2009	19,000	37,809	25,515	5,000	6,200	19.0	**93,543**	**16.1**

1) in the case of pump storage power plants, electricity generated from natural inflow only,
2) solid, liquid, gaseous biomass, landfill and sewage; Until 1998 only feed-in the general supply grid
3) Share of biogenic waste in incineration plants estimated at 50 %

Source: BMU-KI III 1 according to AGEE-Stat; as at: March 2010; provisional figure

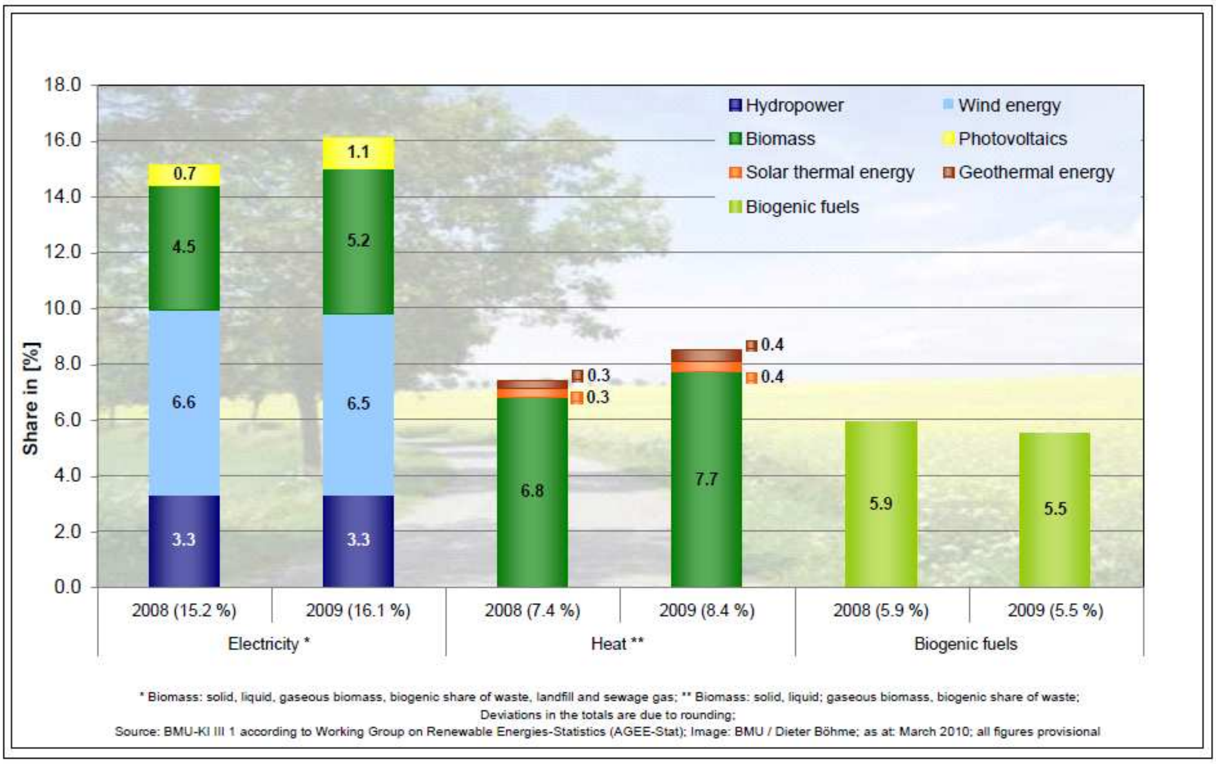
The growing proportion of renewable energy sources reduces emissions from the energy sector, and makes a significant contribution towards achieving the Government's reduction targets. Throughout all energy usage areas (electricity, heat, fuel), fossil energy resources are being replaced by renewable energies. Overall, in 2009, this enabled us to avoid some 109 million tonnes of greenhouse gases (GHG), representing a significant contribution towards the climate protection target. Germany has undertaken to reduce its greenhouse gas emissions by 40 % by 2020, compared with 1990 levels.

In 2009, electricity generation from solar power, wind energy, hydropower, all biomass and geothermal energy was roughly the same as in the previous year, totaling 93.5 billion kWh. In this regard, it should be noted that wind energy and hydropower fell far short of their true generation potential, due to the prevailing weather conditions. Mathematically speaking, the volume of electricity generated from renewable energy sources equates to more than two-thirds of the electricity generated by Germany's nuclear power plants over the same period1. In 2009, 16.1 % of Germany's total electricity consumption was attributable to renewable energy sources (2008: 15.2 %).

The Renewable Energy Sources Act (EEG), which gives priority to the feed-in of electricity from renewable energy sources into the national grid at largely fixed fees, is pivotal to the development of the electricity sector. In 2009, the EEG applied to around 72 billion kWh or 77 % of electricity from renewable energy sources. The 2009 amendment to the EEG created the requirements to further increase the proportion of renewables in the electricity sector. The construction of new electricity generation capacity in 2009 indicates that this policy has succeeded despite the current economic climate, particularly in the areas of wind energy, biogas and photovoltaic energy.

In the heat market, the use of renewable energy sources increased from just under 106 billion kWh in 2008 to more than 110 billion kWh in 2009. Once again, significant rises were seen in solar thermal energy and as a result of the amendment of the EEG in relation to biogas (CHP process). As the financial crisis prompted a substantial reduction in overall heat consumption, the share of total final energy consumption for heat attributable to renewables increased significantly against the previous year, from 7.4 to 8.4 percent.

Table 9.2 Share of renewable energy sources in total final energy consumption in Germany 2008/2009.

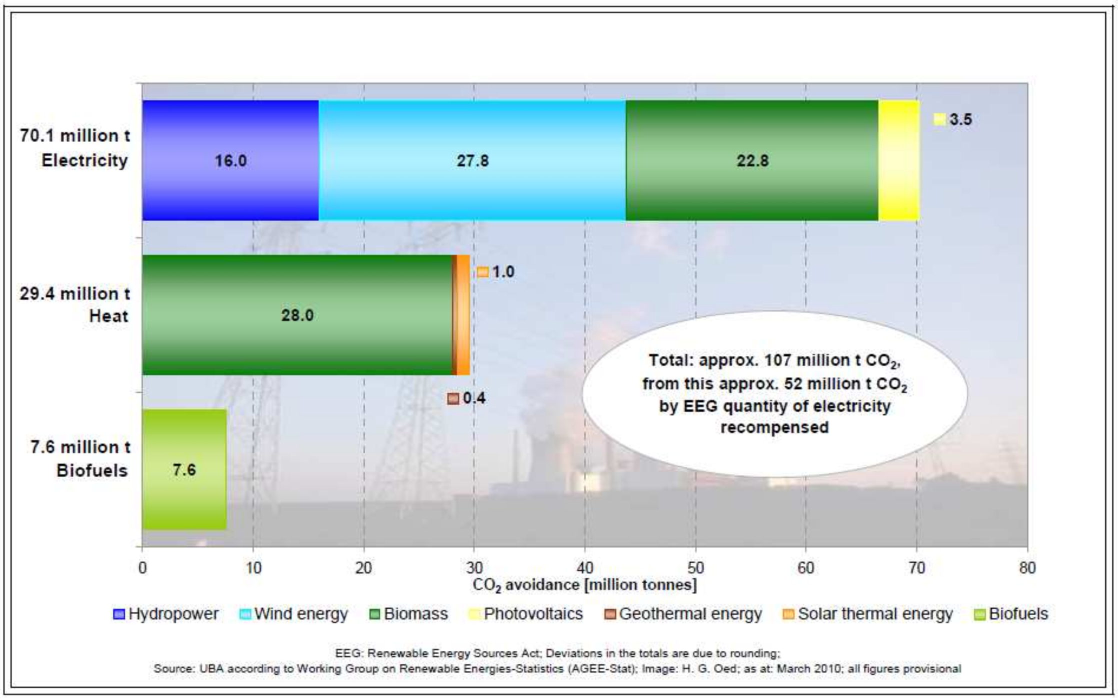


In 2009, the share of total fuel consumption attributable to biofuels dipped again slightly to 5.5 % (2008: 5.9 %). The downward trend will be halted this year following the introduction in 2009 of a quota for the share of fuel sales attributable to biofuels, which is being increased in 2010. Additionally, the Growth Acceleration Act waived the planned reduction in tax relief for pure biofuel, and ruled that the 2009 rates would remain in force until 2012.

The growing proportion of renewable energy sources reduces emissions from the energy sector, and makes a significant contribution towards achieving the Government's reduction targets. Throughout all energy usage areas (electricity, heat, fuel), fossil energy resources are being replaced by renewable energies. Overall, in 2009, this enabled us to avoid some 109 million tonnes of greenhouse gases (GHG), representing a significant contribution towards the climate protection target. Germany has undertaken to reduce its greenhouse gas emissions by 40 % by 2020, compared with 1990 levels. In the electricity sector, the volume of avoided greenhouse gases totaled 74 million tonnes, around 55 million tonnes of which is electricity remunerated under the Renewable Energy Sources Act (EEG). Around 30 million tonnes of emissions were avoided in the heat sector, and approximately 5 million tonnes in the fuel sector.

Considering CO2 emissions in isolation, in 2009 around 107 million tonnes of CO2 were avoided thanks to the use of renewable energy sources.

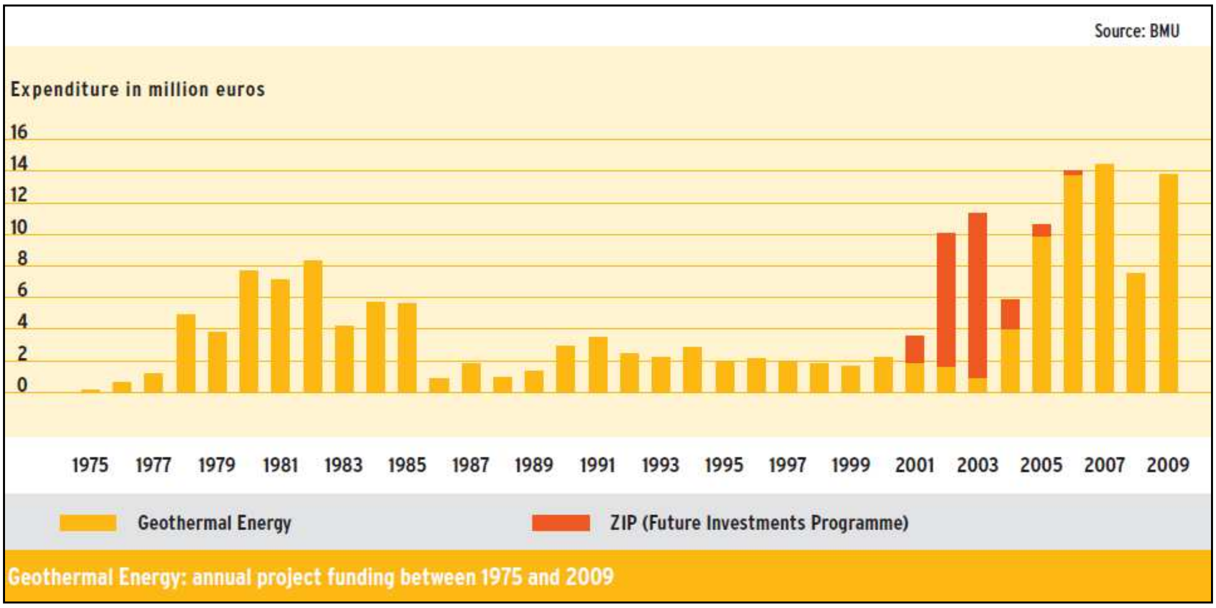
Table 9.3 Greenhouse gas (GHG) emissions avoided via the use of renewable energy sources in Germany 2009.



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

In its most recent funding announcement of 20 November 2008, BMU outlined its priority areas for research funding in the field of geothermal energy. The aim is to continuously reduce the cost of extracting and using heat and electricity from geothermal reservoirs.

Table 9.4 Geothermal energy annual project funding between 1975 and 2009.



In 2009, BMU approved a total of 14 new projects with a funding volume of 14.9 million euros. At the same time, 13.8 million euros were allocated to ongoing projects.

9.2 Current Status of geothermal Energy Use

9.2.1 Electricity Generation

In 2009, the electricity generation was 19 GWh with an installed capacity of 6,6 MW.

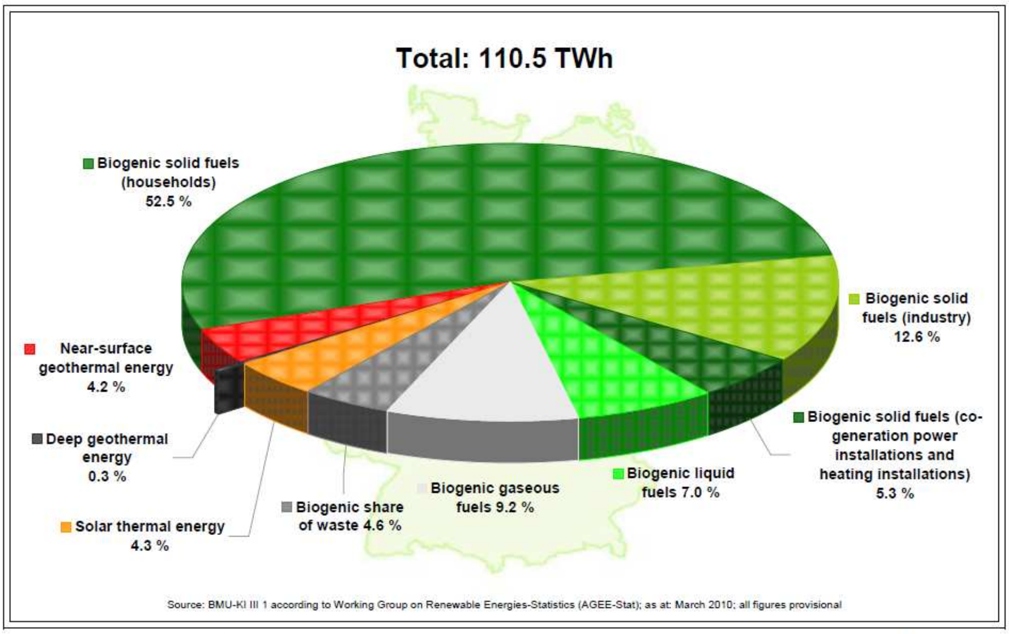
9.2.2 Direct Use

Heat supply from heat pumps is also continuing its upward trend. In 2009, 54,800 new heat pump systems (all systems) were installed, increasing the total stock to more than 400,000. At 4.7 billion kWh, heat supply from heat pumps was roughly on a par with that from solar thermal energy.

Table 9.5 *Direct use of heat in Germany 2009. (from: www.geotis.de)*

www.geotis.de/vgs	Direct use of geothermal heat in Germany, date 18th August 2010		
Main use	**Installed capacity totala**	**Installed capacity geothermal****	**Annual production**
District heating	219,0 MW_t	98,2 MW_t	299,2 GWh/a
Building	1,2 MW_t	1,2 MW_t	0,8 GWh/a
Balneology	44,9 MW_t	44,9 MW_t	379,4 GWh/a
Green houses	-	-	-
others	-	-	-
Total	265,0 MW_t	144,2 MW_t	679,4 GWh/a

Table 9.6 *Structure of heat supply from renewable energy sources in Germany, 2008. (from: AGEE-Stat.)*



9.3 Market Development and Stimulation

In addition to the combined heat and power bonus under the Renewable Energy Sources Act, the more widespread use of waste heat from geothermal energy generation will now also be encouraged through the Act on the Promotion of Renewable Energies in the Heat Sector (Renewable Energies Heat Act), which was adopted by the Bundestag (Lower House) on 6 June, 2008, and entered into force on 1 January, 2009. Under the Act, all owners of new buildings are obliged to purchase part of their heat demand from renewable energy sources.

BMU's market incentive programme for renewable energies is another tool to stimulate the market for deep geothermal energy. The funding focuses on technologies that generate heat from renewable energies. In 2009, some 400 million Euros were made available to promote renewable energies in the heat market, considerably more than in previous years. Since 2008, the funding incentives that are aimed specifically at heat-generating deep geothermal systems have been considerably more attractive. The programme offers subsidies for the installation of the power or heating plant and for manufacturing costs for deep boreholes. Unforeseen additional costs incurred due to the technical risks associated with deep boreholes are also eligible for subsidies. The market incentive programme also supports district heating networks that run on regenerative resources. As part of the market incentive programme and in collaboration with the KfW banking group, BMU has created a new loan programme to provide long-term financing for deep geothermal drilling. Munich Re is backing KfW as a cooperation partner. The loan programme helps to hedge the discovery risk for hydrothermal projects – i.e. the risk of failing to find sufficient temperatures or water volumes when drilling. Special loans from KfW will finance up to 80 % of the drilling costs of a project, including stimulation measures. In the event of failure to find adequate heat or water, this loan need not be repaid. If heat or water is found, the funds become available for use in another project. In order to ensure that the largest possible number of drilling projects can be financed through the loan programme, the risk of failure is limited by strict application requirements and screening procedures. In this way, one of the main barriers to the faster market development of deep geothermal projects is minimized.

In the economic crisis year 2009, renewable energy sources clearly proved that they have developed into a significant economic factor, as already witnessed in previous years. Renewables succeeded in bucking the downward trend; despite the extremely problematic economic environment, initial estimates on behalf of the BMU indicate that investments in plant for the use of renewable energies increased by around 20 % against the previous year, to 17.7 billion Euros. Together with the revenues associated with the operation of these plants (feed-in fees under the EEG and revenues from the electricity, heat and fuel markets), in 2009 renewable energy sources generated a total turnover of more than 33.4 billion Euros (2008: 30.7 billion Euros).

The sharpest rises in investments were seen in electricity generation from biomass (doubled), photovoltaics (+ 22 %) and wind energy (+ 15 %). If operating revenues are added to these figures, solar thermal energy is now the strongest sector (13.9 billion Euros), followed by biomass (11.5 billion Euros).

Employment in the renewable energies sector reflects this development to a certain extent, and employment figures rose again last year. In an initial estimate for 2009, an on-going research project on behalf of the BMU indicates that there are some 300,500 employees15 involved in the manufacture of plants for the use of renewable energy sources, including exports, operation of such facilities, and the supply of biomass and biofuels, with due regard for upstream value-added steps.

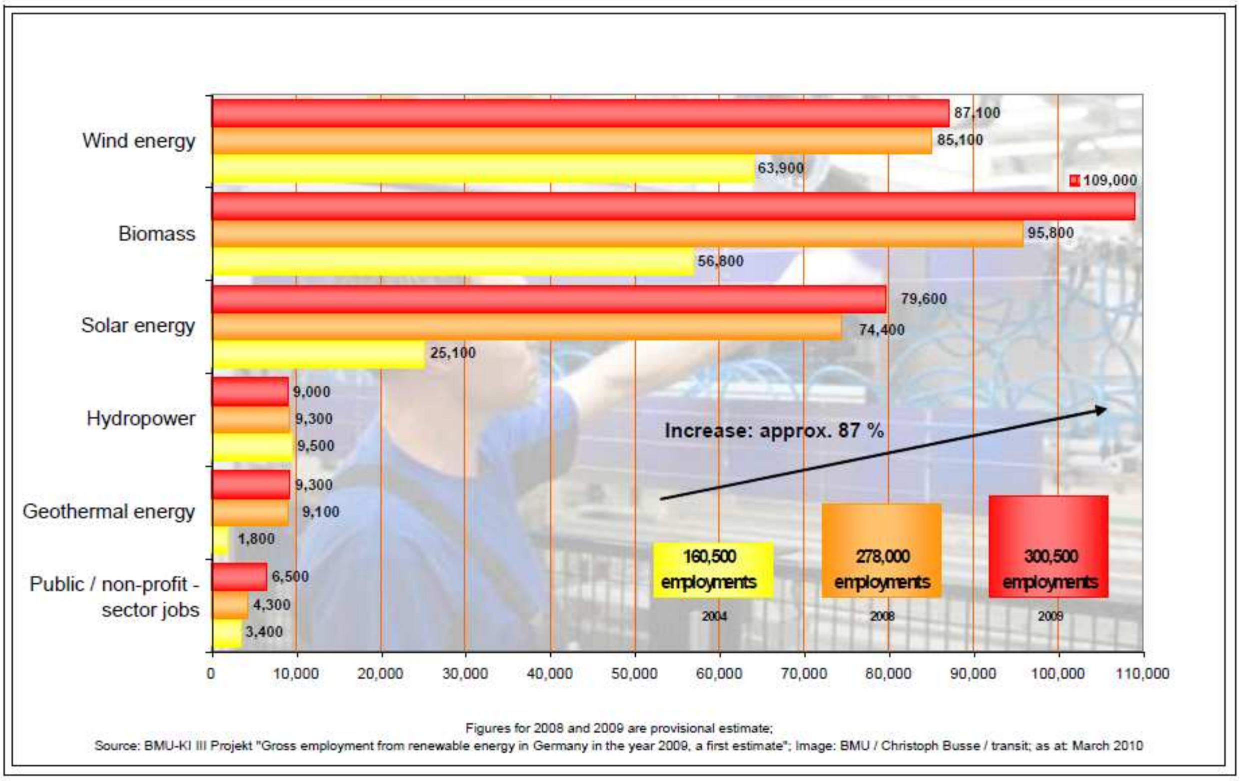
Compared with the previous year (approx. 278,000 employees), this represents an increase of just under 8 %. Since 2004 (approximately 160,500 employees), the number of jobs attributable to renewable energy sources has increased by around 140,000 (87 %) within the space of just five years.

Photovoltaics once again showed a very sharp increase in employment, prompted by the sharp rise in new installations. Another winner of the past year has been the biogas sector, which following the previous year's downturn, rallied again, in line with expectations. Plants for the use of solid biomass likewise followed this trend. In the heating market, by contrast, a very good year in 2008 was followed by a slight dip in 2009.

Overall, biomass continues to contribute the largest share to gross employment with around 36 % (109,000 jobs), followed by wind energy with 29 % (87,100), solar energy with just under 27 % (79,600), geothermal energy with around 3 % (9,300) and hydropower with 3 % (9,000).

The employment created by the supply of public and private funding in research and administration may be conservatively estimated at around 6,500 jobs in 2009, corresponding to 2 % of gross employment.

Table 9.7 *Jobs in the RES sector in Germany 2004, 2008 and 2009.*



9.4 Development Constraints

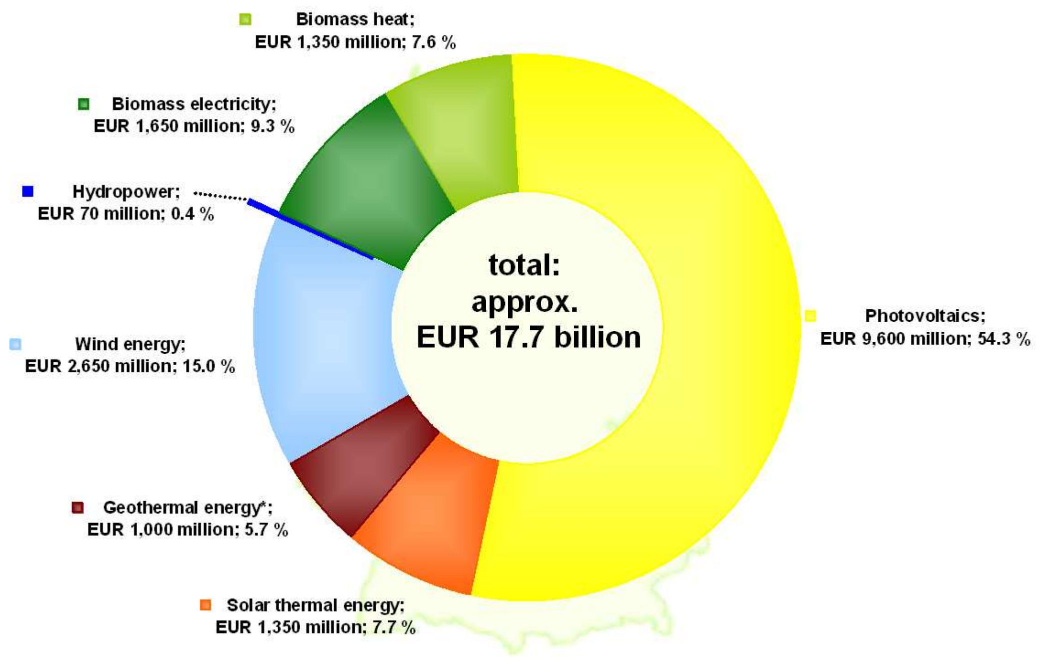
The average of the geothermal gradient in Germany is 30 °C/km and quiet low for deep geothermal applications. Only in certain regions like the upper Rhine rift valley and the German Molasse basin higher geothermal gradients occur. Therefore deep drilling down to 3000 – 4000 m is necessary to reach temperature above 100 °C for with 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 complicate geological structures in some regions of interest. In the northern basin of Germany the geothermal sources have a high salinity.

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

9.5 Economics

As for 2008, 2009 was a year with high investments in large geothermal energy plants and heat pumps.

Table 9.8 Investments in plants for the use of renewable energy sources in Germany 2009.



* Large plants and heat pumps; Deviations in the totals are due to rounding;
Source: BMU-KI III 1 according to the Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW); as at: March 2010; all figures provisional

Any reliable figures for drilling cost, machines, devices etc. are not available due to the individual circumstances of each project.

The production price of conventional generated electricity is about 4 – 7 ct€/kWh and the consumer prices are between 18 and 22 ct€. Prices for energy – oil, gas, coal, electricity - are depending of world market prices.

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

9.6 Research Activities

9.6.1 Focus Areas

In its funding announcement of 20 November 2008, the BMU outlined its priority areas for research funding in the field of geothermal energy. The aim is to continuously reduce the cost of extracting and using heat and electricity from geothermal reservoirs. For this reason, the following topics and tasks are a particular focus of funding:

- Development of methods and techniques to minimize the discovery risk involved with drilling during exploration
- Development of measurement techniques and equipment capable of supplying reliable data, both during drilling operations under the high temperatures, high atmospheric pressures and corrosive conditions that typify geothermal projects, and for the management of geo thermal reserves; they can also be used for modeling forecasts and reserves
- Development and improvement of drilling techniques used specifically for tapping geo thermal reservoirs
- Development and improvement of methods and techniques to optimize management of reservoirs and influence productivity, such as stimulation techniques, fracing techniques, and monitoring systems
- Development of equipment, apparatus and machinery – especially pumps – capable of reliable, low-maintenance operation under the high temperatures, pressures and corrosive conditions that typify geothermal applications
- Investigation, optimization and development of methods and techniques for converting geo thermal energy (hot water and steam) into usable heat and electricity (e.g. cogeneration of power/heat/cooling, ORC (organic Rankine cycle) and Kalina process or innovative techniques, including combinations with other renewable energies
- Addressing fundamental technical issues relating to the incorporation of geothermal energy into local supply systems (heat/electricity) – including combinations with other renewable energies – in areas with a high multiplier potential

9.6.2 Government Funded R&D Projects

9.6.2.1 Preparation and Planning

Development risk is one of the crucial factors when planning geothermal plants. In the preparation phase for geothermal projects using hydrothermal heat energy, the achievable extraction rate, extraction temperature, density and specific heat capacity of the hot, sometimes highly saline, deep water are the decisive parameters in assessing the development risks. In addition to that, data from hydrochemical analyses are indispensable, since they allow conclusions to be drawn about the technical ease of handling with regard to the behavior of the dissolved salts in the geothermal water and what corrosion-resistance standards the plant will need to meet. Only when these variables are known is it possible to qualitatively asses a preliminary exploration and only thereafter can the prospects for success and the exploration risk be estimated. Against this backdrop, Freiburg's regional council (Regierungspräsidium) is carrying out a project to develop a prediction tool to support site-specific predictions about the development potential of hydrogeothermal projects in Baden- Württemberg. The idea is to make the prediction tool available free of charge via an Internet portal to potentially interested parties from industry and research.

The prediction tool will also be connected to the geothermal information system (GeotIS), which provides a compilation of data and information on deep aquifers (underground layers of water-bearing permeable rock) that can be considered for possible geothermal use in Germany. The GeotIS information system developed by the Leibniz Institute for Applied Geophysics (LIAG) will be continued. In this second phase of development, hydrothermal systems, in particular petrothermal systems will be incorporated into the database along with additional regions that have not yet been considered. Other topics for the next phase of funding include software optimization, acting on feedback from users, compilation of data gained from new boreholes and exploration activities, homogenization and validation of data, a uniform interpretation of geothermal and hydraulic data and improving the temperature modeling and discovery prediction.

9.6.2.2 Developments in Technology

One of the main areas funded in 2009 was techno logical development. Here the focus was on pumps that meet the specific requirements of deep geo thermal applications in Germany. Basically, two types of pumps are available: line shaft pumps that are operated at the surface and submersible centrifugal pumps. Submersible centrifugal pumps have been state of the art in the oil production industry for a long time, where they run reliably for several years. In the rare case of pump failure, oil production is transferred to a neighboring well. In the case of geothermal projects, the situation is totally different: the pumps used in geothermal systems have to extract higher volumes and transport different media (water that sometimes contains highly saline and therefore aggressive substances). They have to be particularly temperature-resistant. Also in terms of system reliability, the specifications they have to meet are far higher, since regular pump failure would mean an interruption in the electricity and heat supply to consumers. Thus, overall the technical specifications for pumps for geothermal systems are very different. In two projects conducted by Flowserve Hamburg GmbH and Baker Hughes INTEQ GmbH, high-volume pumps (capacities of up to 150 l/s, maximum pumping height of 750 m, maximum temperature 150°C) are being developed for use in the Molasse basin in southern Germany, for example. When developing geothermal pumps, particular attention is also paid to long-term behavior and corrosion.

Drilling costs account for two-thirds of the cost of a geothermal plant. In a whole-system approach, the drilling and tubing procedures would be technically modified to bring about significant cost reductions. A project on the design, development, manufacture and testing of innovative and cost-effective geothermal tubing systems by Baker Hughes INTEQ GmbH will initially examine the feasibility of new types of underground tubing systems for geothermal, wells. Efforts at optimizing cost will focus on improving operating behavior but also on reducing volumes drilled, materials used and installation time. Volumes drilled and material usage can be significantly reduced by using what is known as a mono bore system. Further investigations will focus on the possibilities of merging drilling and completion technology, since only a whole-systems view can identify the savings potential.

With regard to optimum operation and economic use, there are still numerous obstacles to overcome. The durability and operational reliability of surface and subsurface components, such as pumps and heat exchangers, are severely compromised by chemically aggressive, saline deep water and the gases it may contain and are thus a risk-laden cost factor.

For that reason, a project on gas geochemical investigations as a basis for ascertaining gas-mineral equilibrium in geothermal systems being carried out by Boden, Wasser, Gesundheit (BWG) GbR is working on optimizing a methodology for ascertaining the gas-water ratio in deep waters. Its aim is that by calculating the equilibrium pressure and taking into consideration the dynamic processes in the re-injected thermal water it will be possible to make better predictions about pressure maintenance, which is a key cost factor.

A project being conducted by the Karlsruhe Institute of Technology (KIT) is investigating the kinetics of precipitation of barium in geothermal water. To this end, an experimental plant is being set up to track the reaction progress of the kinetics of precipitation of barium and formation of mixed crystals and study the relationship between surface properties and rate of crystal formation. Typical heat exchanger geometries and typical hydraulic and thermal design parameters will be recorded and the heat exchangers will then be evaluated in terms of their tolerance to scaling due to precipitation. The results of the calculations will be checked in a pilot plant. The outcome of the project will be recommendations on the design of heat exchangers to minimize precipitation of barium and formation of mixed crystals and thus increase the availability of geothermal plants.

9.6.2.3 Demonstration Projects

Unterhaching- Germany's largest combined geothermal heat and power plant has been up and running at Unterhaching near Munich for some time now. Compared with pure heat generation projects, geothermal power stations of this kind present new challenges in terms of planning and operational management as a result of the considerably higher circulation rates that have to be continuously available and the greater degree of cooling in the circulating thermal water. The geothermal water circuit in this case takes in both wells and the surface pipelines, including heat exchangers and filters. Geothermie Unterhaching GmbH & Co. KG is therefore running a programme to monitor the initial years of operation, which is designed to provide new information about optimum operation, risk potential and how to deal with it and the extent and type of monitoring required in the long term. The major part of the studies has been subcontracted to GTN GmbH (Geothermie Neubrandenburg). They will help not only to guarantee the operational reliability of the Unterhaching geothermal plant but also provide findings that can be transferred to future plants.

The project's analysis programme records key geochemical parameters within the circulating geothermal water, such as composition of the water, solids loading and gas content. Fluids and solids also undergo microbiological testing. Periodic sampling, analysis and evaluations based on the plant's operation are also carried out. For example, GTN's solids analysis, which also includes X-ray diffraction analysis and scanning-electron-microscope studies, gives information about the composition, size distribution and origin of particles on filters and other components of the system and about the conditions under which they were formed.

Bruchsal- The geothermal power station at Bruchsal was officially commissioned on 18 December 2009. The plant, which uses a hydrothermal system, extracts a 120°C hot brine from a depth of 2,542 m at currently 24 l/s. This geothermal power station, which uses a Kalina system, is designed for 5,500 kW thermal and 550 kW electrical capacity. The interactions between the complex geothermal reservoir and the permanent power station operation with all its components are part of the collaborative accompanying project on long-term operation and optimization of a geo thermal power plant in a fractured porous reservoir in Oberrheingraben – LOGRO. The project is a collaboration between the Karlsruhe Institute of Technology (KIT), the Georg August University in Göttingen and the European Institute for Energy Research (EIfER) in Karlsruhe.

The project, which is being funded by BMU and EnBW Energie Baden-Württemberg AG, is investigating the potential for optimization and assessing the long-term stability of the geothermal water circuit using hydraulic, hydrochemical and thermal criteria, particularly taking into account restrictions such as corrosion and scaling. The reservoir geometry and the complex chemical composition of the geothermal brine with its very high gas and salt content and heavy metals pose particular challenges for the sampling and analysis procedures.

9.7 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 lecture are held by several institutions and associations involved in geothermal energy.

9.8 International Cooperative Activities

The Federal Ministry for Environment, Nature Conservation and Nuclear Safety Focus supports the project in Soultz-sous-Forêts and participate in the IEA as member of the Geothermal Implementing Agreement.

9.9 References

Note: Most of the text is adopted from references BMU (2009a and 2009b).

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9.10 Author and Contact

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National Activities

Chapter 10

Iceland

Figure 10.5 *Wells at Hellisheiði power plant which Reykjavik Energy operates.*
(Photo courtesy of Jonas Ketilsson)

10.0 Introduction

Practically all stationary energy and 85% of primary energy in Iceland are derived from indigenous renewable sources with near carbon-free electricity production. This is the result of an effective policy in making renewable energy a long-term priority in Iceland. Geothermal primary energy consumption contributed 66% in year 2009, equivalent to 158 PJ. Nowhere else does geothermal energy play a greater role in providing a nation's energy supply.

The energy current from below Iceland has been estimated to be about 30 GW, of which 7 GW is estimated to be harnassable current (Figure 10.1). Above 10 km depth, the energy stored is estimated to be $12 \cdot 10^{14}$ GJ, of which it is thought to be technically and economically possible to install 4,300 MW_e of geothermal power at current electricity prices in Iceland and generate about 30 TWh of electricity.

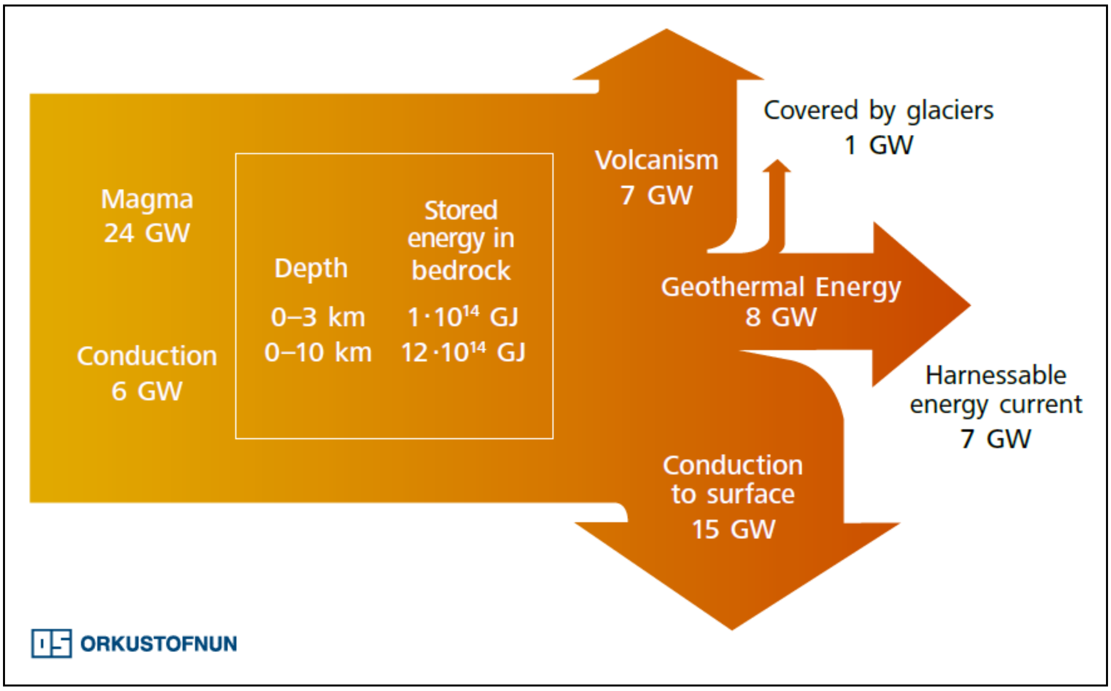

Figure 10.1 Terrestrial energy current through the crust of Iceland and stored heat. (Orkustofnun, 2010)

10.1 Highlights for 2009

Currently, eight geothermal power plants with a total estimated 785 MW_e installed capacity are under formal consideration as can be seen in Table 10.1 of which at least 90-180 MW_e will be installed in 2011-2012. In Figure 10.2 primary energy use is plotted against time from 1940-2009. In Figure 10.3 installed capacity and electricity generation in Iceland is shown for 2008 and 2009.

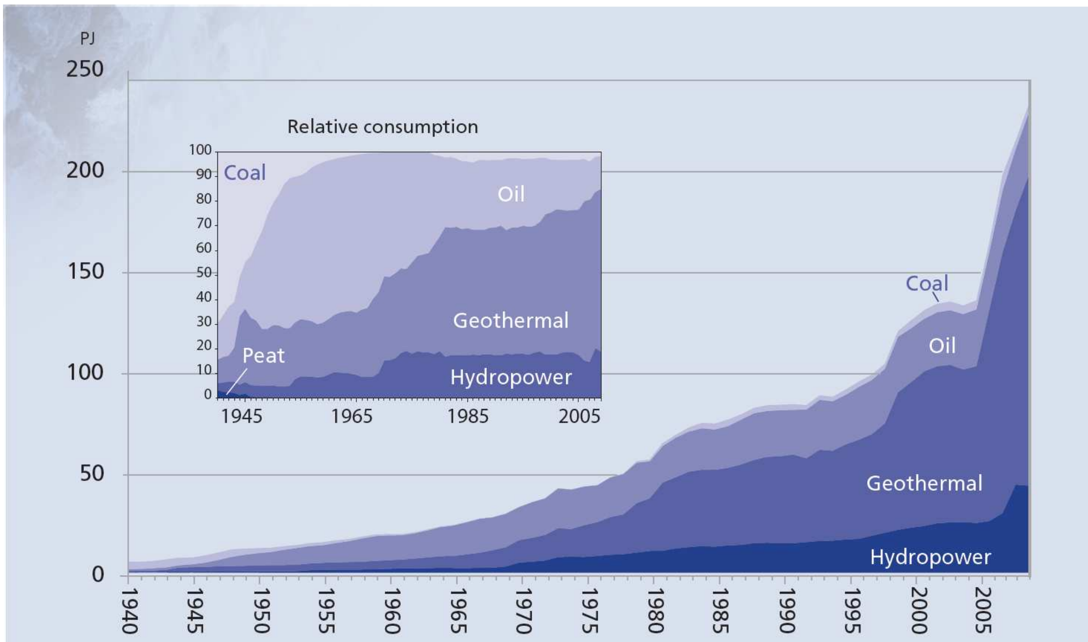

Figure 10.2 Primary energy consumption in Iceland 1940-2009. (Orkustofnun, 2010)

Installed capacity in power stations

	2009		2008	
	MW	**%**	**MW**	**%**
Hydro	1,883	73,0	1,879	73,0
Geothermal	575	22,3	575	22,3
Fuel	121	4,7	120	4,7
Total	**2,579**	**100,0**	**2,574**	**100,0**

Electricity production

	2009		2008	
	GWh	**%**	**GWh**	**%**
Hydro	12,279	73,0	12,427	75,5
Geothermal	4,553	27,0	4,038	24,5
Fuel	3	0,0	3	0,0
Total	**16,835**	**100,0**	**16,468**	**100,0**

Figure 10.3 Generation of electricity in Iceland in 2009 and 2008. (Orkustofnun, 2010)

10.2 National Policy

It is the policy of the Government of Iceland to increase the utilization of the renewable energy resources even further for power intensive industry, direct use and the transport sector in harmony with the environment. A broad consensus on conservation of valuable natural areas has been influenced by social opposition, which has increased over the last decade, against large hydropower and some geothermal projects. The Icelandic Government decided in 1997 to develop a Master Plan for potential power projects. All proposed projects are being evaluated and categorized on their energy efficiency and economics, and also on the basis of the impacts the power developments would have on the environment. The Master Plan is to be presented to the Icelandic Parliament for formal consideration in 2011. There has, as well, been a governmental effort to search for geothermal resources in areas where geothermal energy has not yet been found. A map of Iceland with identified and anticipated geothermal resources is illustrated in Figure 10.4.

In Iceland, ownership of resources is associatated with the ownership of land. However, exploration and utilization is subject to licensing. Three major amendments have recently been made to the energy legal framework in Iceland: (1) The ownership of resources can no longer be sold by the state or municipalities, although utilization rights can be leased to a developer for up to 65 years with a possibility of extension. Royalties for the utilization are determined by the Prime Minister. (2) Producers of electricity compete on an open market in Iceland. Therefore CHP power plants are obliged to keep separate accounts for heat and power production to prevent cross subsidization of electricity. (3) The National Energy Authority can grant licenses on behalf of the Minister of Industry.

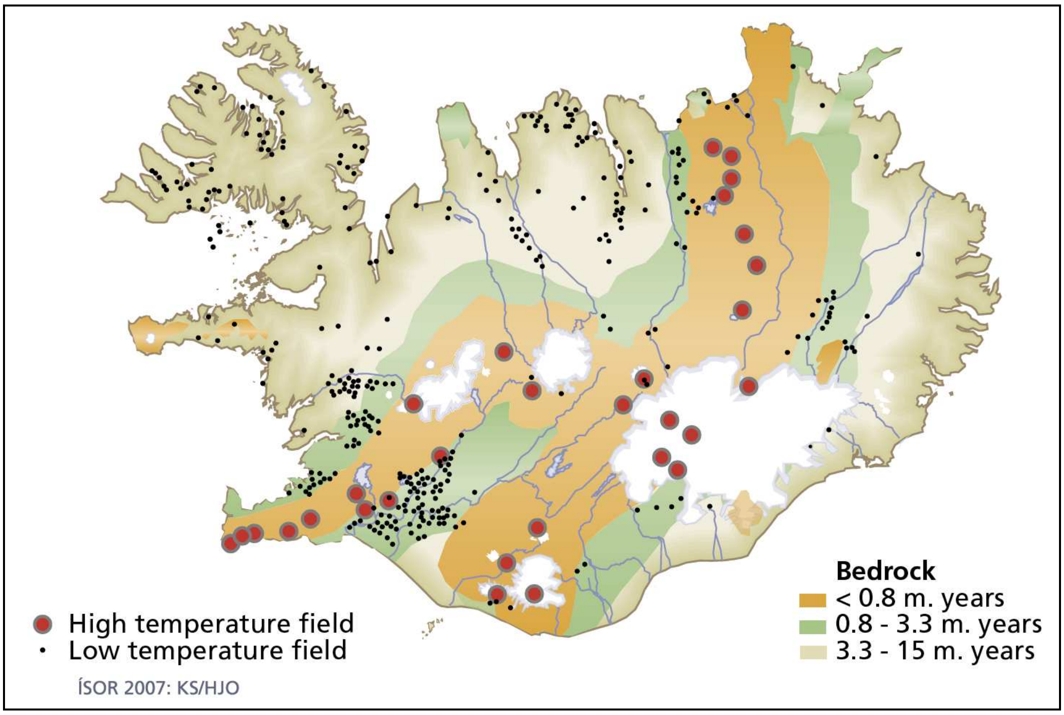

Figure 10.4 Location of high temperature geothermal fields in the volcanic zones of Iceland and clusters of low temperature springs on the flanks of the volcanic zones. Iceland is located on both a hotspot and the Mid-Atlantic Ridge, which runs right through it. This combined location means that geologically the island is extremely active. (Orkustofnun, 2010)

10.3 Current Status of Geothermal Energy Use in 2009

10.3.1 Electricity Generation

As a result of a rapid expansion in the power intensive industry in Iceland the demand for electricity has increased considerably. This growth has partly been met by increased geothermal electricity generation. Total installed electric capacity of geothermal power plants was 575 MW_e in the end of year 2009. Electricity generation from geothermal power plants was 4,553 GWh in year 2009 (Figure 10.3). In the near future, electricity generation is estimated to double as can be seen in Table 10.1.

Table 10.1 Installed and planned electric capacacity in November 2010. (Orkustofnun, 2010)

Geothermal Field [MWe]	2005	2006	2007	2008/2009	Licensing	EIA completed	EIA started
Bjarnarflag	3	3	3	3	-	90	-
Krafla	60	60	60	60	-	-	150
Þeistareykir							250
Húsavík	2	2	2	2	-	-	-
Hengill area	120	210	243	333	180	135	-
Svartsengi	46	46	76	76		-	-
Reykjanes		100	100	100	80	-	-
Other fields	-	-	-	-	-	-	-
TOTAL	*232*	*422*	*485*	*575*	*260*	*225*	*400*

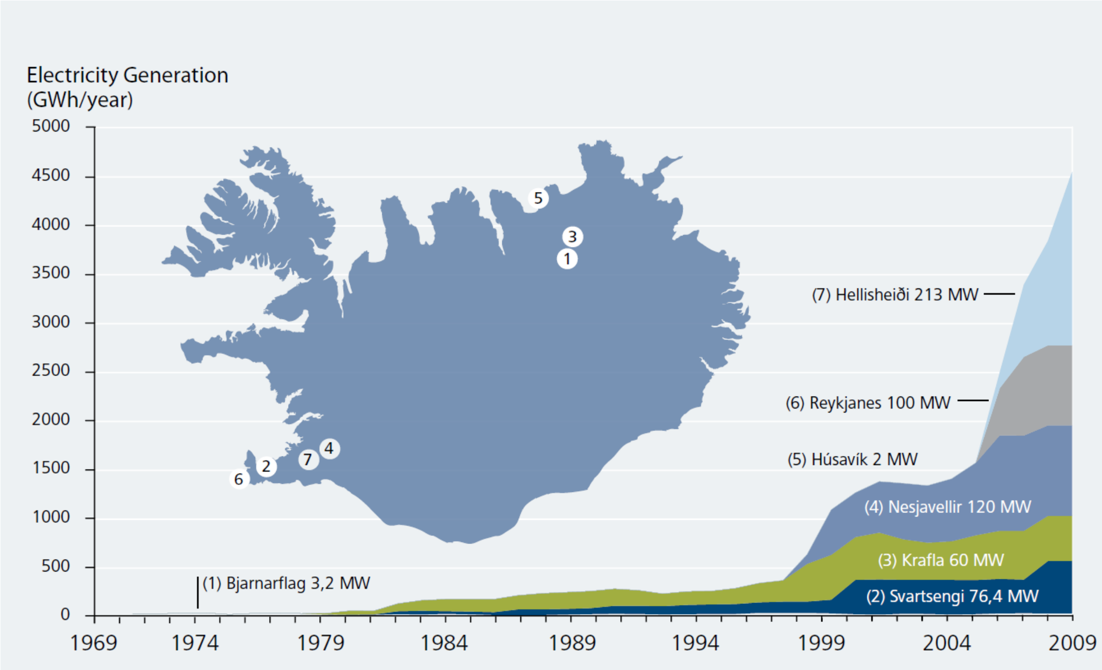

Figure 10.5 Electricity generation from geothermal power plants in Iceland since 1969-2009. (Orkustofnun, 2010)

10.3.2 Direct Use

The total direct use of geothermal energy in 2009 is estimated to be 25.4 PJ, of which 18.8 PJ is for space heating. Currently, 90% of houses are heated with geothermal energy. The share of oil for heating continues to decrease and is at present at about 1%. The share of electric heating is about 9%, but one third of that comes from heating plants where electricity is used to heat water for district-heating systems. Heating of swimming pools is also one of the most important types of geothermal utilization in Iceland and the one with the longest tradition. Currently there are 163 geothermal swimming pools in Iceland at 134 sites with a total surface area of 37,550 m². Snow melting on pavements and parking lots has been common in Iceland for the past 15-20 years and the total area covered is about 1,200,000 m². There has been no increase in direct industrial uses of geothermal energy in Iceland during the last years, and in 2004 the diatomite plant at Lake Myvatn, which consumed 444 TJ/yr, closed down. A seaweed processing plant at Reykhólar, W-Iceland, uses about 250 TJ/yr for drying. A plant for the commercial production of liquid CO_2 has been in operation at Haedarendi, in SW-Iceland, since 1986. Geothermal water is also used for heating greenhouses and for small scale timber and fish drying. In Figure 10.6 direct use of geothermal energy is shown.

10.3.3 Energy Savings

In 2008, the total CO_2 emission from geothermal power plants was 185,140 tonnes, as can be seen in Table 10.2. Geothermal utilization was equivalent to 4,638 Mtoe in year 2008 (IEA conversion factors: 1,163 GWh/Mtoe for electric generation and 20,921 TJ/Mtoe for direct use). The values for year 2009 have yet to be finalised.

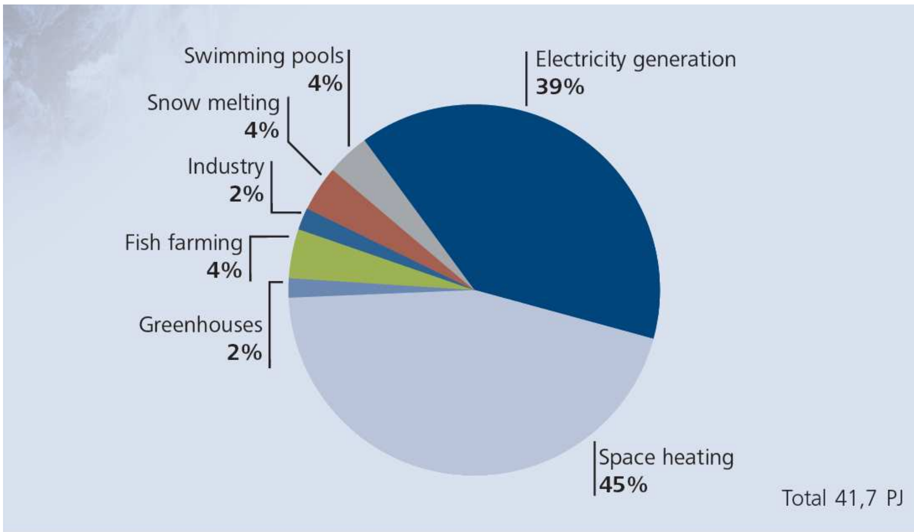

Figure 10.6 Direct use of geothermal energy and electricity generation in 2009. (Energy Statistics 2010, Orkustofnun, 2010)

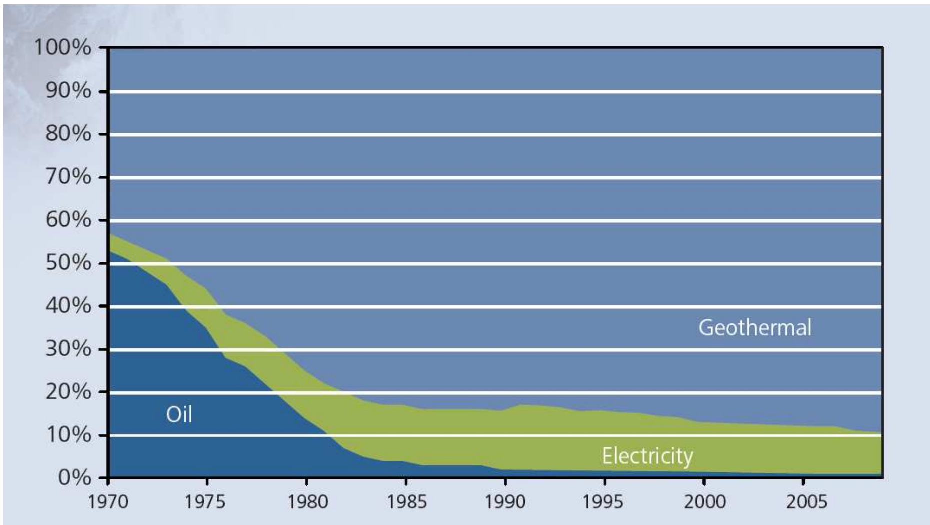

Figure 10.7 Space heating by source from 1970-2009. (Orkustofnun, 2010)

Table 10.2 Emission of CO_2 in year 2008 per electric and heat production. (Orkustofnun, 2010)

Geothermal Field	Emission (tonnes/a)	Emission per electricity production (g/kWh)	Emission per CHP production (g/kWh)
Reykjanes	24,310	28.1	
Svartsengi	61,182	108.8	39.3
Hellisheiði	32,937	29.2	
Nesjavellir	20,904	21.4	6.5
Námafjall	1375	86.7	
Krafla	44,272	90.8	
TOTAL	*185,140*	*Weighted average: 45.9*	

10.4 Market Development and Stimulation

The high demand for electricity for power intensive industry resulting from the favorable prices of electricity has resulted in large-scale geothermal power development in Iceland. The power intensive industry consumed 79% of the total consumption in year 2009. Due to the success in Iceland, the geothermal industry has been increasingly exporting the know-how to other countries both as consultants and as investors at the feasibility stage. The government gives grants to various projects with emphasis on finding usable geothermal water for space heating in areas where resources have not yet been found.

10.5 Development Constraints

Development constraints are mostly due to environmental issues and low electricity prices in Iceland, though geothermal energy was looked upon more positively than hydropower in a recent national review. Local issues do place constraints on drilling sites and access to them. As well, the visual impact of geothermal power plants is becoming increasingly important. Another development constraint is the governmental subsidies, amounting to 1,300 M ISK in 2009, to communities where there is no access to geothermal water for space heating (Figure 10.3). The subsidies, although effective for regional development, can decrease interest in search for geothermal resources.

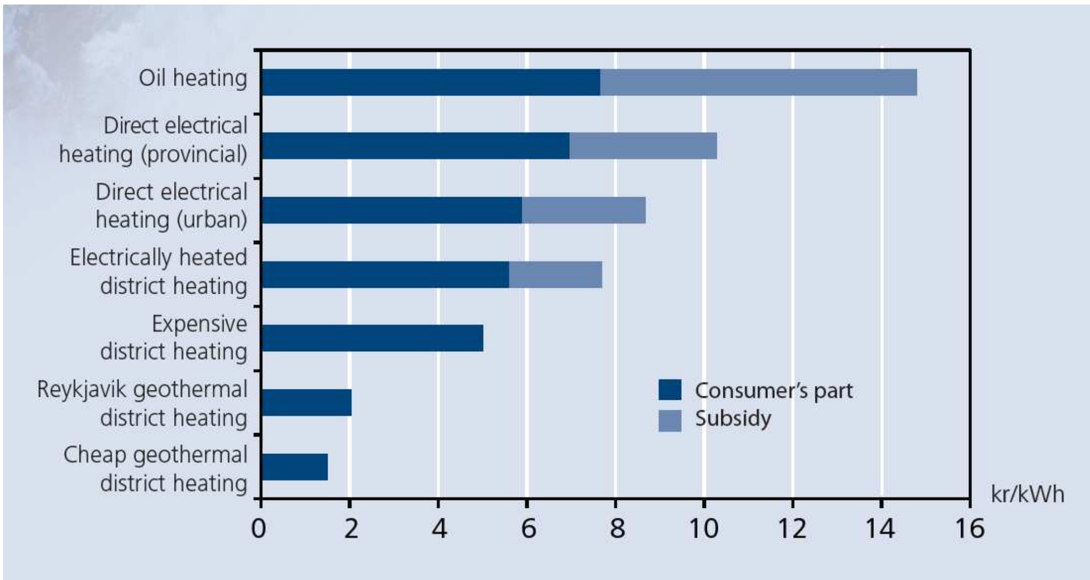

Figure 10.8 Comparison of energy prices for residential heating in mid year 2010. (Orkustofnun, 2010)

10.6 Economics

Geothermal power is competitive with hydro in Iceland; providing reliable base load, green energy and favorable prices; 8 ISK/kWh + VAT for 3.5 MWh/yr consumption, but can get considerably lower for the power intensive industry due to very high load factor. For residential heating see Figure 10.8. It is estimated that the installation cost of a relatively large geothermal power plant is around 2.5 million US$/$MW_e$, with about 2% annual maintenance and operation costs.

10.7 Research Activities

10.7.1 Focus Areas

The Iceland Deep Drilling Project (IDDP) could start a new era in geothermal development. The main purpose is to find out if it is economically feasible to extract energy and chemicals out of hydrothermal systems at supercritical conditions. The drilling at Krafla was initiated in 2008, with intermediate casings set at 90 m, 300 m and 800 m. In March 2009 the largest drill rig in Iceland, Týr, continued drilling with a 12 ¼-in bit with the aim of placing the next casing at 2,400 m. In the depth interval of 2,000 to 2,100 m the rig ran into repeated trouble which turned out to be due to veins of molten lava. Superheated steam rich in HCl entered the well and turned corrosive when mixed with liquid water. The well was then completed with a casing cemented down to 2,000 m. The well is now believed to be the hottest well in the world with a measued enthalpy of 3,400 kJ/kg. Fluid handling and evaluation along with pilot plant testing will commence in year 2011. The decision on where to drill the next well has not yet been made. For the Master Plan, research is ongoing on high temperature geothermal areas. In addition, geothermal areas are being searched for near districts that do not have geothermal space heating and Orkustofnun is involved in a few heat pump installations.

10.7.2 Government Funded Research

The international GEOthermal Research Group (GEORG) was launched in 2009 with participation of all the major power companies, research institutions and authorities. GEORG is financially supported by the Science and Technology Policy Council in Iceland, RANNÍS with up to 70 million ISK annual contribution for seven years. Orkustofnun represents the government in a steering committee of the IDDP. The total amount from Orkustofnun will be at maximum US$ 4.6 M. For a few years, the Ministry of Industry has been running a program to encourage geothermal exploration for domestic heating in areas where geothermal resources have not been identified. For years 2007-2009, 172 M ISK were granted to exploration in 29 places, of which the total cost is estimated to be 300 M ISK. The Icelandic International Development Agency (ICEIDA) is involved in stimulating geothermal utilization in developing countries like Nicaragua. The cost of just the Nicaragua-project as a whole is estimated to be slightly over US$ 4 M. ICEIDA has also participated in a joint project with six states in northwestern Africa. The project is in cooperation with the UN Environmental Programme, the KfW Bank in Germany and the Global Environment Fund, along with other donors involved with the research and use of geothermal energy in the northern reaches of the East African Rift (ARGeo).

10.7.3 Industry Funded Research

The three major power companies in Iceland each grant US$ 1.4 M for R&D of the IDDP. In addition, the power companies are responsible for drilling down to 3.5 km depth at their geothermal areas with an estimated cost of around US$ 13.9 M per well. The energy fund of Reykjavik Energy granted, in year 2009, 94 M ISK to 44 projects. The energy fund of Landsvirkjun Power granted, in year 2009, 46 M ISK to various energy projects.

10.8 Geothermal Education

The United Nations University-Geothermal Training Programme (UNU-GTP) has been operating in Iceland since 1979, with the aim to assist developing countries with significant geothermal potential to establish groups of specialists in geothermal exploration and development. A MSc programme was started in 2000 in cooperation with the University of Iceland. UNU-GTP receives its funding from the government of Iceland, US$ 5 M/yr. Since 1979, 452 scientists have graduated from 47 countries. They have come from countries in Asia (42%), Africa (29%), Latin America (15%), and Central and Eastern Europe (14%). Amongst these have been 81 women (18%).

The School for Renewable Energy Science (RES) in Akureyri and Reykjavik Energy Graduate School of Sustainable Systems (REYST) both started their first academic years in 2008, offering education in the field of renewable energy, emphasizing on geothermal. RES graduated 35 students from 11 countries with MSc in Renewable Energy Science and REYST graduated nine students.

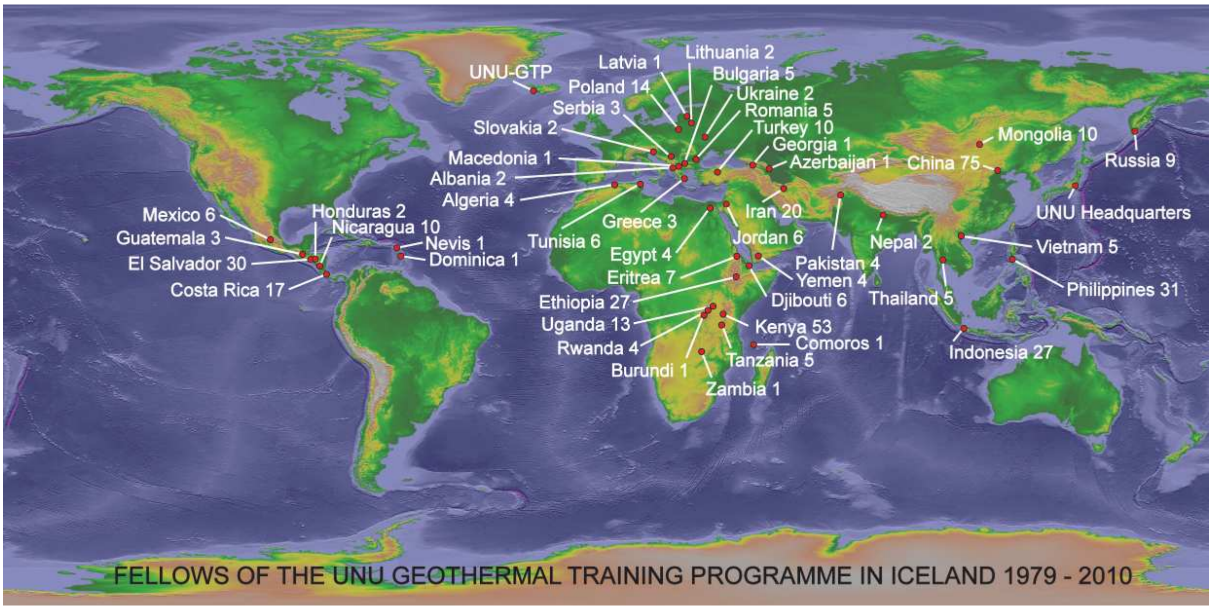

Figure 10.6 *Fellows of the UNU Geothermal Training Programme in Iceland 1979-2010. (Orkustofnun, 2010)*

10.9 International Cooperative Activities

Iceland chairs the International Partnership for Geothermal Technologies (IPGT) this year and participates in all of the six working groups that IPGT has established; Lower Cost Drilling, Zonal Isolation/Packers, High Temperature Tools, Stimulation Procedures, Modeling and Exploration Technologies. Iceland is a member of IEA-GIA and leads Annex VIII and Task E of Annex I. It is a member of the International Geothermal Association with three BoD Members, and now hosts the IGA Secretariat until end of this year, having done so since September 2004. Iceland is also a Member of the World Energy Council; cooperates within the EU; and is a partner of the Enhanced Geothermal Innovative Network for Europe (ENGINE) and the HiTi-project, designing high temperature instruments for supercritical geothermal reservoirs, both of which are partly funded by the 6th EU Framework Programme; and is part of the Strategic Energy Technology Plan (SET-PLAN) of the EU. Orkustofnun hosts the UNU-GTP and ICEIDA is involved in stimulating geothermal utilization in developing countries. In addition, Iceland together with the US and New Zealand founded a partnership aiming at solving unique energy problems that small islands face in the EDIN program (Energy Development for Island Nations).

Iceland has a great deal of know-how and experience in the harnessing of geothermal sources, both for space heating and electricity generation. The Icelandic firms offer technical and investor know-how to maximize the profitability of investment in geothermal projects world-wide: Iceland

GeoSurvey, Landsvirkjun Power, Mannvit, Verkís, Efla and Iceland Drilling Company take part in international cooperative activities.

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National Activities

Chapter 11

Italy

Vale Secolo Power Plant with installed capacity of 120 MW (Two 60 MW units).

11.0 Introduction

In Italy, the geothermal resources are mainly exploited for the purpose of electricity generation. An overview of the activities carried out in the year 2009 is presented in this chapter.

All the plants in operation are located in Tuscany, in the two "historical" areas of Larderello-Travale and Mount Amiata. In 2009, with an installed capacity of 842.5 MW the gross electricity generation reached 5,200 GWh.

Though this represents only 1.6% of Italy's total domestic generation, it meets about 25% of the electricity demand in Tuscany, the Italian region where all the geothermal plants are located.

Besides the electricity generation, geothermal fluids are used as heat sources, mainly for spas, space and district heating, greenhouses and fish farming.

In 2009, the supply of thermal energy totalled about 10,000 TJ.

11.1 The Electricity Market in Italy

In accordance with the liberalization process of the electricity market in Italy, Enel was obliged to reduce its quota of electricity generation to below 50% (it was 73% in 1998) and 15,057 MW of its generating capacity were sold to other operators in the period 2001-2003. As a consequence, several international competitors are now present in the Italian electricity market and Enel, which is still the main operator, has now a quota of about 30% of electricity generation.

From 1 April 2004, the Italian Power Exchange has been operating and in the same year an independent private company, called TERNA, was established for the ownership and management of the national high voltage electric grid (transmission network).

In the year 2009 the electricity needs in Italy reached 333,400 GWh, with a domestic contribution of 86.5%, while a relevant 13.5% was imported.

As regards the 288 TWh of domestic electricity generation, 76% comes from fossil fuels, 17% from hydro and 7% from geothermal, biomass, wind and solar.

Even if the contribution of geothermal electricity generation is only 1.6% of the whole Italian generation, it covers about 25% of the electricity needs in Tuscany, giving a substantial contribution to the green energy generation in this Region.

11.1.1 Enel Green Power

In response to the growing demand for renewable energy recorded in recent years as a result of commitments signed by many governments aimed at reducing CO_2 emissions, a new company, Enel Green Power, fully owned by Enel Group, was established in December 2008.

This company draws its strength from Enel expertise and experience in geothermal, small-hydro, wind, biomass and solar power generation and is dedicated to developing and managing energy generation from renewable resources both in Italy and abroad (Europe and American continent).

At present, Enel Green Power operates in sixteen countries and is the world leader in this sector, with 20.7 TWh produced (covering the energy consumption of 7 million families and avoiding 15.5 million tons of CO_2 emissions every year). The installed capacity is around 5,700 MW, and there are over 500 plants currently in operation or under construction around the world.

11.2 Current Status of Geothermal Energy Use

11.2.1 Electricity Generation

All the plants in operation are located in Tuscany, in the areas of Larderello/Travale-Radicondoli and Mt. Amiata (Figure 11.1).

As of 31 December 2009, 247 production wells were in operation, with a total length steam network of 184 km. In addition, 32 reinjection wells were in operation with a total water network of 244 km.

33 units (with capacities in the range 10-60 MW) were in operation with a total installed capacity of 842.5 MWgross.

The net electricity generation in 2009 was 5.2 TWh, 88% of which in the Larderello/Travale-Radicondoli area and 12% in the Mount Amiata area.

11.2.1.1 Drilling Activities

The following drilling activities were carried out throughout 2009:

- Drilling and completion of 8 production wells.
- Workover/deepening activities of 5 wells

A total of 16,335 m were drilled in 2009.

A new innovative drilling rig has been acquired (Figure 11.2).

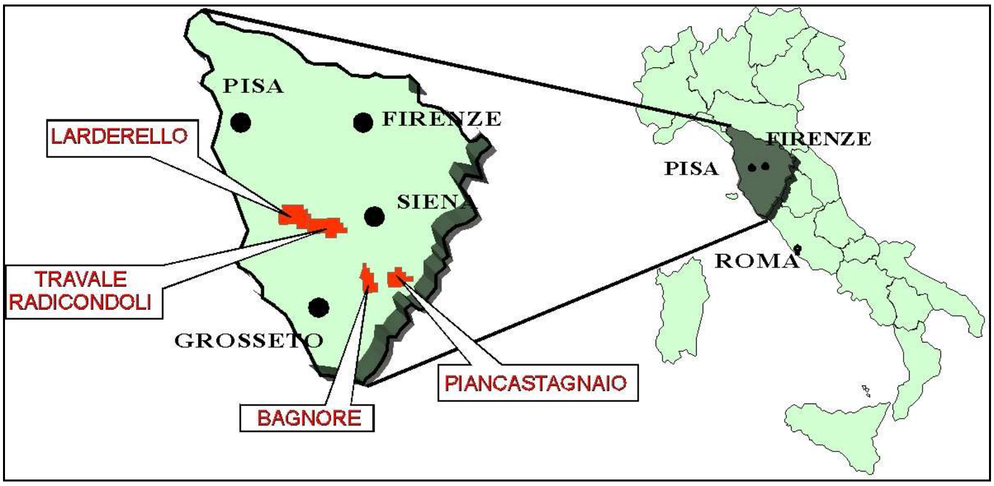

Figure 11.1 Location of geothermal fields in Italy.

Figure 11.2 A view of the new rig.

11.2.1.2 Power Plant Construction

Two new 20 MW units, Sasso 2 and Nuova Lagoni Rossi, were put into operation in 2009 (*Figures 11.3 and 11.4*).

Figure 11.3 *Two views of the 20 MW Sasso 2 power plant installed in the western area of the Larderello Field.*

Figure 11.4 A view of the 20 MW Nuova Lagoni Rossi power plant installed in the southern area of the Larderello field.

The Nuova Lagoni Rossi unit has replaced the old 8 MW Lagoni Rossi power plant (Figure 11.4).

In 2010, two new 20 MW units are currently under construction; repowering of the Nuova Radicondoli power plant (Figure 11.5) and construction of the Chiusdino 1 power plant (Figure 11.6); they will be commissioned at the end of 2010.

Figure 11.5 A view of the 20 MWe Chiusdino 1 power plant, under construction in the southern area of the Travale-Radicondoli field.

Figure 11.6 A view of the cooling tower of the 20 MWe Chiusdino 1 power plant, under construction in the southern area of the Travale-Radicondoli field.

11.2.2 Direct Uses

In Italy, besides electricity generation, the geothermal fluids are also used as thermal sources. In 2009, the yearly average total heat supply was about 10,000 TJ/yr.

An important direct use application (32% of the supply) is for bathing (temperatures less than 40 °C), which has a long tradition in Italy, dating back to Etruscan and Roman times. Heating (green houses and district heating) represents the largest application (59% of the supply). There are also several other uses including fish farming, industrial process heat and geothermal heat pumps (10% of the supply).

Enel is engaged in the direct uses, supplying the equivalent of about 1,100 TJ/yr of geothermal heat. Moreover, it also sells about 36,000 t/yr of nearly pure CO_2, produced from a deep well located in the Torre Alfina Field (Latium) that, after purification, is used in the food industry.

11.2.3 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, about 3 million tons of CO_2 emission into the atmosphere.

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 emissions from geothermal power plants have not been included by ARPAT (the Italian Agency for the Protection of the Environment and the Territory) into the GHG inventory.

11.2.4 Geothermal Exploration

In 2009, the Italian Government has modified the Italian regulatory frame for geothermal resources exploitation. With respect to the previous law, the main aspects that have been introduced are:

- Classification of geothermal resources depending on their temperature
  - High enthalpy resources T> 150 °C
  - Medium enthalpy resources 90 °C<T≤ 150 °C
  - Low enthalpy resources T≤ 90 °C
- Increase of the contributions to be paid to the local administration up to
  - 1.3 €/MWh to the municipalities
  - 1.95 €/MWh to the Region (upper administrative level)
- Introduction of a one-off contribution (payable in 10 years) at the start up of new power plants. The amount of the contribution is fixed at the 4% of the construction costs
- Discharge of the Enel's exclusive right for the geothermal resource exploitation in some Tuscan areas

As a consequence of this latter point, several companies have applied for research permits (authorizations) in areas close to Enel leases under exploitation, addressing their targets especially to medium or low enthalpy geothermal resources. These research studies are mainly aimed at developing small binary power plants (<1 MW_e) that are entitled to special economic tariffs.

In 2009, Enel Green Power also applied for new research leases for a total surface area of 950 km^2, looking for both high and medium enthalpy resources.

11.3 Market Development and Stimulation: Policies Supporting Renewable Resources

Specific policies for supporting the development of renewable resources have been adopted in Italy. As from the year 2001, all the operators (importers and producers of electricity from non-renewable sources) have to supply a quota of their input into the grid within the following year from renewable sources. This quota was initially, i.e., from the year 2002, set to 2% of the total energy, produced or imported, exceeding 100 GWh (excluding cogeneration, auxiliary consumption and exports).

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 the required "green" energy, or simply acquiring their rights (as in the spirit of the "Green Certificates").

According to a Decree Law issued on 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 on CO_2 emission reduction. In 2007, with a subsequent law, the quota was updated to 3.80% for 2007 and a yearly increase of 0.75% per year was fixed up to 2012.

The value of the Green Certificates was modified at the end of 2007, making it equal to the difference between 18 €-cent/kWh and the average market price of the electricity; a multiplying coefficient (different for each renewable energy source; it is 0.9 for geothermal) has then to be applied to this difference. Small power plants (typically below 1 MW) are allowed a fixed price (again, differentiated by source; it is 20 €-cent/kWh for geothermal).

The calculation mechanism may be updated every three years. Green Certificates are awarded to new power plants in operation after April 1999, and for a period that was initially 8 years, subsequently extended to 12 years; plants in operation after January 2008 are awarded for 15 years.

For 2010, the value of the net kWh generated from new or recent geothermal power plants awarded with Green Certificates is around 11 €-cent/kWh. This incentive makes it possible, in Italy, to proceed with the exploration, development and utilization of deep geothermal resources up to 3,500-4,000 m depth, which require the drilling of very expensive wells.

The electricity produced by geothermal plants with an installed capacity lower than 1 MW is sold at a fixed price of 200 €/MWh.

State incentives for the direct use of heat from geothermal sources are also provided. They consist of an:

- Incentive of 10.33 €/MWh_{th} to the end users on a permanent basis, plus 15.49 €/ MWh_{th} to be confirmed every fiscal year
- Incentive to the developers for new supplies or for the increase of the existing ones amounting to 20.66 €/ kW_{th}

11.4 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 high enthalpy projects.

Aiming at the retrieval of a constructive and mutually beneficial relation with the territory, Enel has set forth a number of initiatives to reduce the environmental drawbacks and increase the acceptability.

New design solutions have been adopted to reduce the noise and visual impact of drilling pads, gathering systems and power plants. Moreover, an innovative plant for the abatement of mercury and hydrogen sulphide (AMIS) was designed and put into operation with very positive results, improving significantly the acceptability by the local population.

11.4.1 AMIS Plant Construction

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 consequent acceptability improvement from the local population. It will eliminate the bad smell of H_2S present in the geothermal areas.

Four additional AMIS plants have been installed in 2009. Currently, a total of 23 AMIS plants have been installed, allowing treatment of more than 80% of the emission due to the generation portfolio. A picture of the AMIS plant installed at the Nuova Gabbro plant (20 MW) is given in Figure 11.7.

Figure 11.7 The AMIS plant for the Hg and H_2S abatement installed at the 20 MW Nuova Gabbro power plant.

11.5 Royalties and Contributions

The royalties for exploitation leases are 1,186.2 €/km².

In addition, it should be noted that, by law, for each kWh generated from geothermal resources ENEL must pay royalties to the municipalities and to the District where the plants are located and a "one-off" payment for the new plants that will be commissioned (see Section 11.3.4).

11.6 Economics

The geothermal projects recently developed in Italy are deep resources, with relevant huge investments in drilling activities (wells up to 3,000-4,000 m), and, therefore, the total capital cost for a new development project is around 4 million €/MW_e installed, depending on well depths, productivities, and chemical composition of the fluids.

Accordingly to the above mentioned considerations, new project developments are still feasible thanks to the presence of Green Certificates.

11.7 Research Activities

Research activities have been focused both on the implementation of advanced methodologies (3-D seismic) aimed at reducing the mining risk of deep drilling, and on the methodologies aimed at solving/mitigating corrosion problems in wells, gathering systems and power plants, which are caused by chlorine occurrence 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.

11.8 International Activities

Enel has been engaged in several exploration and development programs in Central and South America, and the USA. In El Salvador, as a partner of La Geo, Enel has completed the further development of the Berlin field with the drilling of wells and the construction of a 44 MW power plant that began commercial operation in February 2007.

Exploration activities have started-up in some areas of Chile, Nicaragua and Guatemala, while in USA, development programs for about 140 MW binary units have been initiated in four different areas of Nevada, Utah and California.

In Nevada, 12 wells have been drilled in the two areas of Stillwater and Salt Wells, and the construction of the power plants was completed in February 2009 for a total installed net capacity of 48 MW_e (34 MW_e at Stillwater and 14 MW_e at Salt Wells).

In Chile, the first 3 wells for a 40 MW_e power plant project have been drilled in the Apacheta area (northern Chile).

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National Activities

Chapter 12

Japan

Figure 12.8 A proton beam treatment room for cancer therapy in the Medipolis Medical Research Institute, Ikedako-tobu, Japan on 9 March 2010, of which large amounts of electricity consumption will be supplied by geothermal power in the near future.
(Photo courtesy of H. Muraoka)

12.0 Introduction

Japan's first geothermal power generation of 1.12 kW_e was experimentally performed in Beppu, Oita Prefecture, Kyushu, in 1925. The practical use of geothermal power commenced in 1966, with the installation of the first plant, the Matsukawa Geothermal Power Plant of 9.5 MW_e (23.5 MW_e at present and sustainably working for 43 years), Iwate Prefecture, in northern Honshu.

Japan, as a volcanic country, is blessed with potential geothermal resources for development. However, the construction of geothermal power plants has been restricted due to factors such as the restrictions in National Parks and huge numbers of hot spring resort areas. At the end of the 1980s only nine plants were operating, with a total capacity of about 215 MW_e.

Since the two oil crises, the government rapidly promoted research and development in several areas of geothermal exploration and technology throughout the 1980s. As a result, geothermal development in several areas in the Tohoku and Kyushu Districts attained a construction rush in the early 1990s, more than doubling the total capacity to about 534 MW_e.

Immediately after the rush, Japan faced a deflation economy stage in the late 1990s, and the lines of incentive policies were withdrawn from geothermal energy, thus freezing the geothermal market. No new geothermal power plants have been constructed since the late 1990s, except for small-scale plants such as the Kuju Kanko Hotel of 2 MW_e in 1998, the Hachijojima geothermal power plant of 3.3 MW_e in 1999, the Hatchobaru geothermal binary power plant of 2 MW_e in 2006, the Suginoi Hotel of 1.9 MW_e in 2006, and the Kirishima geothermal binary of 0.22 MW_e in 2006. This pessimistic trend will soon be changed by the dynamic market force in the international geothermal sector.

12.1 Highlights for 2009

The year 2009 was marked by several highlights:

- The landslide winning of the Democratic Party in the Lower House election on 30 August 2009 will bring optimistic trends in the Japanese geothermal sector including the possible introduction of the Feed-in-Tariff
- A prototype of the hot spring power generation (50 kW-class Kalina-cycle) system has been completed in March 2010 (by GERD and AIST)
- Ministry of the Environment (MOE) adopted two geothermal R&D projects for the coming three years starting from 2010
- The Japan International Cooperation Agency (JICA) has dispatched the Preparatory Survey Mission to Indonesia in April 2009 to launch "the Project for Capacity Building for Enhancement of the Geothermal Exploration Technologies in Indonesia"
- Hirosaki University founded "the North Japan New Energy Research Center" (renamed "the North Japan Research Institute for Sustainable Energy" in October 2010) in Aomori City on March 2009 for the energy paradigm shift in cold districts

12.2 National Policy

12.2.1 Strategy

The Agency for Natural Resources and Energy (ANRE), the Ministry of Economy, Trade and Industry (METI), is in charge of Japan's energy policy. METI states that the promotion of the geothermal energy development is extremely important, because it is one of the oil alternative energies, and it is clean; stable power supply from the geothermal power of domestic production answers a social need like helping mitigate global environmental problems. Therefore, inducement at the early stage of the geothermal power generation development is aimed at private entrepreneurs.

To adjust environmental contribution statistics of the international standard "Renewable Energy", the New Energy Committee of ANRE (under METI) proposed that the small-scale hydro and geothermal energy should be placed back into the Japanese-specific category "New Energy", on 24 March 2006. This motion was positively discussed in the following two meetings of the Committee and adopted as an express statement in 26 May 2006. This was legally enacted in "the Special Measures Law for the Promotion of Utilization of the New Energy" (so-called the New Energy Law) in April 2008.

The landslide winning of the Democratic Party in the Lower House election on 30 August 2009, will bring optimistic trends in the Japanese geothermal sector including the possible introduction of the Feed-in-Tariff.

12.2.2 Legislation and Regulation

The "Law Concerning Promotion of the Development and Introduction of Alternative Energy" was enacted in 1980 and the promotion strategy for geothermal energy was described. While the "Special Measures Law for the Promotion of Utilization of the New Energy (so-called New Energy Law)" was launched in 1997, geothermal energy was excluded from the definition of New Energy which needs governmental support. Then the "Renewable Portfolio Standard Law" was enacted in 2003, where 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.

12.2.3 Progress towards National Targets

The numerical target for geothermal electrical capacity has stayed at 535 MW_e for the electricity power industries since FY2000. This means that the objective for the moment is only to maintain the current state. However, promotion of geothermal energy development is expected 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, there is no target for the direct use of geothermal energy, either qualitatively or quantitatively.

122.4 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 (Thermal and Nuclear Power Engineering Society, simplified as TENPES hereinafter, 2010).

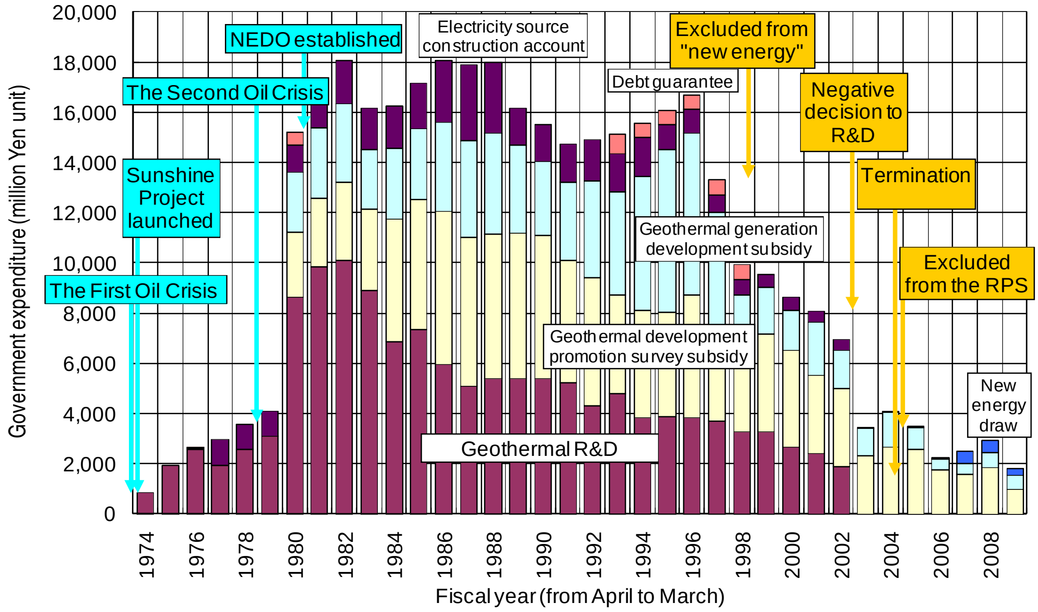

Figure 12.1 A chronological change of annual geothermal budgets in Japan.

The government expenditure has drastically been decreasing during the last decade, reflecting that the geothermal energy was excluded from "New Energy" in 1997. Particularly, national geothermal R&D projects ceased in FY2002.

12.2.5 Industry Expenditure on Geothermal R&D

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

12.3 Current Status of Geothermal Energy Use in 2009

12.3.1 Electricity Generation

12.3.1.1 Installed Capacity and Electricity Generated

The total installed electricity generation capacity of geothermal energy at the end of March 2009 was 535.26 MW_e, including that of the companies' own private use power plants (TENPES, 2010; Figures 12.2 and 12.3 and Table 12.1).

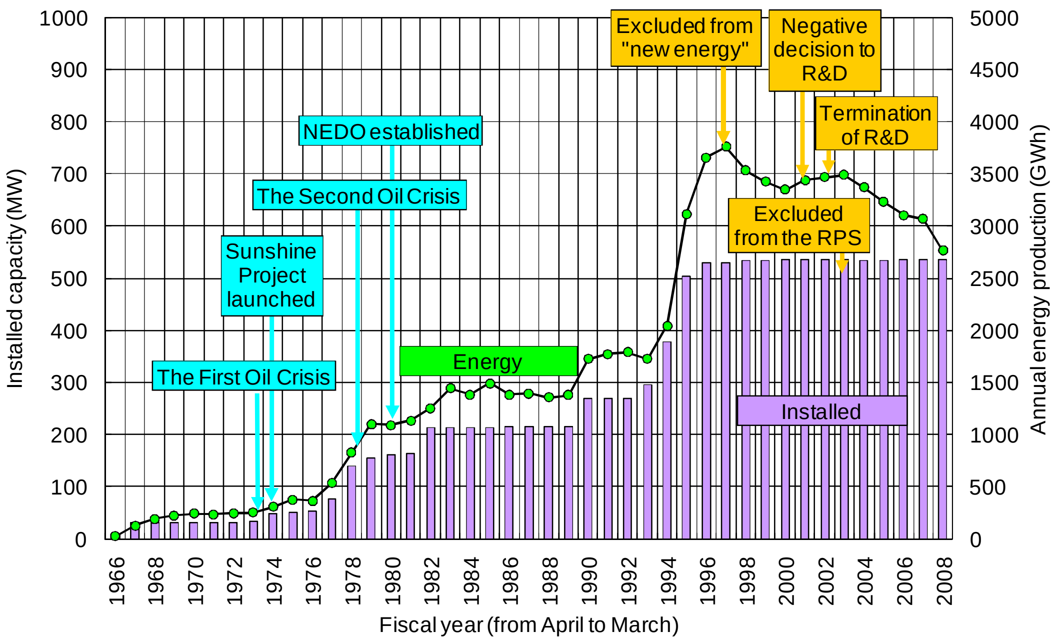

Figure 12.2 A chronological change of installed capacity and annual energy production of geothermal power plants in Japan.

The total electricity generation from geothermal energy in Japan during FY2008 (from April 2008 to March 2009) was 2,765 GWh (TENPES, 2010; Figure 12.2 and Table 12.1). A relatively high rate of decline in the electricity generation was mainly ascribed to the Kakkonda geothermal power plants where a landslide occurred on 20 April 2008 and damaged steam pipelines. Though temporary repairs were made on 17 June 2008, repairs will not be complete for another year (TENPES, 2010).

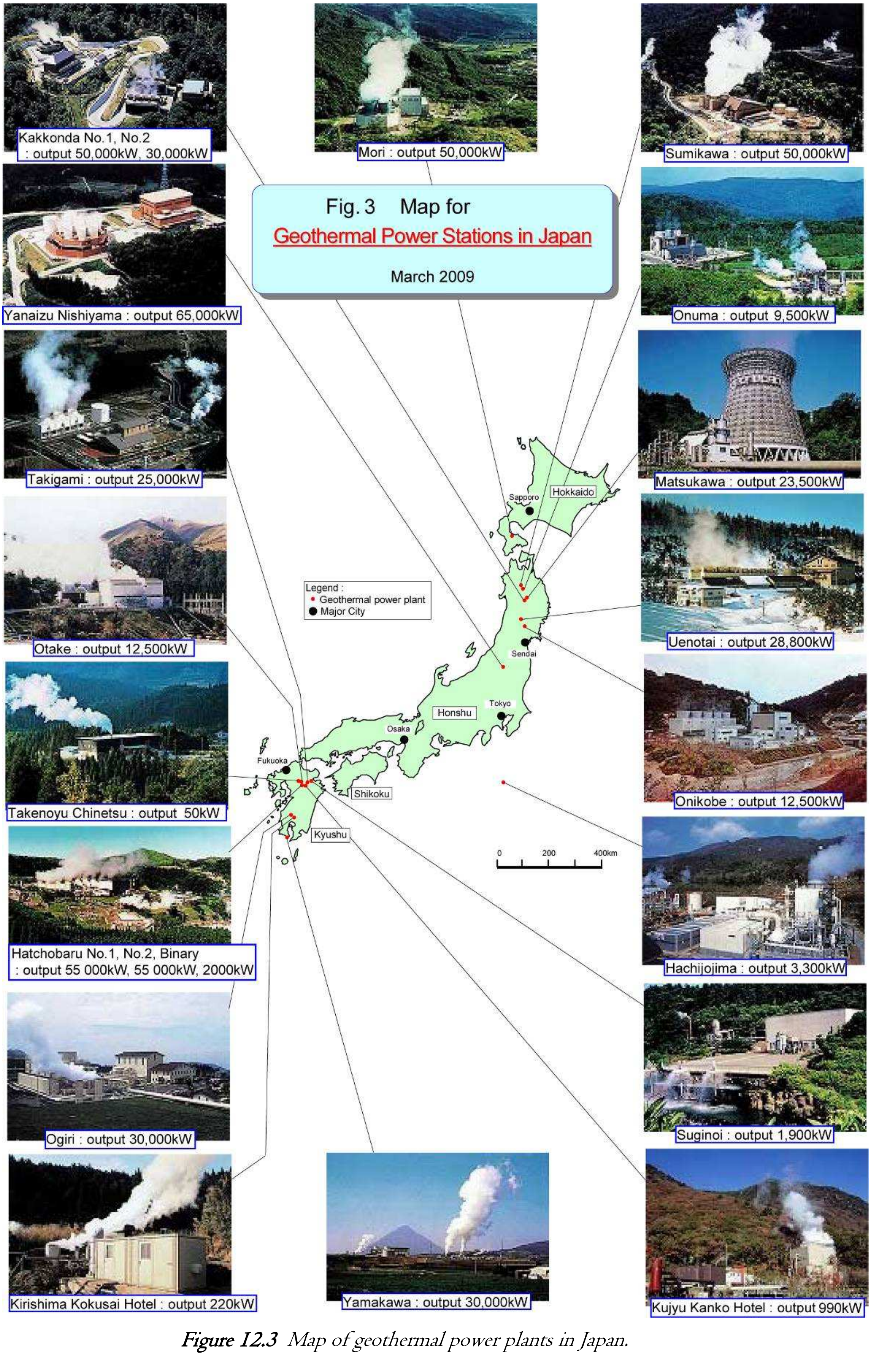

Figure 12.3 Map of geothermal power plants in Japan.

Table 12.1 Operating geothermal power plants in Japan from April 2008 to March 2009.

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	111,321	Nov. 1982
Sumikawa	Tohoku Electric Power Co., Inc.	Mitsubishi Materials Corporation	50.00	312,071	Mar. 1995
Onuma	Mitsubishi Materials Corporation	Mitsubishi Materials Corporation	9.50	58,828	Jun. 1974
Matsukawa	Tohoku Hydropower & Geothermal Energy Co., Inc.	Tohoku Hydropower & Geothermal Energy Co., Inc.	23.50	126,362	Oct. 1966
Kakkonda 1	Tohoku Electric Power Co., Inc.	Tohoku Hydropower & Geothermal Energy Co., Inc.	50.00	10,602	May 1978
Kakkonda 2			30.00	38,487	Mar. 1996
Uenotai	Tohoku Electric Power Co., Inc.	Tohoku Hydropower & Geothermal Energy Co., Inc.	28.80	204,059	Mar. 1994
Onikobe	Electric Power Development Co.	Electric Power Development Co.	12.50	79,702	Mar. 1975
Yanaizu - Nishiyama	Tohoku Electric Power Co., Inc.	Okuaizu Geothermal Ltd. Co.,	65.00	288,808	May 1995
Hachijojima	Tokyo Electric Power Company	Tokyo Electric Power Company	3.30	13,350	Mar. 1999
Suginoi	Suginoi Hotel	Suginoi Hotel	1.90	9,037	Mar. 1981
Kuju	Kuju Kanko Hotel	Kuju Kanko Hotel	0.99	7,444	Dec. 2000
Takigami	Kyushu Electric Power Co., Inc.	Idemitsu Oita Geothermal Co., Ltd.	25.00	200,622	Nov. 1996
Otake	Kyushu Electric Power Co., Inc.	Kyushu Electric Power Co., Inc.	12.50	82,850	Aug. 1967
Hatchobaru 1	Kyushu Electric Power Co., Inc.	Kyushu Electric Power Co., Inc.	55.00	401,332	June 1977
Hatchobaru 2			55.00	435,501	June 1990
Hatchobaru Binary			2.00	6,525	Apr. 2006
Takenoyu	Hirose Trading Co., Ltd.	Hirose Trading Co., Ltd.	0.05	0	Oct. 1991
Ogiri	Kyushu Electric Power Co., Inc.	Nittetsu Kagoshima Geothermal Co., Ltd.	30.00	253,965	Mar. 1996
Kirishima Kokusai Hotel	Fuji Electric Systems Co., Ltd.	Daiwabo Kanko Co., Ltd.	0.22	869	Feb. 1984
Yamakawa	Kyushu Electric Power Co., Inc.	Kyushu Electric Power Co., Inc.	30.00	122,865	Mar. 1995
Total			**535.26**	**2,764,600**	

12.3.1.2 New Developments in 2009

No new developments were made during FY2008 (from April 2008 to March 2009).

12.3.1.3 Rates and Trends in Development

Japan's geothermal power market has lost in the last decade since geothermal energy was excluded from "New Energy" in 1997. Although geothermal energy was placed back into "New Energy" in 2008, the future trend is still obscure. Investment in large-scale power plants is too risky at present; circumstances that inevitably focus activities on the realistic option of developing small-scale power plants for the next few years.

12.3.1.4 Wells Drilled

During the year 2009, 2 exploratory wells were drilled in the Wasabizawa area, 4 production wells were drilled at 4 power stations (Kakkonda, Onikobe, Yanaizu Nishiyama and Otake), and 5 reinjection wells were drilled at 5 power stations (Sumikawa, Onikobe, Takigami, Hatchobaru and Yamakawa).

1 exploratory well was drilled in Ikedako-tobu for a Geothermal Development Promotion Survey.

12.3.1.5 Contribution to National Demand

ANRE reported statistics on the details of national electricity generation capacity for FY 2008 (from April 2008 to March 2009) in the Energy White Paper 2010 on its website (ANRE, 2010). The total installed electricity generation capacity of ten electric power companies at the end of March 2009 was 241,480 MW_e, where LNG power accounted for 25.5 %, nuclear power 20.2 %, oil and other fire power 19.1 %, coal power 15.7 %, pumping-up power 10.6 %, hydro power 8.6 %, and renewable energy including geothermal power 0.2 % (Figure 12.4).

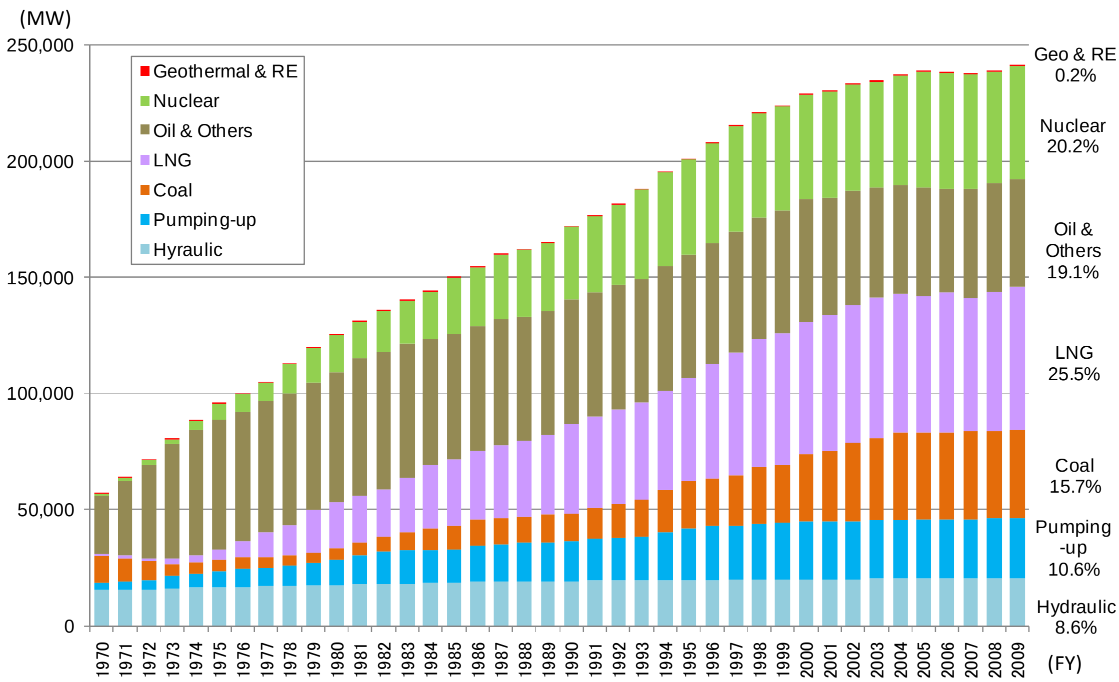

Figure 12.4 Share of installed capacities by individual generation sources in Japan since 1970 (ANRE, 2010).

The national electricity generation is again adopted from the Energy White Paper 2010 (ANRE, 2010). The total annual electricity generation for the country at the end of March 2009 was 955,100 GWh, where LNG power accounted for 29.4 %, nuclear power 29.2 %, coal power 24.7 %, oil and other fire power 7.6 %, hydro power 7.3 %, pumping-up power 0.7 % and renewable energy including geothermal power 1.1 % (Figure 12.5).

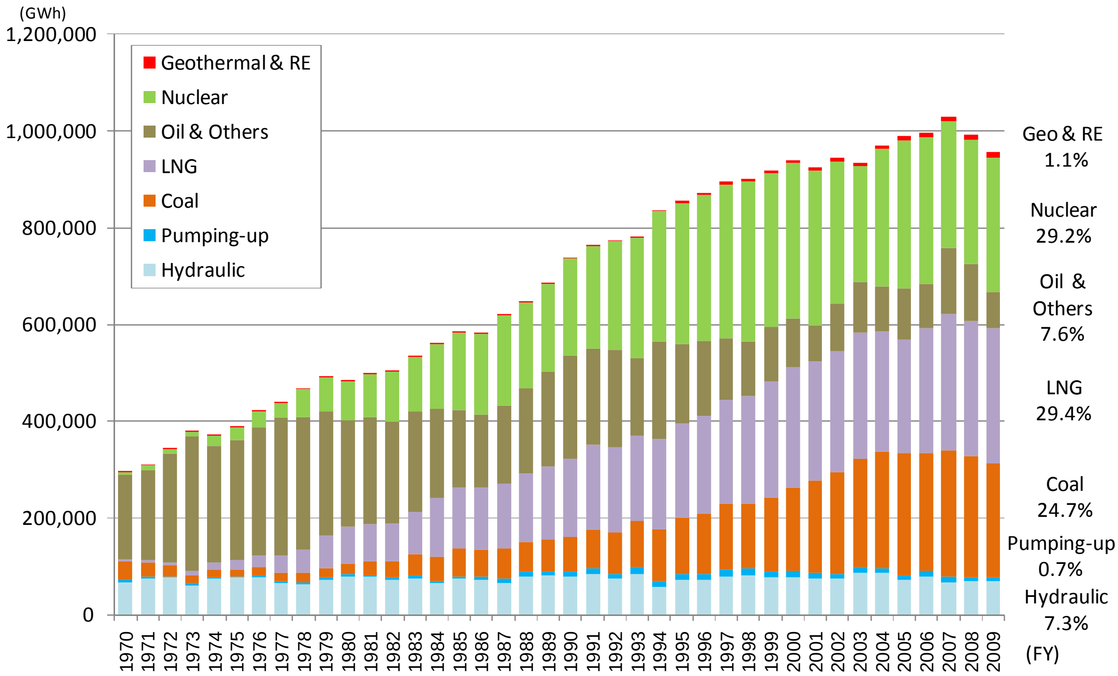

Figure 12.5 Share of electricity production by individual generation sources in Japan since 1970 (ANRE, 2010).

12.3.2 Direct Use

To summarize geothermal direct use in Japan, special attention should be given to its huge number of hot springs for bath use. As often discussed, the energy saved by the hot springs for bath use in Japan is difficult to estimate because of the huge numbers of hot springs, but these hot springs are economically more important than any other geothermal resources for direct use in Japan.

Geothermal resources for direct use are classified here into three categories: hot water for thermal uses excluding bath use, geo-heat use including geo-heat pumps, and hot springs for bath use. Estimating the energy contribution by hot spring bath use is a long-pending project in Japan. Lund, *et al.* (2005) stated "...who do not keep accurate records of temperatures and flow rates of more than 25,000 hot spring sources in Japan". This is true; however, we started to try to estimate the energy contribution by hot springs for bath use as described on the 2006 Japan Country Report (GIA, 2009). Here, we introduce this category from the latest publication (Sugino and Akeno, 2010).

12.3.2.1 Installed Thermal Power

Installed thermal power is described here for the three categories mentioned 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 (NEF, 2007).

Questionnaires for hot water thermal uses, excluding bath uses, were sent to 267 municipalities in Japan and answers were returned from 116 of them. The number of facilities for the various hot water uses in Japan as of March 2006 was 697 (NEF, 2007). The facilities are generally dominant in northern and colder areas, but are also known in southern Kyushu. Installed capacity of hot water uses in Japan as of March 2006 was 400.7 MW_{th} (Sugino and Akeno, 2010; Table 12.2). The largest application of hot water utilization is for road snow melting and it is followed by house heating and welfare facilities heating.

A questionnaire survey for geo-heat uses including geo-heat pumps was also conducted by NEF in 2006. The number of geo-heat use facilities in Japan as of March 2006 was 638, of which geo-heat pumps, in a narrow sense, are restricted into 116, and the others are more primitive types using soil air circulation. They are mostly used for house heating, followed by snow melting. Installed capacity of geo-heat uses in Japan, as of March 2006, is 13.4 MW_{th} (Sugino and Akeno, 2010; Table 12.2).

Estimating the energy contribution from hot spring bath use is a long-pending project in Japan. First of all, it should be noted that the Japanese commonly prefer thermal water at a temperature 42 °C for bathing. In fact, the Japanese are heating water up to the temperature 42 °C 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.

A method to estimate the fuel alternative energy by hot spring bath use was described by Muraoka in Ehara *et al.* (2008). To conservatively estimate, hot spring sources less than 42 °C are neglected here, with those higher than 42 °C only counted, because some of hot springs less than 42 °C save a small amount of fuel energy but others rather consume fuel energy for heating to 42 °C, almost compensating each other. Then, fuel alternative energy by hot spring bath use can be estimated as the thermal energy between the mean ground surface temperature in Japan 15 °C and the bath use temperature 42 °C for all the hot springs that are higher than 42 °C in Japan. Excess thermal energy higher than 42 °C is not effectively utilized in the way of bath use so that this should not be counted for the fuel alternative energy.

Based on this method and 24,807 hot spring data, the Sustainable-Zone Research Group recently estimated the fuel alternative energy by hot spring bath use to be 1,685.5 MW_{th} (Sugino and Akeno, 2010; Table 12.2).

12.3.2.2 Thermal Energy Used

As of March 2006, the total hot water thermal energy used for thermal use, excluding bath use, was 4,900.4 TJ/yr (Sugino and Akeno, 2010; Table 12.2). Hot water supply is the largest type of hot water utilization, and its capacity factor is relatively high because it is for all-seasonal uses. The "weighted" average capacity factor for hot water use is 0.39.

The total thermal energy used for geo-heat applications in Japan, as of March 2006, was 67.9 TJ/yr (Sugino and Akeno, 2010; Table 12.2). The average capacity factor for geo-heat uses is 0.16.

For hot spring bath use, even if bath tubs are always filled with hot water, its utilization (capacity) factor depends on visitors' soaking hours and is not known. According to the data from fiscal year 2005, the number of hot spring accommodations is 15,024, the accommodation guest capacity is 1,413,088, and the annual guest accommodation is 136,613,954 man-days. This means that the mean guest capacity of a hotel is 94.1 persons and an average hotel has 24.9 guests every day through the year. Even if there is some seasonal bias and popularity bias from one hotel to another, its utilization (capacity) factor is expected to be very high. However, to conservatively estimate, the annual day utilization factor related to the seasonal and popularity biases is assumed to be 0.75. In addition, most of bath tubs are cleaned every day so that the hourly utilization factor is assumed to be 0.52. Then, 0.75 multiplied by 0.52 makes 0.39, a very conservative assumption for the utilization (capacity) factor.

We obtain the annual fuel alternative energy by hot spring bath use is 20,729.7 TJ/yr (Sugino and Akeno, 2010; Table 12.2). The utilization (capacity) factor is here assumed to be 0.39 for a conservative estimate. This will improve the statistical data of direct use in Japan (Lund, *et al.,* 2005).

The grand total of the three categories of the used thermal energy for direct use in Japan is 25,697.9 TJ/yr (Table 12.2).

12.3.2.3 Comment on Categories of Use

We here summarize the direct use in Japan (Table 12.2). We have conservatively estimated the fuel alternative energy by hot spring bath use for heating water up to 42 °C. Nevertheless, as seen in Table 12.2, the hot spring bath use represents the largest contribution, 80.67 % of the direct use in Japan. Hot water use, excluding bath use, is 19.07 %, and geo-heat use including geo-heat pumps is 0.26 %. In other words, there is plenty of room for development in the other categories such as geo-heat pumps.

12.3.2.4 New Developments in 2009

As has been mentioned, NEF periodically conducts a questionnaire survey on two categories of direct use: hot water thermal use without bathing and geo-heat use including heat pumps. The two most recent surveys were carried out in 2002 and 2006 (NEF, 2003; 2007). Therefore, we can only compare four years' results between 2002 and 2006. The hot water thermal use without bathing decreased from 5,138.3 TJ/yr in 2002 to 4,900.4 TJ/yr in 2006. The main reason for this result is ascribed to the recoverability of the questionnaire surveys- they decreased from 147 replies/260 recipients in 2002 to 116 replies/267 recipients in 2006. The geo-heat use including geo-heat pumps increased from 22.4 TJ/yr in 2002 to 67.9 TJ/yr in 2006, more than a factor of three during the four years. Hot springs for bath use are constantly developed every year. The number of hot spring sources for bath use increased from 27,644 in March 2005 to 27,866 in March 2006, i.e. by 222, or 0.8 % annually. The discharge rate of hot springs for bath use increased from 2,712,140 l/min in March 2005 to 2,761,300 l/min in March 2006, an increase of 49,160 l/min, or 1.8 % annually.

12.3.2.5 Rates and Trends in Development

The hot water thermal use, excluding bathing, apparently decreased from 2002 to 2006 due to the recoverability of the questionnaire surveys, but this category may not have changed much. The geo-heat use, including geo-heat pumps, increased at factor of about three during the four years. Although the present market for geo-heat use is still small, this rate is promising a rapid expansion in the near future. The numbers of hot springs for bathing were 13,079 in FY1962 and 27,866 in FY2005. If we simply apply a linear trend, the mean annual increment is 344 (Figure 12.6). The discharge rate of hot springs for bathing was 930,110 l/min in FY1963 and 2,761,300 l/min in FY2005. If we simply apply a linear trend here, the mean annual increment is 43,600 l/min. This must be the largest and steadiest direct use market in Japan.

Table 12.2 *Summary of direct use in Japan (Sugino and Akeno, 2010).*

Category		1							2	3	Total	Total
Contents of category		Hot water for thermal uses excluding bath use							Geo-heat use including geo-heat pumps	Hot springs for bath use		
Subdivision of category		Green-house Heating	Fish breeding	Industrial process heat	Space heating	Hot water supply and swimming pool	Snow melting and air conditioning (cooling)	Total of category 1	Ground heat uses (including heat pump)	Fuel-alternative energy by hot spring bath use		
Unit		(MWt)									(MWt)	(TJ/y)
WGC2005 (Statistics on the year 2003)	Total (MWt)	43.11	16.91	1.10	103.59	106.47	138.17	409.35	3.99	0.02	413.36	
	Total (TJ/y)	428.50	212.34	27.34	1409.98	2583.68	476.49	5138.33	22.35	0.38		5161.06
	Capacity Factor	0.32	0.40	0.79	0.43	0.77	0.11		0.18	0.60		0.4
WGC2010 (Statistics on the year 2006)	Total (MWt)	36.92	7.91	1.24	77.37	124.73	152.54	400.71	13.36	1685.46	2099.53	
	Total (TJ/y)	451.73	141.86	30.92	969.49	2790.11	516.27	4900.38	67.86	20729.70		25697.94
	Capacity Factor	0.39	0.57	0.79	0.40	0.71	0.11		0.16	0.39		0.39

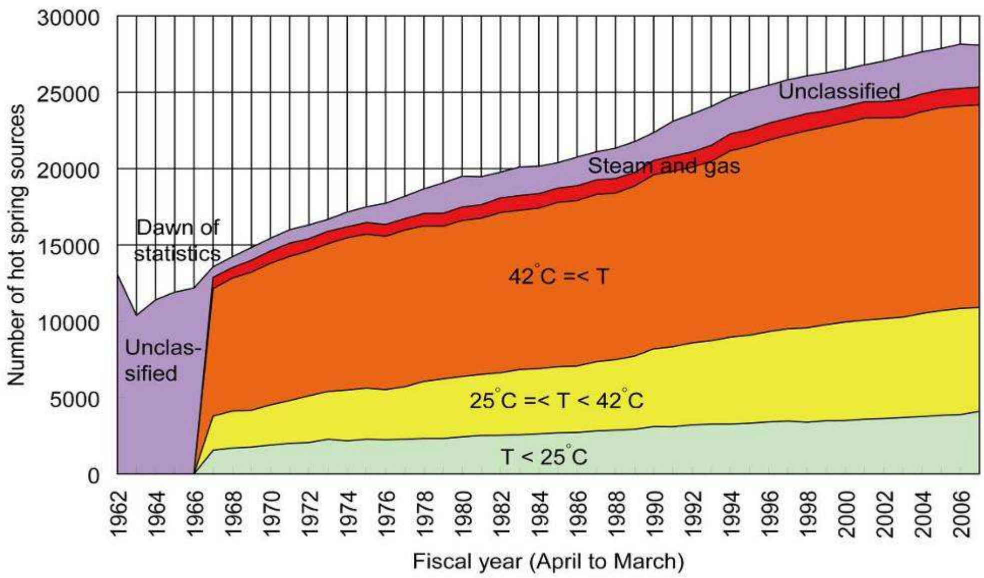

Figure 12.6 Expanding Japanese hot spring market (Ministry of Environment, 2009).

12.3.2.6 Number of Wells Drilled

The recent increase of hot spring sources for bathing is almost entirely due to drilling. Therefore, the numbers of drilled wells are roughly the same as the increment number of hot spring sources 222 in FY2005. The numbers of drilled wells for the hot water uses and geo-heat uses are not given in the results of the questionnaire surveys (NEF, 2007). In some cases, development may be from drilling one well for hot water use; while for other cases, development may be by drilling several shallow wells, such as for geo-heat pump use. However, it seems clear that the number must be larger than the increment number of the facilities. The numbers of facilities of hot water uses increased from 692 in 2002 to 697 in 2006, and the increment was only 5 during the four years. The numbers of facilities of geo-heat uses increased from 276 in 2002 to 638 in 2006, and the increment was 362 during the four years.

12.4 Energy Savings

12.4.1 Fossil Fuel Savings/Replacement

The total geothermal electricity produced in Japan is saving 700,651 toe/yr (toe = tons of oil equivalent) in FY2008, 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 904,567 toe/yr in FY2005, based on the IEA-GIA conversion factor 1 TJ = 35.2 toe in produced heat (*ibid.*).

The direct use energy produced in Japan must have increased from FY2005 to FY2008. Therefore, although the statistics of direct use is taken from FY2005, in the grand total of geothermal power and direct use, Japan is saving at least 1,605,218 toe/yr, in FY2008.

12.4.2 Reduced/Avoided CO_2 Emissions

When we assume the oil thermal power plants as a baseline, the total geothermal electricity produced in Japan results in avoidance of 2,259,005 tonnes of CO_2/yr in FY2008, based on the IEA-GIA CO_2 factor 817 kg/MWh in produced electricity (Mongillo, 2005).

When we assume the oil thermal power plants as a baseline, the total direct use energy produced in Japan avoids CO_2 emissions by 2,919,567 tonnes/yr in FY2005, based on the IEA-GIA CO_2 factor 409 kg/MWh in produced heat (*ibid.*).

The direct use energy produced in Japan must have increased from FY2005 to FY2008. Therefore, although the statistics of direct use are taken from FY2005, in the grand total of geothermal power and direct use, Japan avoided CO_2 emissions of at least 5,178,572 tons/yr, in FY2008.

12.5 Market Development and Stimulation

12.5.1 Support Initiatives and Market Stimulation Incentives

NEDO initiated "Geothermal Development Promotion Surveys" in prospective geothermal areas where investigation is hampered by survey risks, thereby expediting the development of geothermal power generation by private-sector companies. This program started in 1980. The survey program is composed of Surveys A, B and C, varying the scale and content depending upon regional potential and existing data. Surveys have been completed in 67 areas at the end of FY2009. 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

Figure 12.7 *Production test of the N21-IK-4 well, Ikedako-tobu, Kagoshima Prefecture, Japan. (Photo courtesy of A. Takaki)*

Figure 12.8 *Well production test SD-1 in Sado, Niigata Prefecture, Japan. (Photo courtesy of A. Takaki)*

large-bore production wells for long-term production tests is included. The four areas selected for the surveys FY2009 are considered to have potentials suitable for binary power plants smaller than 15 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 Ikedako-tobu, the area of third year, one production well was drilled and production test was conducted (Figure 12.7). The exploitable geothermal reserve is 1 MW and a private company examines power station construction.

In Sado, the area of third year, geothermal development was finished because the permeability did not reach the targeted value (Figure 12.8).

In Otari-mura, the area of second year, the exploitable geothermal reserve is 0.3 MW and it was decided to terminate this survey.

In Shimoyu, the area of second year, geothermal development was finished because the permeability did not reach the targeted value.

The Japanese government has taken a leading role in the development of geothermal energy resources. The government has introduced a compensation system for geothermal developers that provide compensation for interest on bank credits to support developers undertaking well drilling, a process that requires a large investment at an early stage. There are two types of subsidies for companies developing power plants, one aimed at the drilling of exploration wells, with a subsidy ratio of 50%; and the other for the construction of production and reinjection wells, and facilities above the ground, with a subsidy ratio of 20%. These systems started in 1983. Beginning in 2002, binary facilities in geothermal power generation systems were rewarded with a subsidy ratio of less than one-third.

Actual subsidy record for FY 2009:

- 2 exploratory wells were drilled at Wasabizawa

- 4 Production wells were drilled at: Kakkonda, Onikobe, Yanaizu Nishiyama and Otake
- 5 Reinjection well were drilled at: Sumikawa, Onikobe, Takigami, Hatchobaru and Yamakawa
- 4 Power Plant Facilities: new pipe laying at Onikobe, Yanaizu Nishiyama and Takigami, pH control system at Takigami

12.5.2 Development Cost Trends

The latest construction of the conventional steam turbine type geothermal power plant was in Hachijojima in 1999. There are no recent statistics on the development cost, so that it is difficult to mention to the development cost trends. During the last ten years' stagnancy, the trend of geothermal power plant design is shifting from a large-scale to a relatively small-scale. Therefore, the total cost of construction tends to decrease, but the unit construction cost is increasing.

12.6 Development Constraints

The recent reduction of political support to geothermal development is a primary constraint to geothermal market promotion in Japan. Internationally, geothermal energy is categorized as a renewable energy together with solar, wind, hydro and biomass energy. However, in Japan, only solar and wind were classified as "New Energy" that enjoyed protection under the Special Measures Law for the Promotion of the Use of New Energy enacted in 1997. Geothermal energy was not included. Moreover, in 2001, biomass was added to the list of "New Energy" to be promoted by the New Energy Subcommittee of the Advisory Committee for ANRE, but geothermal energy was not.

According to the Energy Supply and Demand Outlook presented by the government, future growth in geothermal energy is assumed to be zero. Consistent with this perspective, in 2001, METI decided to cut the entire budget for geothermal energy research and development (Figure 12.1). This decision was purely political. However, geothermal energy was legally included in the category of "New Energy" in 2008, and this will reduce constraints on development.

12.7 Economics

Japan's economy entered a serious deflation recession stage beginning 1991, after a long-lasting growing stage since 1955. Particularly, it has come to be more serious by sliding down to minus growth since the Asian currency crisis in 1997. This has dramatically made governmental tax revenues shrink and the government has withdrawn a variety of incentives from many fields, including geothermal R&D. Then, Japan's economy gradually recovered since 2002, but the Lehman Brothers Company's shock in 2008 again attacked Japan prolonging its economy recovery.

12.7.1 Trends in Geothermal Investment

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

12.7.2 Turbine, Project, Well Drilling and O&M Costs

Reliable data for most of these items are not available, partly due to their confidential nature and partly due to too few references in the current inactive geothermal market. One of the reference data for the drilling cost is available from the cost estimation of conventional geothermal power developments in Japan (NEDO, 2002), where the drilling cost for a large-diameter production or reinjection well is assumed to be 230,000 Yen/m. This is equivalent to US$ 2,150/m and US$ 4.3 million for drilling a 2,000 m depth well. This is still more expensive than the world standard, but the recent drilling cost may have been further improved.

12.7.3 Trends in the Cost of Energy

Cost of energy is seldom published even from the government because of difficulty in the equal-base comparison under the different levels of political supports. Though relatively old, ANRE (2001MS) estimated costs of a variety of energy sources as of 1999 that showed 7.3 Yen/kWh (6.8 US cents/kWh) for fire power averaged from oil, coal and LNG, 5.9 Yen/kWh (5.5 US cents/kWh) for nuclear power, 66.0 Yen/kWh (61.7 US cents/kWh) for photovoltaic power and 11.5 Yen/kWh (10.7 US cents/kWh) for wind power. The cost of geothermal power at the nearest year can be referred to NEDO (2002). NEDO (2002) estimated costs of conventional geothermal power developments in 31 target geothermal areas without incentives from the Geothermal Development Promotion Surveys and drilling subsidy. The cost varies from 10.0 to 24.0 Yen/kWh, and most of them range from 10 to 14 Yen/kWh (from 9.3 to 13.1 US cents/kWh). This range indicates a general cost of geothermal power in Japan. However, the traditional cost regime was drastically changed by the recent steep rise in the crude oil price.

As Japan is an oil-importing country, the recent steep rise in the crude oil price is changing the energy market regime. Geothermal power generation has been economically marginal in Japan, but, if the crude oil price will further rise, geothermal power generation will soon become competitive in cost to the hydrocarbon thermal power generation.

12.7.4 Geothermal Sector Employment

There is no reliable data on geothermal sector employment, but the Geothermal Research Society of Japan has about 550 members, which gives an indication of the number of people employed in the geothermal sector in Japan, because a number of non-geothermal employee members of the society may be roughly comparable with that of geothermal employees outside the society.

12.8 Research Activities

There have been no full-scale national projects for geothermal R&D in Japan since April 2003. However, the Geothermal Research Society of Japan still has about 550 members, preserving a high-level of motivation for geothermal R&D. Research activity is individually performed by national universities, national institutes and the private sector with their own budgets.

12.8.1 Focus Areas

Many researchers who are concerned with enhanced geothermal systems or engineered geothermal systems (EGS) are cooperatively participating in the Cooper Basin Project in Australia, including those from the Graduate School of Environmental Studies in Tohoku University, the Civil Engineering Research Laboratory (CERL) in the Central Research Institute of Electric Power Industry (CRIEPI) and the Institute for Geo-Resources and Environment (GREEN) in the National Institute of Advanced Industrial Science and Technology (AIST).

Geo-heat pump systems are currently one of the key research issues in Japan, mainly investigated by the Faculty and Graduate School of Engineering in Hokkaido University, Tohoku University, the Graduate School of Engineering in Kyushu University and AIST.

Geothermal reservoir engineering is mainly carried out by Kyushu University and AIST.

Geothermal exploration techniques are mainly studied by Tohoku University, Kyushu University, Akita University and AIST. Nationwide geothermal resource assessments and databases are mainly conducted by AIST. AIST has done the first GIS (Geographic Information System) base geothermal resource assessments in Japan during 2008 (Figure 12.9; Muraoka et al., 2008). Shallow-depth hydrothermal resources above 150 °C were estimated to be 23,470 MW_e in Japan.

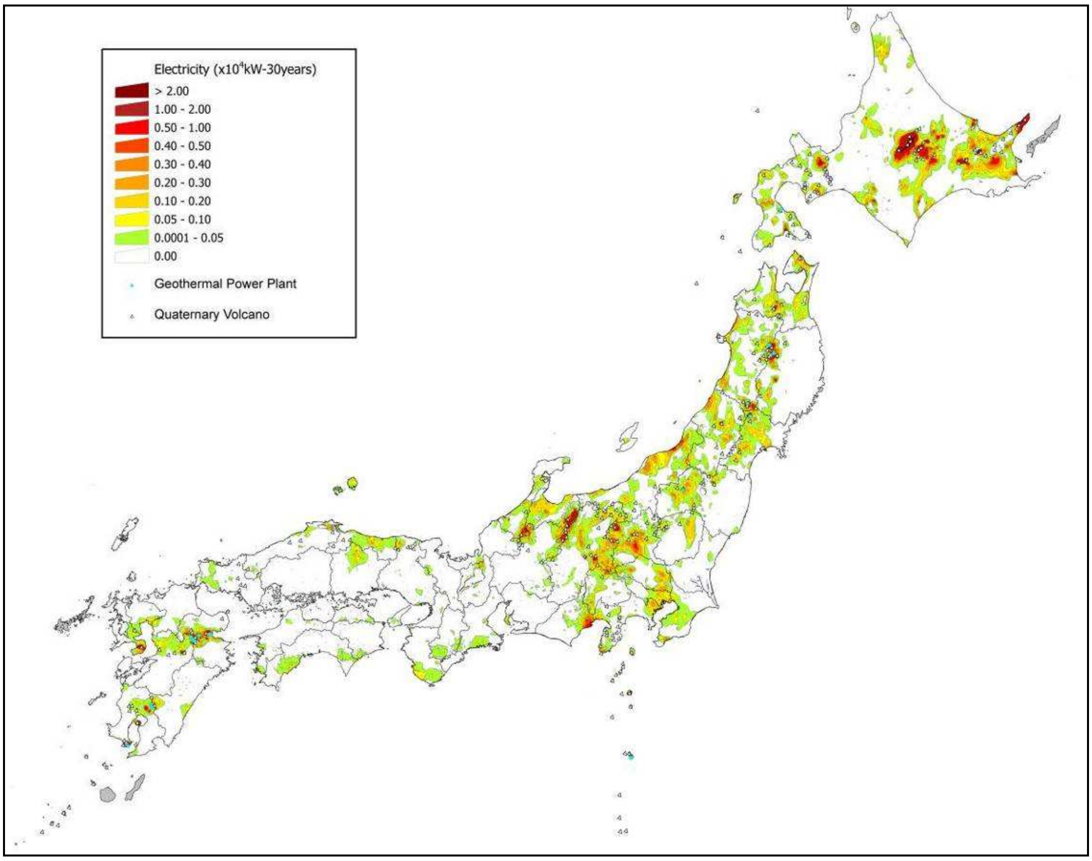

Figure 12.9 *Distribution of the shallow-depth hydrothermal resources above 53 °C (Muraoka et al., 2008).*

Numerous hot springs used to be one of the main obstacles for geothermal power development in Japan. However, the Kalina-cycle, a current low-temperature power generation technique, enables us to generate electricity from waste thermal energy of high-temperature hot springs above the bath use temperature. The hot spring power generation also enables cooling of the high-temperature hot springs down to an adequate bath use temperature without dilution of balneological constituents. To open the new market for the hot spring power generation, the Geothermal Energy Research & Development Co., Ltd. (GERD) and GREEN, AIST, proposed the "Development of the Hot Spring Ecogene (ecology + co-generation) System" project to the competitive grant "Project to Support Innovative New Energy Technology Ventures" in NEDO. This proposal was adopted as the phase I (feasibility stage) in August 2007 and adopted as phase II in March 2008. A prototype of the 50 kW class Kalina-cycle power generation system adequate for the hot spring power generation market was completed in March 2010.

The Ministry of the Environment (MOE) adopted two geothermal R&D projects for three years starting from 2010 in the competitive research grant application round on March 2010. One project is conducted by AIST and will aim at the geothermal reservoir management technology for the coexistence with hot springs. Another project is conducted by GERD and will aim at the demonstration of the hot spring power generation system that will follow the 50 kW class Kalina-cycle project.

12.8.2 Government Funded

Geothermal research at national universities and AIST is supported by grants from the government. The amounts used in geothermal research in Kyushu University and Tohoku University are approximately 60 million Yen and 30 million Yen in FY2009, respectively. The amount used for geothermal research at AIST is dispersed among several research groups and is approximately 20 million Yen in FY2009.

12.8.3 Industry Funded

Information about funding for geothermal R&D in the private sector is not necessarily open to the public and is difficult to estimate. Japan's turbines and generators still have 50% share in the world geothermal power plants and these makers may be investing in these R&D fields. For example, the new 220 kW_e binary plant at Kirishima Kokusai Hotel, installed in August 2006, is a R&D demonstration facility owned by the Fuji Electric Systems Co., Ltd. The electric companies and their institute, CERL in CRIEPI, are funding geothermal R&D, but the amounts are unknown.

12.9 Geothermal Education

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

A new geothermal course was initiated at Kyushu University in October 2002 following the end of the JICA international geothermal course. It is a doctoral program in the Graduate School of Engineering entitled: "International Special Course on Environmental Systems Engineering". Twenty students are admitted per year into the Graduate School of Engineering, ten of which are awarded with MEXT (Ministry of Education, Culture, Sports, Science and Technology) Scholarships. Participants in this course study under five advanced departments of the Graduate School of Engineering: Earth Resources Engineering, Civil and Structural Engineering, Urban and Environmental Engineering, Applied Quantum Physics and Nuclear Engineering and Maritime Engineering. Due to the international nature of this course, all the education is conducted in the English language.

Hirosaki University founded "the North Japan New Energy Research Center" in Aomori City in March 2009 for the energy paradigm shift in cold districts, and it was renamed "the North Japan Research Institute for Sustainable Energy" when expanded to a department on October 2010 (Figure 12.10).

12.10 International Cooperative Activities

Japan International Cooperation Agency (JICA) dispatched a preparatory survey mission to Indonesia in April 2009 to launch "the Project for Capacity Building for Enhancement of the Geothermal Exploration Technologies in Indonesia" (Figure 12.11).

This project will aim at the capacity building of numbers of geothermal exploration engineers due to increasing demand for the rapid geothermal developments in Indonesia. The mission also visited the Kamojang geothermal field, the oldest geothermal power plant in Indonesia (Figure 12.12).

Figure 12.10 *Renaming celebration of the North Japan Research Institute for Sustainable Energy (NJRISE) for the expansion to be a department of Hirosaki University on 1 October 2010. (Photo courtesy of H. Muraoka)*

Figure 12.11 *Indonesia-Japan preparatory meeting for the JICA capacity building project at Garut near the Kamojang geothermal field, Indonesia, on 16 April 2009. (Photo courtesy of the Center for Geological Resources, the Geological Agency)*

Figure 12.12 *In front of the Kamojang Pertamina Office, Indonesia on 16 April 2009. (Photo courtesy of H. Muraoka)*

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National Activities

Chapter 13

Republic of Korea

Figure 13.2 An example of geothermal heat pump system for greenhouse. (a) Installtion of slinky-type horizontal heat exchanger. (Photos courtesy Turbo Energy Co., Ltd.)

13.0 Introduction

13.0.1 Background

Direct use geothermal utilization in Korea has been quite active for the last six years, especially geothermal heat pump installation. The rapid increase in geothermal heat pump uptake is mainly due to active government subsidizing programs for renewable energy deployment, but recently private investments in geothermal heat pump installations without subsidies are also increasing. Geothermal heat pump installations and operation for greenhouses, covering additional 70 MW_t, were made in 2009 according to a special government subsidy program which came into effect at the end of 2008.

There is growing interest in low-temperature power generation using geothermal water from deeply-extended fracture and/or enhanced geothermal system (EGS). In addition to continuing exploration efforts of geothermal water resources in a potential area, a preliminary feasibility study on EGS in Korea was conducted by Korea Institute of Geoscience and Mineral Resources (KIGAM) with the financial support from Korea National Oil Corporation (KNOC) in 2009. The results showed that a pilot plant of 3.5 MW_e might be possible with a triplet system down to 5 km depth.

13.0.2 Major Highlights and Achievements for 2009

- Geothermal heat pump installations for greenhouse heating and cooling of some 70 MW_t were actively made and put into operation in rural villages in 2009.
- A preliminary feasibility study of EGS in Korea was made to propose a pilot plant project for the next seven years.

13.1 National Policy

13.1.1 Strategy

In 2008, the Korean government proclaimed *The First National Energy Master Plan (2008-2030)* according to *The Energy Law* passed in 2006 and amended in 2008 under the slogan of "*low-carbon, green-growth*". There are four basic strategies: a low-carbon and energy-conscious society, increased clean energy supply, green-driven growth, and affordable energy for all. This plan also emphasizes balancing of the 3-E's; energy security, energy efficiency, and environmental protection.

According to the master plan, *The Third Basic Plan on New & Renewable Energy Technology Development, Utilization and Diffusion (2009-2030)* has been set up aiming to have new and renewable energy's share of 11% of total primary energy supply and of 7.7% of electricity generation by 2030. Among the new and renewable energy, photovoltaic (PV), wind and hydrogen/fuel cell are of primary concern. An ambitious deployment project named *One Million Green Homse by 2020* has also been launched. This is to be fulfilled by developing the *Smart Energy System* that combines various renewable sources such as PV, solar, geothermal, wind and fuel cells. This project will help geothermal heat pump installations continue to increase in the future.

13.1.2 Legislation and Regulation

From 2004, the *Mandatory Public Renewable Energy Use Act* has come into effect and states that "in construction of all public buildings bigger than 3,000 m^2 in area, more than 5% of the total budget must be used to install renewable energy equipments." Geothermal heat pump installations are active in public sector with this act.

13.1.3 Progress Towards National Targets

The total use of new and renewable energy at the end of 2008 reached 5.858 million ton of oil equivalent (toe) accounting for only 2.43% of the total primary energy consumption (240.75 million toe). Renewables' share in 2009 was estimated to be 2.6%.

The status and prospects of geothermal energy in the national target still does not seem significant because the government program focuses on the three major items for electricity generation: photo voltaics, wind power and fuel cells. Fortunately, however, the importance of geothermal utilization is being acknowledged by the government and the public sector and the geothermal's share of the market stimulating incentive has become significant. Therefore, we could see some remarkable progress of geothermal heat pump installation in the coming years.

Increases of geothermal heat pump installations and energy uses are presented in Figure 13.1. The values are based on the officially reported installations and we expect the actual number of installations is bigger than reported.

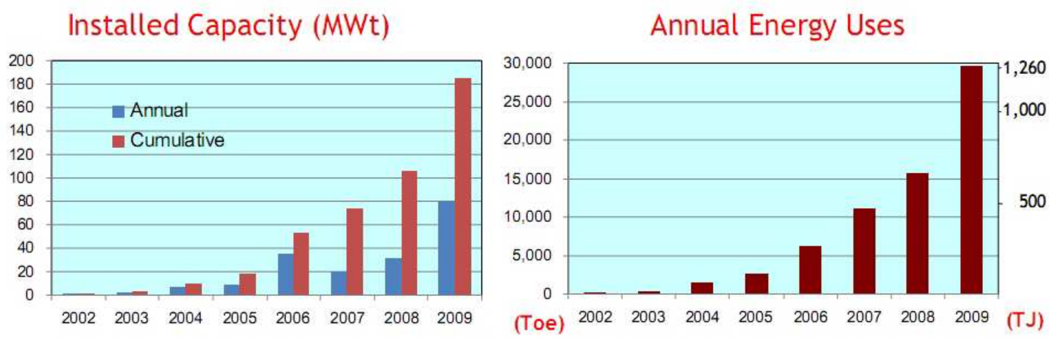

Figure 13.1 Increasing trend of geothermal heat pump installations (left) and annual energy uses (right). (Data from Korea Energy Management Corporation; estimates for 2009 based on the subsidy)

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

In 2009, total investments by government amounted some US$ 7.8 million (assuming a currency exchange rate of US$ 1 ~ 1,000 KRW) including:

- Development of geothermal resources for combined heat and power generation: US$ 2.5 million
- Construction of geothermal information database based on Web GIS: US$ 0.5 million
- Various geothermal heat pump utilization and demonstration programs: US$ 4.8 million

Government R&D expenditure has remained at almost the same level as in former years, reflecting that government investment is more focused on the subsidizing deployment program for geothermal heat pumps than R&D. Table 13.1 shows the statistics of the last six years.

Table 13.1 Geothermal R&D expenditure for the period 2004-2009.

In Thousand US$ (US$ 1 = 1,000 Won)

	2004	2005	2006	2007	2008	2009
Government	5,505	5,979	6,943	7,792	6,914	7,760
Industry	758	881	1,148	1,800	1,383	1,800
Total	6,263	6,860	8,091	9,592	8,297	9,560

13.1.5 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 15-50 % of total budget depending on the size of the participating industry's business. In 2009, the total amount is estimated to be some US$ 1.8 million.

13.2 Current Status of Geothermal Energy Use in 2009

13.2.1 Electricity Generation

There is no geothermal power generation in Korea.

13.2.2 Direct Use

13.2.2.1 Installed Thermal Power

By the end of 2009, the installed thermal power is 228.7 MW_t, mainly for geothermal heat pump and hot spa usage (see Table 13.2).

Table 13.2 *Geothermal direct heat uses, fossil fuel saving and avoided CO_2 emission in Korea as of December 2009.*

Use	Installed Capacity (MWt)	Annual Energy Use ($TJ/yr=10^{12}J/yr$)	Capacity Factor	Fossil fuel saving** (toe/yr)	Avoided CO_2 emission** (ton)
Individual Space Heating	8.66	53.43	0.20	1,881	6,070
District Heating	2.21	31.28	0.45	1,101	3,554
Greenhouse Heating	0.17	1.33	0.25	47	151
Bathing and Swimming	32.56	507.61*	0.49	17,868	57,670
Geothermal Heat Pumps	185.1	1,260.0	0.23	44,352	143,150
Total	228.7	1,853.65		65,248	210,595

* $\sum$ [(supplying water temp.: 42 – leaving water temp.: 27)×flow rate×operating time]
** uses 35.2 toe/TJ and 113,611 CO_2 kg/TJ assuming 70% of boiler (following IEA-GIA conversion rate)

13.2.2.2 Thermal Energy Used

Thermal energy used in 2009 is estimated to be 1,854 TJ (see Table 13.2).

13.3.2.3 Category Used

Direct use in Korea includes individual space heating with hot spring water, a small scale district heating (21 house holds), one greenhouse, bathing (hot spa) and geothermal heat pumps (see Table 13.2).

13.2.2.4 New Developments During 2009

Geothermal heat pump installations in 2009 were mainly focused on greenhouse applications. The Korean government carried out a special rural subsidy program in late 2008 for the purpose of strengthening economic competitiveness of farmers with small agriculture. The total subsidy from the central government reached more than US$ 70 million, offering half of installation costs. Another 30% of the costs were subsidized by local governments, which means that the farmers needed to pay 20% of the installation cost.

Actual installations began in 2009 and about 60% (about 70 MW_t installations) of the budget was spent by the end of the year. Borehole heat exchangers (BHE) are the major heat exchanger type. However, horizontal heat exchangers are also popular in places having enough area, because the installation cost is much cheaper than for BHE. In addition, for greenhouses in alluvial areas close to rivers or streams, groundwater-source heat pumps are attractive options for reducing cost.

Figure 13.2 shows an example with a large scale slinky-type horizontal heat exchanger. A glass-covered, 4,950 m^2 area greenhouse was equipped with 33,300 m long horizontal heat exchanger pipes. Heating and cooling capacity are 399 kW_t and 420 kW_t, respectively. The trench area was 30 m by 111 m and 2.5 m deep.

Figure 13.2b

Figure 13.2c

Figure 13.2d

Figure 13.2 *An example of geothermal heat pump system for greenhouse.*
(a) (see Chapter heading photograph), (b) heat pump units and pipe lines,
(c) greenhouse, and (d) seeding of paprika in greenhouse.
(Photos courtesy of Turbo Energy Co., Ltd.)

The special subsidy program will resume and be extended from 2010 and last for another 5 years. The planned budget amounts to some US$ 100 million/yr to enable an additional 140 MW_t/yr, if the program works as planned. Therefore, greenhouses are going to be a major geothermal heat pump application field in Korea for the time being.

13.2.2.5 Rates and Trends in Development

No data available

13.2.2.6 Number of Wells Drilled

No wells have been drilled in 2009 except for hot spring developments for which detailed information is not available.

13.2.3 Energy Savings

Fossil fuel savings and CO_2 emission reductions are also included in Table 13.2 following IEA GIA conversion rates.

13.3 Market Development and Stimulation

13.3.1 Support Initiatives and Market Stimulation Incentives

The Korean Government offers long-term, low-interest loans, tax benefits and government/public funds for those using renewable energy. The subsidy for geothermal installations through various renewable energy speading programs amounted to US$ 17.2 million in 2009 (see Table 133).

Table 13.3 Subsidies for geothermal heat pump installations for the period 2006-2009.*

In Thousand US$ (US$ 1 = 1,000 Won)

	2006		2007		2008		2009	
	Capacity (MW)	Subsidy (1,000 USD)	Capacity (MW)	Subsidy (1,000 USD)	Capacity (MW)	Subsidy (1,000 USD)	Capacity (MW)	Subsidy (1,000 USD)
Deployment Subsidy Program	16.69	9,541	15.37	8,351	14,11	7,689	6.83	4,150
Rural Deployment Program	3.74	4,239	2.63	1,998	89.55	73,728	11.4**	9,093
1 Million Green home program	-	-	-	-	-	-	5.18 (301 houses)	3,988
Total	20.42	13,780	18.01	10,349	103.66	81,417	23.41	17,231

* Note: Data correspond to year of subsidy support, so actual operations are to be one or two years later.
** estimated value

13.3.2 Development Cost Trends

No data available

13.4 Development Constraints

13.4.1 Technical and Social barriers

A barrier to the progress of geothermal heat pumps from technical and scientific points of view may be explained by the relative disregard for the importance of accurate information on the thermal properties of subsurface materials and the lack of scientific knowledge on hydrogeological conditions influencing heat extraction/injection rates. Such technological drawbacks often lead to over-design of systems and thus reduce economical competitiveness. Although there are huge amounts of alluvial groundwater resources in agricultural areas and towns, utilization of groundwater thermal energy is still quite limited because of unnecessary concern about running out of the resources without understanding the natural water cycle.

Also there is a general perception that geothermal heat pump systems have high initial costs while there are not sufficient guaranteed examples of performance yet. Therefore, people tend to consider that a natural gas or an oil boiler is cheaper in the initial stage and durable. The most serious problem is still lower public awareness level than wind or photovoltaic; even some government officers and energy authorities think that geothermal is nothing but heat pumps.

There is increasing interest for geothermal power generation with low-temperature geothermal water through deeply-extended fractures and/or enhanced geothermal systems. But, insufficient understanding of low-temperature power generation technology available with temperatures even lower than 100 °C and lack of deep drilling experience are technical barriers. Lack of a legal framework supporting deep geothermal development is also major barrier: deep geothermal water in Korea is dealt with only in the *Hot Spring Law*, which states that warm water must be firstly used for hot springs. For that reason, there is no risk guarantee or insurance framework for deep drilling.

13.4.2 Environmental Issues

The 'Groundwater Law' states that all boreholes must be reported on depth and purpose prior to drilling. Also if somebody is to use groundwater, he or she must undergo environmental impact assessment and submit its result. It is also effective for groundwater thermal utilization even though subject to re-injection. Heat pump business society claims that heat extraction from groundwater will not affect the quality of the water and thus thermal utilization should be free from such regulation.

13.5 Economics

13.5.1 Trends in Geothermal Investment

Governmental investment in geothermal has steadily increased since 2003. Investment from industry has also increased as a matching fund to the government R&D budget, but mostly for geothermal heat pumps. Government investment is being made though R&D expenditure and various subsidizing programs; statistics are available in Table 13.1 and Table 13.3, respectively.

13.5.2 Trends in the Cost of Energy

Because 97% of energy resources are imported, energy cost in Korea reflects recent high oil prices. The price of electricity, however, does not change much, partly due to the high portion of nuclear power generation (~40% of total generation) and partly due to government policy. The average electricity price is about US 7.8 cents/kWh.

15.5.3 Number of People in the Geothermal Sector

The number of people employed in geothermal sector is continuously increasing thanks to the active geothermal heat pump business. There are some 60 people in universities and research institutes, including graduate students. In the industry sector, around 60 people are working on geothermal heat pump system design and installation of the borehole heat exchangers.

13.6 Research Activities

13.6.1 Focus Areas

R&D activities in Korea have been focused on 1) exploration and exploitation of low-temperature geothermal water for district heating, 2) characterization of geothermal resources, 3) sampling and measurement of subsurface thermal properties for borehole heat exchangers resulting in big databases, 4) simulation of T-H-C coupled behavior for borehole heat exchangers under groundwater flow, and 5) utilizing groundwater thermal energy along with aquifer thermal energy storage (ATES). Almost all of the research activities are initiated by government fund.

Reflecting growing concern for geothermal power generation, a preliminary feasibility study on enhanced geothermal system (EGS) in Korea was conducted by the Korea Institute of Geoscience and Mineral Resources (KIGAM) with financial support from the Korea National Oil Corporation (KNOC). The work was based on existing well data from KIGAM's Pohang low-temperature development project (see 2006 GIA Annual Report). The results show that a pilot plant of 3.5 MW_e may be possible with a triplet system down to 5 km depth. But due to lack of detailed information on deep structure and stress fields, considerable research efforts should be taken from the initial stage of site selection. The period for the pilot project would then be 7 years and the required budget about US$ 100 million, half of which would better to be invested by government. KIGAM also performed exploration of geothermal water resources for binary power generation in a potential area, Seokmo-Do Island.

13.6.2 Government Funded R&D

R&D in geothermal investigation, exploration and exploitation has been led by KIGAM, the only government funded research institute in the geoscience field in Korea. The Geothermal Resources Department of KIGAM is leading the two major government funded R&D programs: *Development of geothermal resources for combined heat and power generation* and *Construction of a geothermal information database based on Web GIS*, whose grants amounted 38% (about US$ 3 million) of total government R&D or RD&D funding in 2009. These research subjects also include collaboration with some universities through subcontracts.

RD&D programs on various geothermal heat pump applications are funded by the Korea Institute of Energy Technology Evaluation and Planning (KETEP), a government R&D funding agency. In 2009, no new R&D projects were granted for geothermal developments. Instead, two policy topics were granted on the possibility of geothermal power generation and on small-scale geothermal heat pump systems for individual houses.

In 2009, KIGAM focused its activity on exploration of deeply extended fractures which may serve as conduits of geothermal water with temperatures higher than 90 °C, on a small island Seokmo-Do in West Sea or Yellow Sea close to Incheon (the 3rd largest city in Korea), near Seoul, capital city of Korea. There are several artesian wells with discharge temperatures of some 70 °C. Some drilled wells of several hundred meters deep struck deeply-connected fractures in Jurassic granite and a large amount of brine water overflowed the wells. One of the wells was drilled down to a depth of 1,280 m according to the interpretation result of the magnetotelluric data acquired by KIGAM in 2005.

Artesian geothermal water has been used for a small-scale district heating system (21 households) since 2008, and greenhouse heating since 2009. The greenhouse is 1,155 m^2 in area, and the inlet temperature of geothermal water is 68 °C, which is cooled down to 56 °C through a plate heat exchanger, and the average flow rate is designed to be 6 m^3/hr. After heating the greenhouse, cooled geothermal water is supplied to a public bath (see 2008 GIA Annual Report).

Various surveys and investigations, including lineament mapping (Figure 13.3), magnetotelluric (MT) (Figure 13.4) and seismic surveys, well logging and hydrogeologic tests using existing wells, were carried out. Since the hydrologic system on the island is governed by a fracture network and thus by stress distribution, stress measurement with a hydro-fracturing test was also performed (Figure 13.5) to figure out the current stress regime. The resultant stress fields are likely to be in the super-critical thrust regime. Integrated interpretation of all survey results will be done in 2010 and subsequent exploration drilling will be planned.

13.7 Geothermal Education

In 2009, the first regular geothermal course was opened in Seoul National University for the undergraduate level. Public recognition of geothermal is increasing and there are special training courses for HVAC and architectural engineers to introduce general geothermal topics and state-of-the-art heat pump technologies, and to train how to design and install geothermal heat pumps in a proper way. Also, there are many small seminars about general geothermal topics reflecting increasing public recognition.

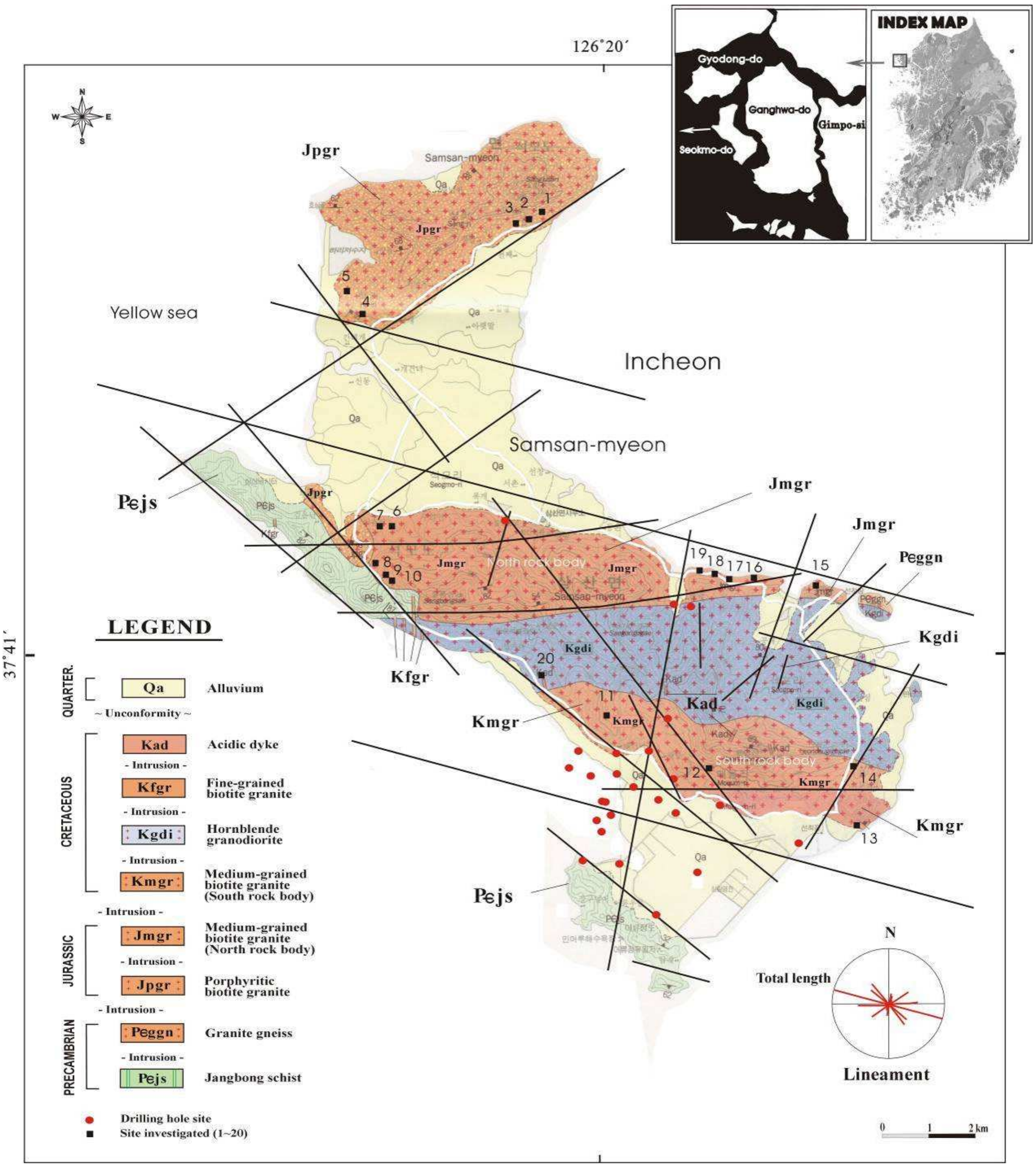

Figure 13.3 *Lineament distribution in Seokmo-Do Island superimposed on geology and location map. Red dots denote location of existing hot spring wells some of which are artesian.*

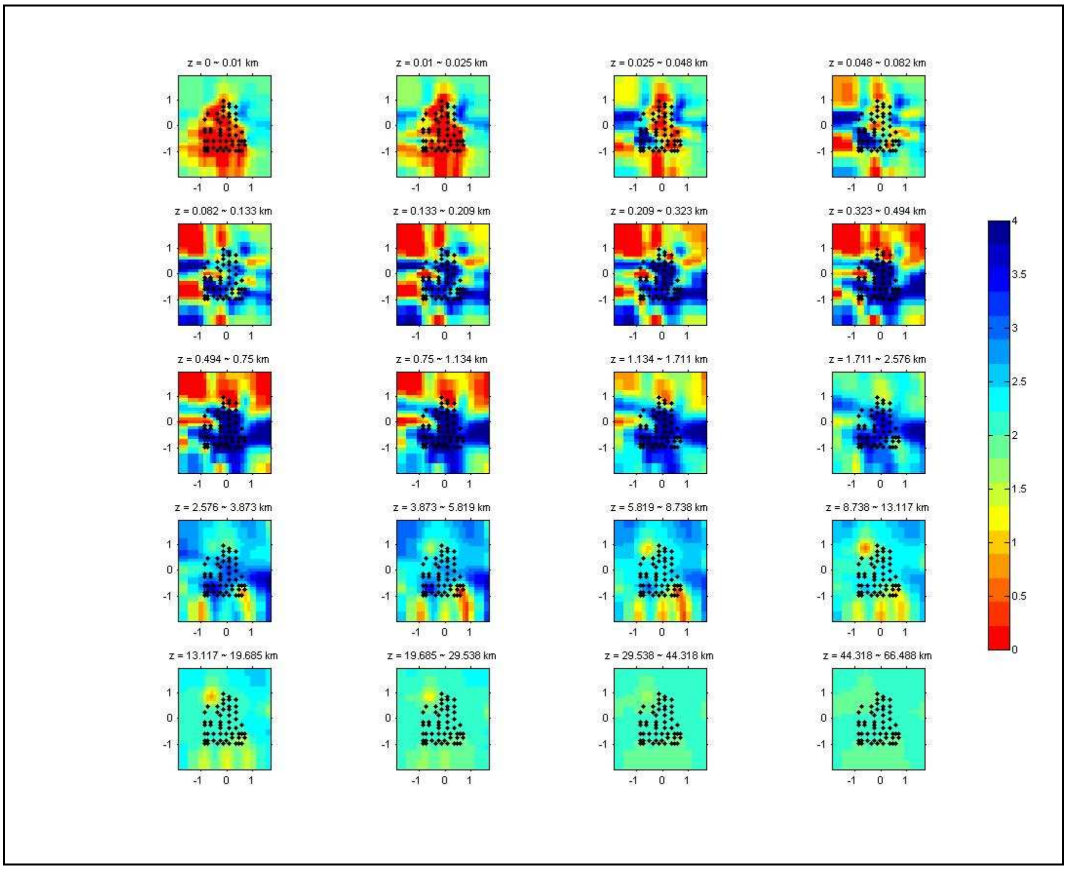

Figure 13.4 *Depth slices of resistivity distribution resulted from a three-dimensional inversion of MT data in Seokmo-Do Island. The black dots denote measuring stations and color scales are in* log_{10} *(ohm-m).*

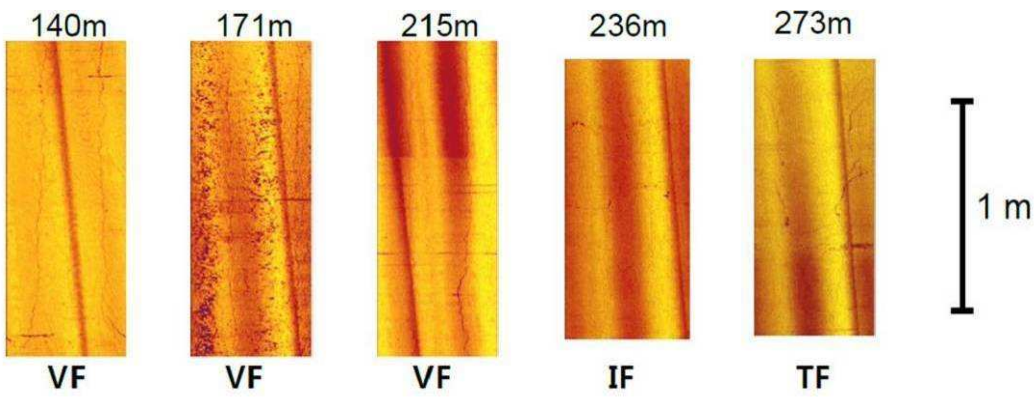

Figure 13.5 *Some sections of borehole acoustic televiewer images acquired after the hydro-fracturing test at a 400 m deep borehole in Seokmo-Do Island. Vertical (VF), tilted (TF) and interacted with pre-existing fractures (IF) resulted from hydro-fracturing can be seen.*

13.8 International Cooperative Activities

The major international cooperative activity of KIGAM is participating on the IEA GIA ExCo and in Annex Ⅷ. KIGAM also maintains research collaboration with Institute for Geo-Resources and

Environment (GREEN) of AIST, Japan, in geophysical exploration of geothermal resources and other geothermal related topics.

The Korean Technology Center for Geothermal Energy (KORGE) was established in 2006, aiming to foster geothermal utilization. KORGE opens the Accredited Installer Workshop in conjunction with International Ground Source Heat Pump Association (IGSHPA).

13.9 Websites

- **http://geothermal.kigam.re.kr**: Geothermal Resources Division, KIGAM
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National Activities

Chapter 14

Mexico

Los Azufres geothermal power station.

14.0 Introduction

Geothermal energy is the most important non-conventional renewable energy source utilized in Mexico, followed by wind energy. 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 2008, the geothermal-based installed capacity for electricity generation was 958 MW_e, placing Mexico in fourth place worldwide.

14.1 National Policy

About 78% of the installed capacity for public-service electricity generation belongs to the two government-owned utilities, namely the Comisión Federal de Electricidad (CFE) and Luz y Fuerza del Centro (LFC). The rest 22% belongs to private-owned companies. CFE is responsible for all electricity generated with geothermal steam. This primary energy source has been utilized for decades for power generation; the technology is considered mature, and it is set to compete under the same bases as fossil-fuel, conventional hydro and nuclear technologies.

14.2 Current Status of Geothermal Energy Use

14.2.1 Electricity Generation

The installed capacity in 2009 was 958 MW_e, distributed among the geothermal fields as follows: Cerro Prieto (720 MW_e), Los Azufres (188 MW_e), Los Humeros (40 MW_e) and Las Tres Vírgenes (10 MW_e).

The total electricity generation with geothermal steam in 2009 was 6740 GWh. The contribution to national demand in 2009 represented around 2.9% of total electric generation for public service in Mexico. The geothermal contribution to electricity generation was 1.5 times higher than its contribution to the installed capacity (1.9%), reflecting a high capacity factor of geothermal electric plants.

14.2.2 Direct Use

The installed thermal power in Mexico in 2009 was estimated to be155.8 MW_t.

Balneology, the main use, was about 155.3 MW_t; at around 160 sites distributed in 19 states.

14.3 Market Development and Stimulation

At present there are no economic incentives for geothermal development in Mexico.

14.4 Development Constraints

As mentioned above, power generation with geothermal energy is considered conventional in Mexico, and thus it is set to compete under the same bases as fossil-fuel, conventional hydro and nuclear technologies. Therefore, it is fair to say that the main constraint for further geothermal development in this country is its economic disadvantage compared to modern fossil-fuel generation technologies. It is expected that the mentioned new renewable-energy act could support the geothermal development.

14.5 Economics

14.5.1 Trends in Geothermal Investment Foreseen

Construction of the first of two 25 MW_e plants in Los Humeros is to start soon. Additionally, 100 MW_e of new plants in Cerro Prieto will replace two of the older units (2 X 37.5 MW_e = 75 MW_e). CFE is working also on the development of 25 MW_e in Cerritos Colorados, and on plans for replacing seven old 5- MW_e units in Los Azufres field with two units, one of 50 MW_e and one of 25 MW_e. CFE is also exploring new fields in Acoculco, Pue., and Tulecheck, BC, and has plans to conduct more exploratory studies in San Pedro, La Soledad and the Chichonal Volcano among other zones with geothermal potential.

14.5.2 Trends in the Cost of Energy

The price of electricity in Mexico has been subject to gradual upward adjustments to cover for the corresponding increases in the cost of operation of the public power system. This trend is expected to continue.

14.6 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.

14.7 Geothermal Education

In the past CFE trained some of their engineers through the geothermal programs offered by Iceland (the United Nations University), New Zealand (the Geothermal Institute of the University of Auckland) and the Baja California University (UABC).

During the last years, CFE has sent young engineers for training to Japan, under an agreement between JICA and the Mexican Government, and CFE is planning to do the same in the coming years. For the most part, mechanical, electrical, chemical and geological engineers are trained on the job, as part of their professional development in CFE and the Instituto de Investigaciones Eléctricas (IIE). Periodic professional meetings (congresses, seminars, etc.) provide a basis for continued education of geothermal personnel.

14.8 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 and Logging Technologies) of the Geothermal Implementing Agreement.

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National Activities

Chapter 15

New Zealand

Photo 15.1 *New Nga Awa Purua (Rotokawa) 140 MW$_e$ power plant, (under construction during 2009, commissioned early 2010)*

15.0 Introduction

Despite a stalling of growth in electricity demand in New Zealand during the 2009 year (resulting from the global financial crisis), there has been continued interest in geothermal development, with construction of new generation, exploration and production drilling, and resource consent application or planning for new geothermal power plants. More than 470 MW$_e$ of additional geothermal generation, on top of the existing 765 MW$_e$, (inclusive of the 140 MWe Nga-Awa-Purua and 23 MWe Te Huka power plants) is identified as development potential awaiting project financial closure. Such a rapid growth is likely to place New Zealand in the top four countries internationally for geothermal generation per annum, and in one of the top two nations for percentage of total electricity generated by geothermal.

Geothermal heat pumps are gradually becoming established, especially in colder regions of New Zealand (e.g., the South Island). This is an area for considerable future growth, along with more industrial-scale direct use applications. The New Zealand Government is committed to accelerating the use of renewable low carbon-emission energy (including geothermal energy) and reducing fossil fuel consumption. Mighty River Power and Contact Energy, the two largest geothermal power plant operators in New Zealand, are choosing geothermal as the best renewable, low-carbon-emitting option for new generation because of significant cost advantages (without subsidies and feed-in tariffs, but including a carbon charge of about NZ$25/tonne of CO_2 equivalent). Current long-run marginal costs for the next 500 MW$_e$ of new geothermal projects are in the range of NZ$ 62-72/MWh (US$ 46-54).

15.1 Major Highlights for 2009

All but one of the existing power plants have been operating normally at full load. Installed capacity by end of 2009 was: Mokai (114 MW_e), Rotokawa (35 MW_e), Wairakei (175 MW_e + 55 MW_e), Ngawha (25 MW_e), Kawerau (122 MW_e), and Ohaaki (104 MW). Ohaaki has been operating at outputs of about 60 MW_e (compared to a low of about 30 MW_e several years ago) due to successful makeup drilling. For field locations see Figure 15.1.

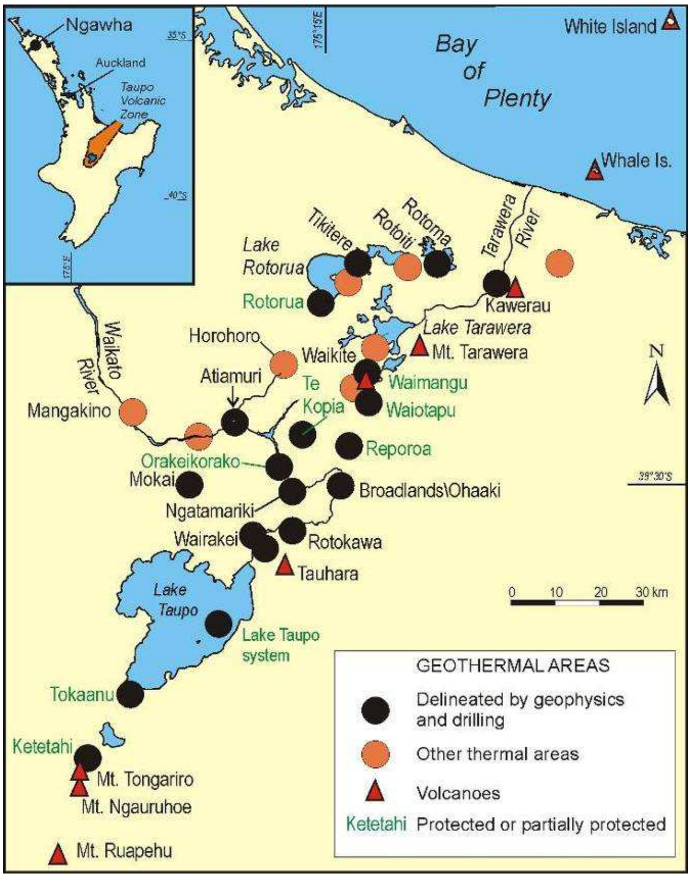

Figure 15.1 Map of New Zealand geothermal systems. (from Hochstein and Bromley, 2009)

Another major highlight for 2009 is the successful construction and testing (ahead of schedule) of 140 MW_e generation capacity at Nga-Awa-Purua (Rotokawa). This utilizes the world's largest geothermal turbine (140 MW_e triple-flash net generation).

Also, a new 23 MW_e binary plant (Te Huka) was constructed at Tauhara, and successfully tested in preparation for commissioning in early 2010. At Tauhara Geothermal Field (linked to Wairakei), a resource consent application for 250 MW_e expansion was prepared, with supporting information from a comprehensive drilling, testing and subsidence investigation. The exploration drilling revealed proven steam reserves sufficient for 100 MW_e and an adequate inferred resource for the proposed 250 MW_e of new capacity.

Drilling at Ngatamariki (north of Rotokawa) delineated a resource area sufficient for up to about 130 MW_e, and an application for resource consent to support a nominal 110 MW_e development was filed, heard and granted.

This acceleration in development activity has been supported by drilling activity in most of the high enthalpy resource prospects of the Taupo Volcanic Zone that are potential sites for power development (about 30 new wells/yr).

15.2 National Policy

15.2.1 Strategy

The New Zealand Government energy strategy (see: www.med.govt.nz) favours renewable energy sources. This strategy is benefiting from the economic reality that geothermal investment is currently competitive with a wide range of alternative generation sources and so presents an investment opportunity (even without renewable energy subsidies or carbon credits). A factor is that wholesale gas prices for thermal generation have more than doubled because of dwindling reserves. Furthermore, it is widely known that the equivalent of an additional 1000-1,200 MW_e of geothermal resources is probably available, at competitive long-run marginal costs, even after disregarding environmentally protected geothermal fields from consideration. Therefore, geothermal projects alone could meet more than a decade of anticipated electricity demand growth (about 700 GWh/yr). Existing projects are costing about NZ$ 3-4 million/MW_e. Near-term future projects will probably have a total capital cost of around NZ$ 4 million/MW_e. The anticipated expansion in geothermal generation equates to an expected NZ$ 4 billion development programme over the next 10 years.

15.2.2 Legislation and Regulation

Geothermal was recognised as a resource vital to New Zealand's future energy mix and is economically competitive at the current average wholesale electricity cost of about NZ$ 80/MWh (about US$ 60/MWh). Spot market prices vary with demand and hydro-lake capacity fluctuations. Long-run marginal costs for new geothermal developments are in the range of NZ$ 60-80/MWh (at NZ$ 1.00 ~ US$ 0.75) (www.med.govt.nz), currently amongst the cheapest of all new generation options.

The New Zealand Government has legislated a carbon emissions trading scheme that is expected to be implemented in 2010. This will provide an additional financial incentive to help boost economically-marginal renewable energy projects (for both electricity generation and direct use), and reduce the use of fossil fuels. The long term strategy is to encourage the transport industry and the public to use more electric vehicles, and to provide the additional energy needed in the form of new, economically-viable, base-load renewable (including geothermal) electricity generation for off-peak recharging of vehicle batteries.

15.2.3 Progress Towards National Targets

Several recent measures have been introduced to stream-line consenting procedures for large renewable energy projects, including a "calling-in" of resource consent applications, to be held before a Board of Enquiry under the Ministry of Environment, with tight timelines for submissions and decisions. This has already achieved some shortening of the normal consenting process for new geothermal projects (e.g., Te Mihi).

In October 2007, the Government set targets for 2025 of 9.5 PJ/yr of additional direct use renewable energy (mostly geothermal or wood biomass), 90% of all electricity from renewables, and fast uptake of electric vehicles. Progress towards the target in geothermal direct use is slow, but for electricity, the renewable percentage of total generation has increased from about 60% to 75%, and is on target for 90% in less than 10 years. Geothermal is expected to contribute about

23%, wind about 8% and hydropower about 58% (Figure 15.2). Variability in seasonal hydro and wind generation means that some standby capacity and peak load capacity will need to be maintained, and it is envisaged that fast-start gas-fired turbines will probably continue to play this role.

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

Government R&D expenditure is presently about NZ$ 3M/yr (US$ 2.3M/yr). Key topics of geoscientific research include the potential of deeper and more-marginal resources, improved simulations of long term reservoir performance, improved management of adverse environmental effects, and enhancement of knowledge regarding resources and technologies suitable for direct use.

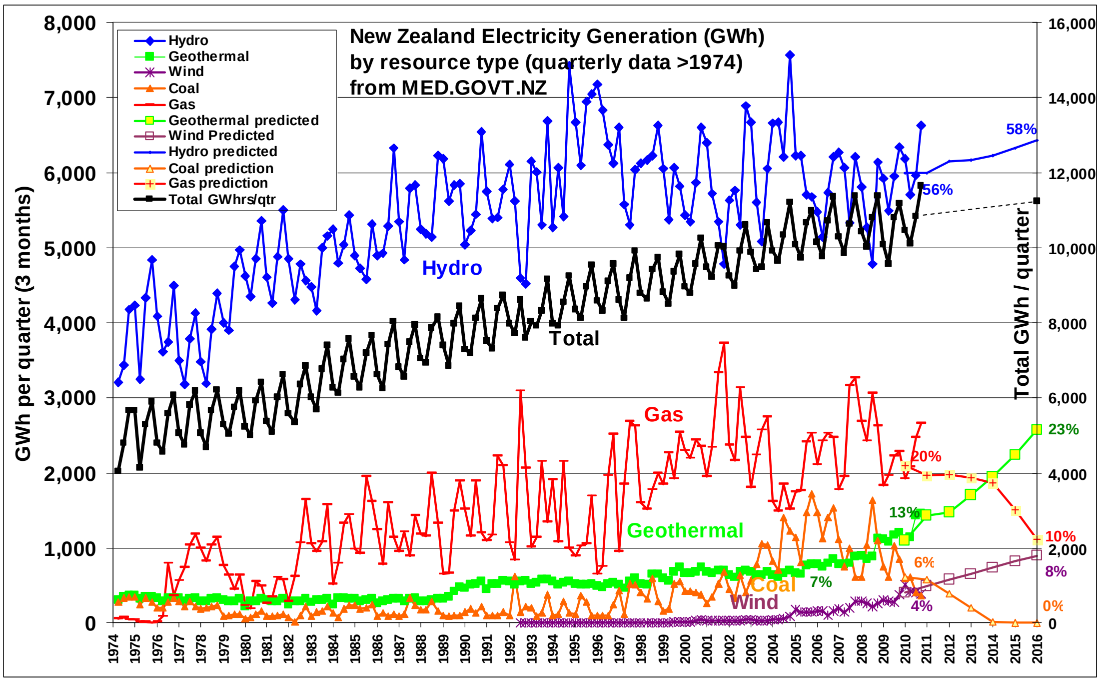

Figure 15.2 Comparison of NZ electricity generation per quarter by type: history and predictions.

15.2.5 Industry Expenditure on Geothermal R&D

The major geothermal operators, Mighty River Power and Contact Energy, between them, intend to spend more than NZ$ 2 billion in developing geothermal resources over the next 10 years. A small proportion of this is targeted at research to improve resource knowledge and reduce development costs. Specific applied research projects are linked with longer-term government-sponsored research programmes. Other significant developers of geothermal energy in New Zealand include Top Energy (Ngawha), Bay of Plenty Energy (Kawerau), and Tuaropaki Power Company (Mokai). At public forums, such as the annual New Zealand Geothermal Workshop, and consent hearings, these companies often release the results of commissioned research and exploration work undertaken on these fields in order to contribute to the wider geothermal knowledge database. It is difficult to quantify in dollar terms the value of such "in-kind" contributions to research outcomes, but it is substantial.

15.3 Current Status of Geothermal Energy Use in 2009

15.3.1 Electricity Generation

Comprehensive information about New Zealand's electricity generation may be found on the New Zealand Ministry for Economic Development website at: www.med.govt.nz. See also Figure 15.2 for a plot of trends since 1974 in quarterly electricity production.

15.3.1.1 Installed Capacity

New Zealand's geothermal installed capacity at the end of 2009 was 632 MW_e, (inclusive of 30 MW_e of surplus (de-rated) capacity at Ohaaki). This was the same as at the end of 2008, but with two construction projects (Tauhara- Te Huka 23 MW_e, and Rotokawa Nga-Awa-Purua 140 MW_e) undergoing testing for early 2010 commissioning, bringing installed capacity to 795 MW_e (765 MW_e operating) by April 2010.

15.3.1.2 Total Electricity Generated

The total electricity generated with geothermal energy in 2009 was 4542 GWh. Generation is expected to increase to about 5500 GWh in 2010, a 21% per annum growth rate.

The average generating capacity factor was ~ 85%.

15.3.1.3 New Developments During 2009

In 2008, a total of 123 MW_e of new generation had been commissioned. This led to a significant increase in baseload generation the following year. In 2009, a total of 163 MW_e (Te Huka and Nga-Awa-Purua) was under construction and readied for 2010 commissioning.

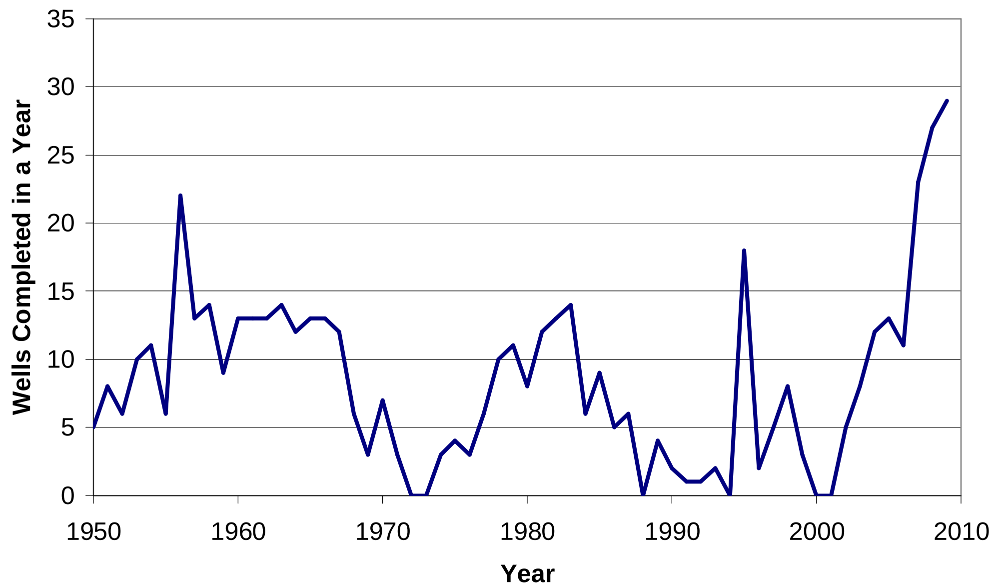

Figure 15.3 Historic trends in NZ geothermal drilling activity.

15.3.1.4 Rates and Trends in Development

Under construction in 2009- At Rotokawa geothermal field, the Nga-Awa-Purua plant incorporating a 140 MW_e triple flash turbine was successfully completed ahead of schedule in early 2010. At the Tauhara geothermal field, a 23 MW_e binary plant identified as Centennial Drive or Tauhara I, was also successfully completed early in 2010.

Projects committed, consents granted and designs/equipment contracts well advanced- The Te Mihi 234 MW_e development is planned to replace the current Wairakei 162 MW_e power station with a more efficient plant. Construction has been delayed, awaiting favourable economic conditions.

Future projects at an early stage of planning-

- Ngatamariki (nominal 110 MW_e, exploration drilling has been successful, and a consent application was lodged and granted in 2009)
- Rotoma I (35 MW_e, consent application lodged and granted in 2009)
- Tauhara II (250 MW_e, delineation drilling successful, consent application lodged and granted in 2010)

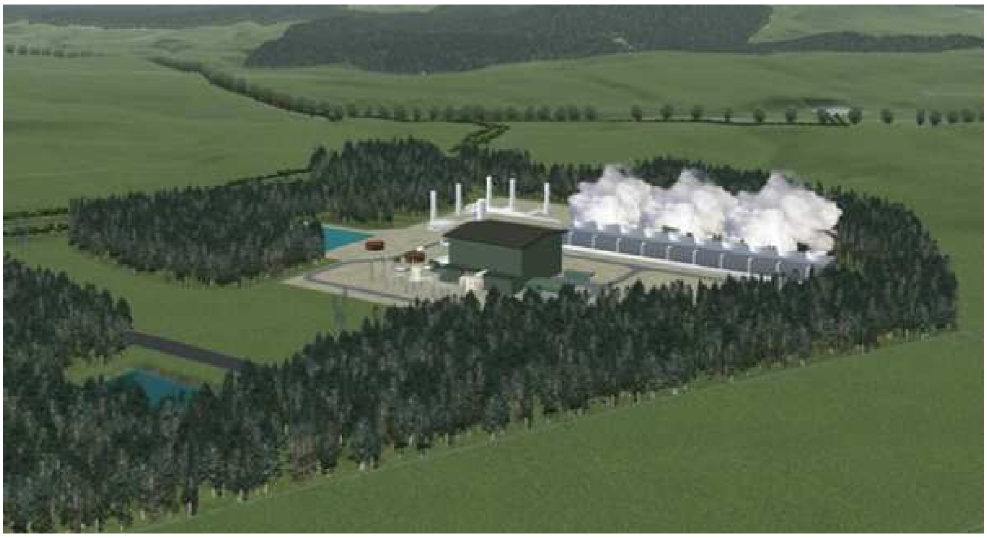

Figure 15.4 *Artists impression of proposed Ngatamariki power plant.*

Possible future projects under consideration-

- Rotokawa III (67 MW_e)
- Mokai IV (40 MW_e)
- Taheke (under drilling investigation)
- Rotorua (10 MW_e proposed)

As a consequence, there is a high probability of increasing geothermal production in New Zealand by at least a further 50% within 5 years.

Table 15.1 *New Zealand geothermal power projects, current, under construction and planned.*

Table of New Zealand Geothermal Energy Use as of 2010						
Geothermal System	Start date	Capacity	Constructing	Planned	*Direct Use*	Notes
		MWe	MWe	MWe	*TJ/yr (net)*	
Wairakei	1958, 2005	176		234-162	*1120*	2015-2016 ?
Poihipi	1996	55				2009 full-load
Tauhara I (Te Huka)	2010, 2007	23			*500*	2010 Binary
Tauhara II				250		2013-2014 ?
Kawerau Mill	1958	14			*5300*	2008 August
MRP & Ka24	2008	108		20		
Ohaaki	1989	75			*400*	originally 105MW
Rotokawa-NgaAwaPurua	1997-2010	175				April2010-140MW
Mokai I &II	1999-2007	114			*150*	
Ngawha I & II	1998-2008	25				
Ngatamariki				100		2013 ?
Rotoma-Tikorangi				35		2012 ?
Rotorua-Taupo-Tokaanu-Waikite-heating/spa					*1950*	
TOTAL		**765**	**0**	**477**	***9420***	

15.3.1.5 Number of Wells Drilled

In 2009, 29 wells were drilled.

15.3.1.6 Contribution to National Demand

Geothermal installed capacity contributes 7% of the total New Zealand national capacity; while generating 11.4% of the national electricity in 2009 (This will increase in 2010).

15.3.2 Direct Use

In 2009, the total primary thermal power discharged was about 22 PJ/yr; with some 10 PJ/yr thermal energy used. The average capacity factor was 43%, with capacity factors for industrial process heating and commercial bathing of 44% and 39%, respectively.

15.3.2.1 Categories of Use

Approximately 55% of the direct use of geothermal energy in New Zealand is industrial use at the Kawerau Pulp and Paper Mill (~200 MW_{th}). This is due to expand in 2010. The balance is mostly bathing and space heating facilities, kiln drying facilities at two sites, a geothermal tourism business, horticulture (e.g., tomato/capsicum glasshouses at Mokai, orchids at Wairakei) and aquaculture (e.g., Prawn Park at Wairakei).

15.3.2.2 New Developments and Wells Drilled in 2009

At Tauhara geothermal field, a ~50 MW_{th} waste-wood pellet-drying facility for producing pellets for use in domestic pellet-burning heaters has been constructed.

The number of new wells drilled for direct use is not recorded.

15.3.2.3 Rates and Trends in Development

Rates of growth in direct use have been relatively static over recent years, but are predicted to increase in the next 10 years. Geothermal tourism is growing; this involves visits by domestic and overseas tourists to geothermal parks or reserves, and bathing at hot spring resorts.

15.4 Energy Savings in 2009

15.4.1 Fossil Fuel Savings/Replacement

Fossil fuel savings/replacement for 4,542 GWh (16.35 PJ) of geothermal electricity generation in 2009 was 1.2 Mtoe/yr, assuming 70.4 toe/TJ. (This was an increase of 15% over the 2008 year.)

Fossil fuel savings/replacement for 10 PJ of geothermal direct heat use in 2009 was 0.35 Mtoe, at 35.2 toe/TJ.

15.4.2 Reduced/Avoided CO_2 Emissions

Reduced/avoided CO_2 equivalent (CO_{2-eq}) emissions (in tonnes of CO_{2-eq} /yr) for 4,542 GWh of electricity (using average of 806 t CO_{2-eq}/GWh net) is 3.67 Mtonnes (Mt) CO_{2-eq}/yr.

Reduced/avoided CO_{2-eq} emissions (in tonnes of CO_{2-eq}/yr) for 10 PJ of direct heat use (using average of 114 t CO_{2-eq} /TJ net) is 1.1 Mt CO_{2-eq}/yr.

Using published data on gas content in discharged steam, the calculated actual CO_{2-eq} (including methane) emissions from all NZ geothermal power plants (at a weighted averaged rate of 93.7 t CO_{2-eq}/GWh) producing 4,542 GWh in 2009 was 0.42 Mt CO_{2-eq}. This would have avoided CO_{2-eq} emissions from an equivalent (Huntly-sized) coal-fired power station (4,542 GWh at 900 tonnes CO_{2-eq} /GWh) of 4.09 Mt $CO2_{eq}$, leaving a calculated net benefit from geothermal of 3.67 Mt $CO2_{eq}$ (same as above). Such a calculation ignores the long-term effects of steam production on natural CO_{2-eq} emission rates through the ground.

15.5 Market Development and Stimulation

15.5.1 Support Initiatives and Market Stimulation Incentives

At present, the NZ government does not support geothermal directly in the form of renewable energy feed-in tariffs or subsidies. Normal market forces are deemed sufficient to drive investment in geothermal. New Zealand participates in the Clean Development Mechanisms programme under the Kyoto Protocol, and a carbon emissions trading scheme was finalised in legislation in 2009 and regulation ready to be implemented in 2010. Future carbon prices of about NZ$ 25 to $50/t CO_2 have been estimated.

15.5.2 Development Cost Trends

Total capital costs of generation from new geothermal plant now average about NZ$ 3-4 M/MW_e installed. Prior to 2008, drilling costs increased significantly to about NZ$ 4 M per 2 km deep well, due to a shortage of rigs, shortage of skilled manpower and increasing consumable costs (steel and cement). Prices and costs have since been quite variable, mainly as a result of the global financial crisis, commodity price swings and changes in the availability of rigs and operators.

15.5.3 Development Constraints

Significant constraints on the potential for future geothermal energy development in New Zealand are the issue of environmental effects and consideration for tourism and natural feature preservation. In the Waikato Region alone, about 50% of the estimated economically accessible resources are categorised by the regional authority (Waikato Regional Council) for *protection* due to outstanding natural characteristics. Others are only available, at present, for small *research* takes or *limited development* as a precautionary measure. Resources that are located near cities (e.g., Rotorua and Taupo) are subject to stricter control of fluid take and injection rates (with more stringent conditions on resource users) in order to minimize the risk of possible adverse effects on urban environments (such as subsidence, hydrothermal eruptions or pressure interference between bore users).

15.6 Economics

15.6.1 Trends in Geothermal Investment

A growth trend in geothermal investment in New Zealand is very apparent, with significant drilling activity, new resource consent applications and power plant construction. Geothermal drilling in known NZ geothermal resources over the past 3 years is achieving ~85% success rate in terms of commercially viable production or injection wells. This has reduced the perception that geothermal drilling is a risky venture, and has encouraged new investment.

Figure 15.5 (from MED, 2010, with assumptions as given) shows that geothermal power is expected to be the cheapest option for most new projects up to about 900 MW_e of capacity. Although the geothermal heat is *free*, these long-run marginal new generation costs include the costs of interest on capital, operations and maintenance, and anticipated make-up drilling.

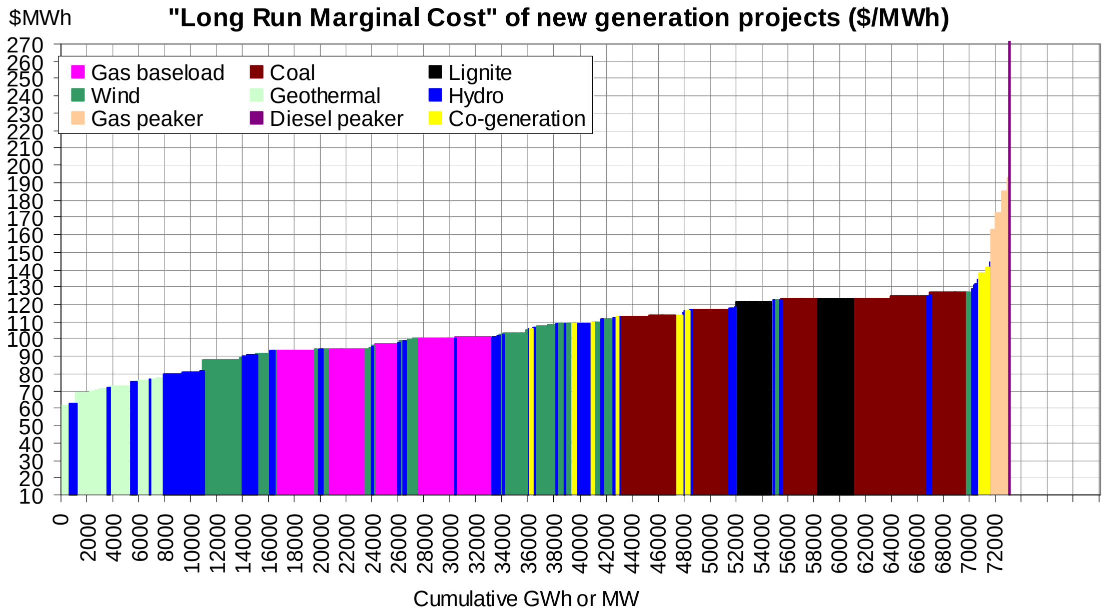

Figure 15.5 *Latest long-run marginal cost curve (NZ$) for identified future NZ generation projects versus cumulative GWh in cost order (Electricity LRMC model.xls, in www.MED.govt.nz). Assumes 8% discount rate, US$ 0.75 ~ NZ$ 1.00 andNZ$ 50/tonne CO_2 charge. Geothermal predominates up to 8,000 GWh.*

15. 6.2 Turbine, Project, Well Drilling and O&M Costs

Typical project costs (including drilling) for new green-field developments in New Zealand were recently presented in a report for the NZ Geothermal Association (Barnett and Quinlivan, 2009). In summary, for resources in the temperature range of 275-300 °C and a power plant size of about

50 MW_e, the total capital costs would range between NZ$ 3.4 M and NZ$ 4.6 M per MW_e (in 2007 $), and the long-run marginal cost is expected to range between NZ$ 70 and NZ$90/MWh (for the next 1000 MW_e). For lower enthalpy resources and smaller power plants, the costs will be greater.

Recent drilling-inclusive, new-project, capital-costs have been NZ$ 3 M/MW_e for the Kawerau 100 MW_e project, NZ$ 3.2 M/MW_e for the Nga-Awa-Purua (Rotokawa II) 140 MW_e project and about NZ$ 4 M/MW_e for the Tauhara 23 MW_e binary plant. Well drilling costs are currently about NZ$ 4 M each for 2 km deep wells.

O&M costs are typically NZ$ 8.5/MWh (for power plant and steam field) plus a long-term average of NZ$ 2.5/MWh for make-up well drilling (although this varies significantly between fields).

15.6.3 Trends in the Cost of Energy

Average wholesale electricity cost at source is presently about NZ$ 80/MWh (US$ 50/MWh), although the average delivered price for large industrial users in 2008 was NZ$ 106.5/MWh, and this has increased 7.1%/yr since 2000 (3 times the rate of inflation). New geothermal generation cost is about NZ$ 70/MWh for the best resources. Older geothermal generation costs (e.g., 25-50 year-old turbines) are much lower (estimate ~NZ$ 15/MWh) because capital costs have been written down (although maintenance costs increase with age).

15.6.4 Geothermal Sector Employment

The number of people employed in the NZ geothermal sector (full time equivalents) was estimated to be about 280 in 2005, and about 350 in 2009.

15.7 Research Activities

15.7.1 Focus Areas

Research focus areas include: geophysical studies (MT, seismicity), environmental (subsidence, hot spring/vegetation effects), deep resource delineation, production sustainability, and shallow hot water resources for direct use.

15.7.2 Government Funded Research

Government funded geothermal research undertaken by GNS Science and Auckland University, receives about NZ$ 3M/yr, for the 6-year research cycle which began in October 2007. In addition, supplementary research projects for deep geothermal resource exploration and for enhanced direct use of lower enthalpy resources were commenced in 2008, and continued through 2009. Details of these can be found on the GNS and Auckland University (IESE) web sites.

15.7.3 Industry Funded

Industry funded research was pursued in several topic areas, including: silica scaling for specific power plants; arsenic removal from separated brines; geotechnical drilling, core analysis and modelling to investigate causes of subsidence anomalies; and micro-seismicity studies.

15.8 Geothermal Education

The New Zealand Geothermal Association and the University of Auckland continue to provide relevant annual seminars, the annual New Zealand Geothermal Workshop (held in November), and short courses. In 2009, Auckland University (IESE) continued the international post-graduate training course (a 5-month course from July to November). One-day geothermal information seminars are organised annually by GNS Science for the benefit of members of indigenous Maori Trusts. The New Zealand Geothermal Association also hosts specialised 1-day workshops with invited speakers on topics of interest as required.

15.9 International Cooperative Activities

New Zealand scientists and engineers collaborate with geothermal projects throughout the geothermal world including: EGS (USA, Australia) and International Deep Drilling Project (IDDP) high temperature drilling (Iceland). Informal geothermal research collaboration with other countries also occurs through organisations such as GEISER, GEORG, IEA-IGA, etc. Consulting by New Zealand based geothermal specialist companies (e.g., SKM, PB Power, GNS Science) is undertaken in a number of geothermal countries.

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Photo 15.2 *Thermal ground at Broadlands Road Reserve near proposed 250* MW$_e$ *project at Tauhara, Taupo.*

National Activities

Chapter 16

Spain

Figure 16.1 *Drilling for Geothermal Heat Pump University of Alcalá de Henares. (Geoter 2010)*

16.0 Introduction

As a result of the energy crises in the 1970s, Spain decided to invest heavily in the development of renewable energies, which it has continued to do since then; intensifying these investments in recent years. This approach has enabled a thriving industry to be developed in our country, founded on technological innovation and the use of the abundant home-grown and clean energy resources at Spain's disposal.

The roll-out of renewable energies across our country has become a model for the world to follow, providing an example of cooperation between the public administration, business and social institutions. This was recognised in a recent report on Spain's energy sector by the International Energy Agency.

Without doubt, the main factor underpinning our success in integrating these energy sources into the electricity generation system has been the economic and legal framework comprising a system of regulated premiums and feed-in tariffs, which has been in force for the last 30 years and has been subject to ongoing improvements and modifications. This framework is stable but adaptable to the current status of each technology as it matures.

At the end of 2009, renewable energies covered approximately 11% of our final energy consumption, and forecasts for 2020 indicate that we are on course to exceed the target established in the EU Directive on Renewable Energies stipulating that Spain must meet 20% of its gross final energy consumption using renewable energies.

The contribution of renewable energy sources to primary energy consumption in 2009 reached 9%, as compared to 7% from 2008. Biomass, wind energy and hydro contribute with the 4.12%.

In the sector diagram below of the contribution of RES to primary energy consumption, geothermal energy is not represented among the other renewable energies.

With respect to global results, it should be noted that the primary consumption of renewable energy increased during this period, reaching a total of 12.2 million toes.

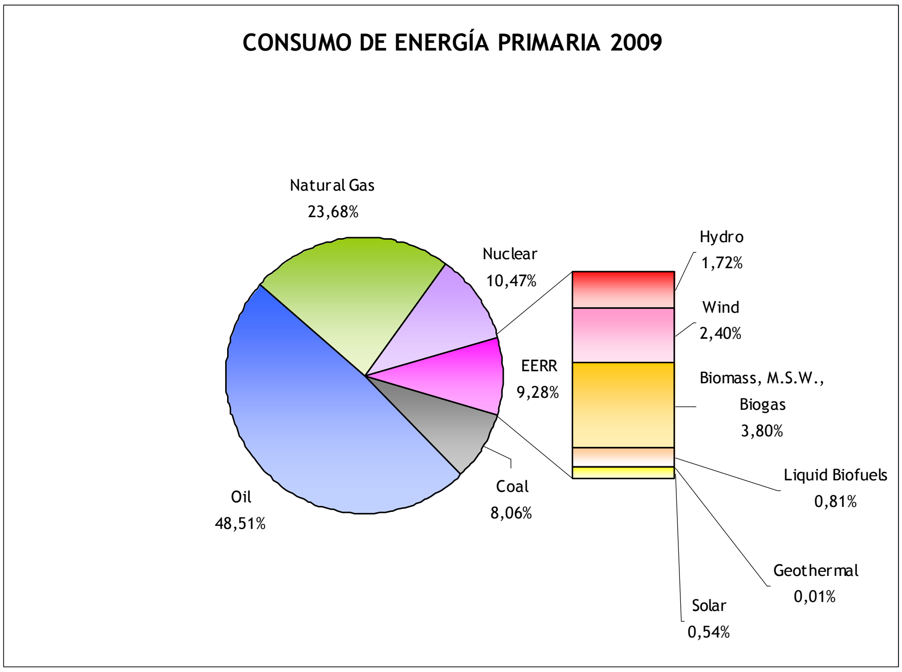

***Figure 16.2** Spanish Contribution of RES to primary energy consumption, 2009.*

At present, geothermal energy in Spain still has a low penetration in our energy balance, despite Spanish geothermal resources being important, as demonstrated by the extensive studies and investigations undertaken during the decade of 1970s-1980s. During the last couple of years, a great interest in geothermal energy in our country has awoken again.

Over the last decade, especially since 2005, renewable energies have made an ever increasing contribution in Spain, driven by a regulatory framework that has promoted development through stability.

At the end of 2009, total renewable electricity capacity installed in Spain reached 40.000 MW_e.

Figure 16.3 Spanish geothermal potential areas.

The Spanish renewable sector employs over 200,000 people directly and indirectly and comprises over 4,000 companies of differing sizes and activities, some of which are internationally renowned for their operating capacity and production of proprietary technology.

16.1 Highlights for 2009

The year 2009 was marked by several highlights illustrating geothermal within the above context:

- Throughout this year work continues within the framework convention between the Spanish Geological Survey (The Instituto Geologico y Minero de España (IGME) and The Institute for the Diversification and Saving of Energy (IDAE) aimed at the implementation of a national inventory of geothermal potential and conducting outreach efforts for the promotion and development of geothermal energy in Spain during the biennium 2008-2009.
- Within the framework of the Spanish Renewable Energy Plan 2011-2020, necessary studies are increasing to complete this knowledge and to have at one's disposal a better assessment of the geothermal potential in Spain. In October 2009, the Notice of competition of tenders for the procurement of technical assistance for the evaluation of geothermal energy potential in Spain for the preparation of the Spanish Renewable Energy Plan 2011-2020 was published.
- In May 2009, at the request of the IEA-GIA, IDAE organized and financed, with the collaboration of APPA, the celebration in Madrid, Spain, of the 21st Executive Committee Meeting of the GIA, which on this occasion coincided with the Meeting of the Board of Directors of the International Geothermal Association (IGA) and taking advantage of having the two groups together held the Joint GIA-IGA Workshop: *Geothermal Energy-its Global Development Potential and Contribution to Mitigation of Climate Change*. These events took place on successive days and had the presence and participation of experts like the General Director of the Spanish Geological Survey.

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

- Diffusion activities:

- IDAE published *Renewables made in Spain*, which aims to raise awareness of the business structure and technological development centres that are the lifeblood of this sector in Spain; and also to share Spanish experience with other countries and provide them with the skills and know-how of a country that has provided its drive, innovative ability and maturity through the development of renewable energies. The project is presented on a website ***www.renovalbesmadeinspain.es*** and a catalogue setting out the milestones that Spain has passed in reaching a position of leadership, as well as individual files on the activity of hundreds of our leading companies and technology and research and development centres working in the renewable energy sector.
- First steps to celebrate a future Second Geothermal Energy Congress for next year (GEOENER 2010) in Madrid.
- In May 2009 was celebrated the Constitutive General Assembly of the Spanish Geothermal Energy Platform- GEOPLAT. GEOPLAT aims to provide a framework within which all sectors involved in the development of geothermal energy, lead by the industry, work together in a coordinated way to ensure the commercial achievement of this renewable energy and its continuous growth, in a competitive and sustainable form. And, the first steps were made towards producing a *Vision for 2030* document.
- Holding many conferences, workshops and congress throughout this year.

➢ Geothermal heat pumps: There is an emerging market (GHPs for individual houses). There is an emerging application area of very-low-temperature geothermal energy for heating, cooling and WSW, mainly through geothermal heat pumps, which are enabling the development of an industrial network which is important to enhance the quality and the specific knowledge of this technology, to avoid market distortions and to ensure high quality products and services to final consumers.

IDAE is working to introduce geothermal energy into technical rules:

- Encourage the use of renewable in construction and urban development.
- Regulation on Indoor Heating/Air-conditioning Systems (RITE, RD 1027/2007).
- Basic procedure for the energy certification of newly constructed buildings. RD 47/2007 (energy efficiency label from the most efficient (A) to the least efficient (G))
- Technical Building Code (CTE, Royal Decree 314/2006) establishes the requirements that must be fulfilled by buildings in relation to basic requirements of safety and habitability.
- Introduce geothermal installations in Energy Rating Programs.

➢ Geothermal district heating: With regards to medium temperature geothermal energy, is currently developing several projects for district heating networks in Madrid, Burgos and Barcelona. Some of these projects are in the initial geothermal exploration phase, and production is expected for 2011, with power generation in 2013.

- In July 2009, a cooperation agreement between the Ministry of Economy and Finance of the Region of Madrid, IDAE, and Petratherm España was signed to promote a network for district heating in Madrid.
- High temperature resources in evaluation. There is a great expectation for high-temperature geothermal energy exploitation and deep uses such as EGS, or HDR, since the use of this energy is not limited to areas with favourable geological

conditions. Spain is starting such investigations, though it will be necessary to increase the knowledge of the subsurface and to investigate advanced new drilling technologies.

16.2 National Policy

16.2.1 Strategy

The Electricity Sector Law 54/1997 deregulated the electricity market in Spain and established that 12% of primary energy demand had to be met using renewable sources by 2010. To this end, this law called for the preparation of a Renewable Energy Development Plan, which was approved in December 1999. The Plan analysed the status and potential of these energies and fixed specific objectives for the different technologies.

In 2005, when it became clear that this objective was becoming difficult to fulfil, the Government approved a new 2005-2010 Renewable Energies Plan (PER) and an Action Plan to improve energy efficiency, in order to increase the speed at which these energy sources were being installed and curb rising energy demand. The 12% renewable share in relation to primary energy demand in 2010 was kept in the 2005-2010 PER and two new objectives were established for that year: 5.83% of petrol and diesel consumption by the transport sector to be satisfied using biofuels, and a minimum of 29.4% of gross electricity demand to be covered by renewable sources.

Over the last decade, especially since 2005, renewable energies have made an ever increasing contribution in Spain, driven by a regulatory framework that has promoted development through stability.

One of the keys to understanding the Spanish renewable success story is the support system that was selected. All nations understand that renewables are clean, primarily home-grown, and practically inexhaustible sources of energy, which frees them, to a large extent, from the price fluctuations suffered by fossil fuels that represent a real challenge for countries which are heavily dependent on external resources such as Spain, with an energy dependence of around 80%.

The recent approval of the European Directive 2009/28/EC came into force in June 2009 to promote the use of energy from renewable sources. This Directive establishes binding national targets, which for Spain, are in line with those set for the entire European Union- 20% of gross final energy demand to be met using renewable energies by 2020 and 10% in the transport sector; and demands that renewables be integrated into other sectors such as construction and urban development. This Directive also expressly refers to the positive externalities of these sources (clean and home-grown energies) and guarantees the use- and control- of support systems by Member States to help meet these targets.

The Directive forms part of the package of measures proposed by the European Commission in January 2008, subsequently ratified by the European Council and Parliament, that included as objectives for 2020, increasing the contribution of renewables to 20% of gross final energy demand and cutting greenhouse gas emissions by 20% compared to 1990 levels. These targets also exist in the context of a 20% improvement in energy efficiency by 2020. This is the so-called 20-20-20 package, which combines various measures aimed at reducing the European Union's energy dependence on the exterior and tackling climate change. Experts therefore consider that the Directive is extraordinarily valuable in ensuring the renewable sector continues to grow and gain market share.

This new scenario in Europe gives rise to an energy policy which Spain has embodied in 2010 in the 2011-2020 Renewable Energies Plan and the Renewable Energies and Energy Efficiency Law, which, along with the Sustainable Economy Law, form the three basic pillars on which the sector's future is based.

Within the framework of the Spanish Renewable Energy Plan 2011-2020, necessary studies are being initiated to complete this knowledge and to have at one's disposal a better assessment of renewable energies and about the geothermal potential in Spain. The following studies are being carried out:

- Strategic Environmental Assessment
- Study of technological evolution and prospective costs of technologies for 2020-2030.
- Analysis of the potential and development criteria grid
- Study of the employment associated with the promotion of renewable energies
- Economic impact of renewable energies in the national production system

The work on the National Renewable Energy Action Plan for which IDAE is responsible, was published on 30 June 2010. However, in December 2009, Spain sent its forecast document to the Commission. This document states an initial estimate of the foreseeable trend in renewable energies in Spain up to 2020: the share of energy from renewable sources in Spain's gross final consumption of energy will rise from 10.5% in 2008 to 22.7% in 2020, compared with a target of 20% for Spain in 2020.

A - FINAL CONSUMPTION OF RENEWABLE ENERGY	2008	2012	2016	2020
Renewable energy for electricity generation (Art. 5.1.A) (ktoe)	5.342	8.477	10.682	13.495
Renewable energy for heating/cooling (Art. 5.1.B) (ktoe)	3.633	3.955	4.740	5.618
Renewable energy in transport (Art. 5.1.C) (ktoe)	601	2.073	2.786	3.500
TOTAL RENEWABLES (ktoe)	9.576	14.504	18.208	22.613
TOTAL RENEWABLES, CORRECTED AS PER DIRECTIVE (ktoe)	10.687	14.505	17.983	22.382
B - FINAL CONSUMPTION OF ENERGY (ktoe)	**2008**	**2012**	**2016**	**2020**
Gross final consumption of energy (Art. 5.6)	101.918	93.321	95.826	98.677
% FINAL RE / FINAL E	10,5%	15,5%	18,8%	22,7%

Figure 16.4 Forecast share of energy from RES in Spain´s gross final consumption of Energy in 2020 (European Commission methodology).

The Renewable Energies and Energy Efficiency Law should improve the framework within which renewable energies are developed in Spain by increasing the visibility of the framework and ensuring it is technically and economically efficient. The new Plan will be the Government's tool for ensuring compliance with the targets established for Spain in the Renewable Energies Directive. As well as reducing the barriers that still exist for the most developed technologies such as wind and photovoltaic, and boosting their efficiency, the new Plan should encourage the development of emerging technologies, and, in particular, result in a suitable mechanism for promoting the use of renewable energies to generate heat in Spain.

16.2.2 Legislation and Regulation

In Spain, with little tradition and experience in the use of geothermal resources, the legislation is poorly developed, especially in regards to the very low temperature geothermal energy. The exploitation of geothermal resources is mainly covered by the mining legislation, because of its nature of energy mineral resources:

- Law 22/1973, of July 21, Mine (amended by Law 54/1980, of November 5). Geothermal resources appear covered in Section D, together with the energy resources of interest
- Regulations for the General System of Mining (Decree 2857/1978, of August 25)
- Regulation of Mining Safety Standards (RD 863/1985, of April 2), developed through Complementary Technical Instructions.

Currently, the Regional Governments are the administrative management of the mining system, according to the law of transfer of functions and services relating to industry, energy and mines. In the general regulation for prospecting and exploitation of these resources (high temperature) three distinct permits exist: permissions for exploration, research permits and exploitation concessions:

- Exploration permit, to be allowed to search for the geothermal deposit
- Exploitation permit that gives the owner an exclusive right on the resource in the perimeter of the permit
- Exploitation Concessions: Legal Right to use geothermal resources to a certain extent for a period of 30 years and extendable up to 90 years

There is a legal framework to obtain exploration, exploitation and research permits, depending on the type of geothermal resource and its use:

- Deep geothermal resources for electricity generation and thermal uses:
    - Mining Regulation: Mining rules establish different authorisations for prospecting and use of geothermal resources, such as exploration permits, research permits and exploitation concessions
    - Environmental Regulation: The specific characteristics of drilling require a previous evaluation from the relevant authority with regard to environment, according the Law of Environmental Impact Assessment (approved by the Royal Legislative Decree 1/2008)
    - Industry Regulation: Royal Decree 1955/2000 which establishes the procedure for the authorisation of electricity facilities. For facilities building administrative permit, project approval and exploitation authorisation are required
- Shallow and very low geothermal resources for thermal uses; a very low geothermal energy facility for heating, SHW or heating and cooling, must fulfil the following legal requirements:
    - Mining Regulation: Drilling could require an authorisation related to mining safety and an evaluation from the relevant environmental authority who will determine the needed procedures
    - Water Regulation: For open geothermal systems, concessions for water extraction and dumping are needed. For closed geothermal systems, an authorisation is needed if the drilling affects the aquifer
    - Industry Regulation: The facility for thermal uses or WSW must be registered following the same standards as a facility which uses conventional energy sources

16.3 Current Status of Geothermal Energy Use in 2009

16.3.1 Power Generation

16.3.1.1 Installed Capacity

In Spain, there is no installed capacity for electricity generation yet, but according several studies mainly carried out by the Spanish Geological Survey (IGME) in the 1970s and 1980s and current studies that are being carried out during 2009 and part of 2010, indicate there are indeed several recognized and identified areas with significant potential.

There is a great expectation for high-temperature geothermal energy exploitation and deep uses such as EGS, or HDR, since the use of this energy is not limited to areas with favourable geological conditions. Spain is starting such investigations, though it will be necessary to increase the knowledge of the subsurface and to investigate advanced new drilling technologies.

16.3.2 Direct Use

Currently, in Spain there are only geothermal heating projects for spa facilities, greenhouse heating or geothermal house heating. The main exploitation project for low temperature geothermal energy at present is greenhouse heating in the Mediterranean area (Murcia, Alicante, and Tarragona) and other projects associated with thermal springs and balneological applications where geothermal energy is mainly used to heat spa buildings.

However, shallow geothermal, or low temperature for heating and cooling, is now a reality in Spain. Although, historically, open systems with heat pumps have been the most used, closed systems have been applied in Spain since 2000, and now heating plants for buildings in the residential and tertiary sector (university, underground station such as Pacífico in Madrid) are increasingly being designed and built. While there is no reliable data on the installed capacity of geothermal energy in Spain, estimates exceed 50 MW_{th}, which supports in parallel the development of a new industry for this sector.

There are some initiatives for geothermal district heating projects which have already begun the exploration phase.

16.3.2.1 Installed Thermal Power

In 2009, the total installed capacity for geothermal heat pumps was 52.32 MW_{th}, according to data registered by the Spanish Autonomous Regions. However current sectoral studies (Boston Consulting Group manufacturers, installers, etc.) indicate that the estimated installed capacity for thermal direct use applications at the end of 2009 was between 80-100 MW_{th}, including geothermal heat pumps.

16.3.2.2 Categories of Use

Figure 16.3 shows different direct use operations in Spain.

Figure 16.5 Geothermal heat pump installation in the Madrid Subway.

Figure 16.6 Direct use in Spain.

16.4 Market Development and Stimulation

16.4.1 Support Initiatives and Market Stimulation Incentives

16.4.1.1 Electricity Generation

The purpose of the Royal decree 661/ 2007 is to set a detailed regulatory scheme of legal and economic provisions for electricity generation under the special regime and thus to strengthen the weak provisions of the Electricity Power Act. The overall aim is to promote the use and the development of renewable energies and to enable these technologies the access to the market.

The decree covers the following regulatory aspects:

- Administrative proceedings for obtaining authorization to operate under the special regime articles 4 – 1
- Rights and obligations of plants operating under the special regime, art. 16 – 23
- Remuneration for produced electricity (established the feed-in tariffs for the production of electricity for renewable energy sources).

Category a)- Producers using cogeneration or other ways of electricity production from waste energy.

Category b)- Installations using any of the non-consumable renewable energies, biomass or any kind of biofuel as primary energy, whenever their titleholders do not carry out production activities under the ordinary scheme.

Group b.3- Installations that only use as primary energy: geothermal energy, wave energy, tidal energy, energy of hot dry rocks, ocean thermal, and the energy of sea currents.

Category c)- Power plants that use waste with energy recovery not stated in category b) as primary energy.

Geothermal Energy in the Spanish Regulation (Royal Decree 661/2007) presents two sale options:

- Article 36: Sets the tariffs and premiums (Updated tariffs 2009 ITC-3801):
  - To the distributor at the regulated tariff (% of average electricity tariff, as set by RD 1432/2002). Option known as feed-in tariff.
    - In the first 20 years: 73.56 €/MW
    - After the first 20 years: 69.50 €/MW
  - Free market sale: price set by the market (calculated on hourly basis) + premium (% of average electricity tariff, as set by RD 1432/2002) + incentives+ complements.
    - In the first 20 years: 41.04 €/MW
    - After the first 20 years: 32.67 €/MW
- Article 39: additional prime specific for each project during the first 15 years.

16.4.1.2 Geothermal Heat

In 2009, geothermal projects have been subsidized for low temperature heat pump and district heating, at regional level, included in the subsidies of the Saving and Efficiency of the Renewable Energy Plan for the 2005-2010 period.

The total amount of the grants was:

- 500€/kW for open-circuit geothermal installation
- 1.100€/kW for closed-circuit with horizontal drilling
- 1.400€/kW for closed-circuit with vertical drilling
- 1.500 €/kW for district heating

The amount of subsidies will be a maximum of 30% of the reference cost. In case of hybrid facilities (geothermal+biomass, geothermal+photovoltaic, etc.) that use automatic boilers for domestic use or in municipal facilities, the amount of the help for the geothermal portion will be up to 50% of the eligible costs.

16.5 Economics

16.5.1 Trends in Geothermal Investment

For the next year, in thermal applications, IDAE has just approved the program *GEOCASA*, which is a funding program for geothermal projects in buildings, carried out by energy service companies (ESCOs), with the aim of promoting a quality of hot water and heating and cooling in buildings suitable for the needs of end users.

16.5.2 Development and O&M Costs

Geothermal energy is emerging in Spain so there are currently no reference costs.

16.5.3 Employment in the Geothermal Sector

The number of people employed in the geothermal sector, mainly in geothermal heat pump sector, was not significant for 2009, however, within the framework of the Spanish Renewable Energy Plan 2011-2020, one of the studies being initiated is the *Study on the Employment Associated with the Promotion of the Renewable Energies,* which could give us knowledge of the impact of geothermal on Spanish employment.

16.6 Research Activities

16.6.1 Focus Areas

During the last couple of years, great interest in geothermal energy has awoken in Spain again.

- The development of knowledge relating to geothermal resources: IDAE and the Spanish Geological Survey has a cooperation agreement to promote and foster the development of geothermal energy in Spain: low, medium, and high temperature and also HDR
- In 2009 IDAE (The Institute for the Diversification and saving of Energy) is initiating the preparation and preliminary studies for initiating the evaluation of geothermal potential in Spain to be held throughout 2009
- With the aim of identifying and developing sustainable strategies for the promotion and marketing of geothermal energy in Spain, in May 2009, the Constitutive General Assembly of the Spanish Geothermal Technology Platform-GEOPLAT- (www.geoplat.org) was formed. GEOPLAT covers all R&D activities in terms of identification and evaluation of

resources, as it covers the use of this renewable energy and its technology. The activities of the Spanish Geothermal Technology Platform are subsidized by the Spanish Science and Innovation Ministry. Also, it has the support of the Spanish Institute for Diversification and Saving of Energy- MITYC (IDAE) and the Spanish Centre for Industrial Technology Development (CDTI). The GEOPLAT Secretariat is managed by the Spanish Renewable Energy Association (APPA) within its two geothermal departments (High and Low Enthalpy Geothermal Departments).

16.6.2 Government Funded Research

Geothermal energy R&D activities in Spain are funded principally through:

- Projects funded by the Spanish Science and Innovation Ministry
- Support of the Spanish Institute for Diversification and Saving of Energy-MITYC (IDAE)
- Support of the Spanish Centre for Industrial Technology Development (CDTI)

16.7 Geothermal Education

A number of training-related projects are currently being carried out in Europe, and Spain participates on them. Also during the last 2 years geothermal energy as a subject within the Executive Masters programs has gradually been introduced.

Additionally, congresses, seminars and lectures are held by several institutions and associations involved in geothermal energy.

16.8 International Cooperative Activities

Since 2008, the Government of Spain has designated the Institute for Diversification and Saving of Energy, IDEA, to participate in the IEA as member of the Geothermal Implementing Agreement.

Spain joined the **QualiCert** project that is financed by the European Union under the Intelligent Energy Program. This program, which started in July 2009, has the objectives to develop positions for common quality certification and accreditation for installers of small scale renewable energy systems.

Article 14 of the Directive on the Promotion of the Use of Energy from RES (2009/28/EC) obliges al EU Member States to develop and mutually recognize accreditation and certification schemes for installers of small scale renewable energy installations. By December 2012, they need to develop certification schemes or equivalent qualification schemes for installers of small scale renewable energy installations, i.e., biomass boilers and stoves, PV and solar thermal systems and heat pumps, including shallow geothermal systems.

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National Activities

Chapter 17

Switzerland

Light and compact mini-drill rig for drilling shallow (100-200 m) wells for GHPs in Switzerland. (Photo courtesy of Swiss Federal Office of Energy)

17.0 Introduction

17.0.1 Background

Switzerland's national energy program (SwissEnergy http://www.bfe.admin.ch/energie/index.html?lang=en) and corresponding cantonal programs which will run until the end of 2010, provide the framework for the uptake of measures related to energy efficiency and renewable energy. The program has been in operation for nine years and continues to have a substantial and measurable impact. In terms of greenhouse gas emissions, Switzerland is on track to reach the targets according to the CO_2 law and the Kyoto Protocol (Figure 17.1). While the Swiss CO_2 law focuses on CO_2 emissions arising from fuels utilized in the heating and transportation sector, the Kyoto Protocol also includes CO_2 emissions from the process industry, and other greenhouse gases.

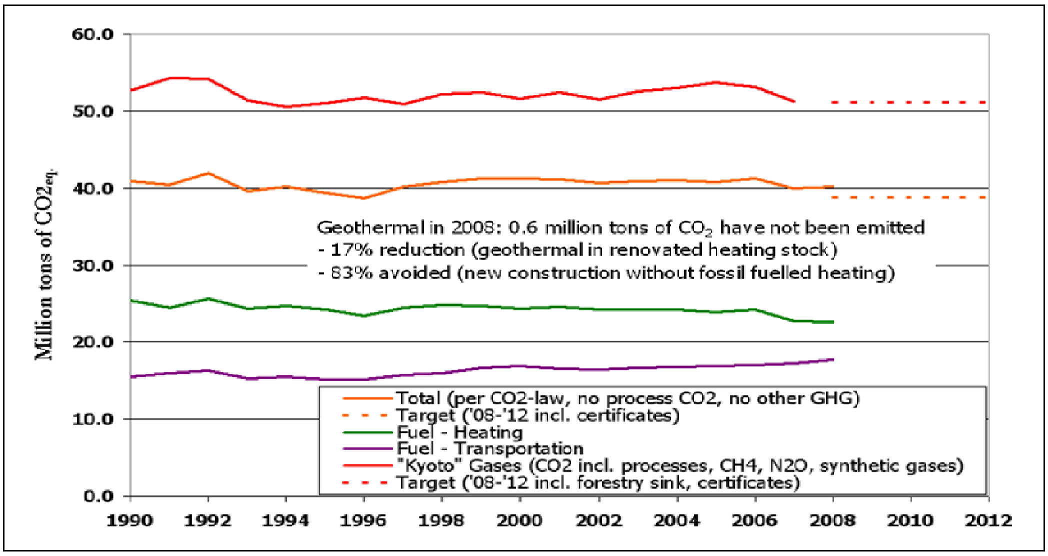

Figure 17.1 *Development of CO_2 emissions in Switzerland.*

Towards the end of 2009, and in response to recent trends in Switzerland's emissions, the federal government decided that the subsequent phase of Switzerland's national energy program would ramp up activities related to energy savings and emission reduction in the areas of mobility, electric equipment, industry and services, and ramp down activities related to renewable energy and buildings. Cross-cutting initiatives related to urban agglomeration, training and education and managing the national energy program will be increased. Federal budgets continue to be under pressure owing to the Swiss people's 2001 decision not to permit unsustainable public finances and stable debt ratios of the federal government during an economic cycle.

17.1 Major Highlights and Achievements in 2009

Major (> CHF 10 million, 1 Swiss Franc (CHF) ~ US$ 1.00) single investments towards the utilization of deep geothermal resources were taken in the cities of St Gall (a 3-D seismic reflection campaign) and Zürich (drilling of an exploration well with a focus on acquiring subsurface data to evaluate the potential of geothermal resources).

Another major achievement was the steady growth of geothermal direct use, mainly due to the advance of geothermal heat pump systems. Such systems are increasingly installed in larger complexes for space heating, cooling, and domestic hot water production. In addition they are replacing fossil fuelled boilers in the course of renovating old building stock.

17.2 National Policy

17.2.1 Strategy

The governmental energy program SwissEnergy provides the general strategic framework for meeting the goals on CO_2 emissions, to slow the growth of electricity consumption and to advance the use of renewable energies. Five focus areas have been identified for the period 2006-2010: the modernization of Switzerland's building stock, the use of renewable energy, efficiency gains in equipment and engines, efficient energy and waste heat use in industrial sectors, and energy efficient and low emission mobility. SwissEnergy mainly works through voluntary agreements with trade and industry, and with information campaigns to improve public awareness.

17.2.2 Legislation and Regulation

The energy article in the Swiss Federal Constitution, the Energy Act, the CO_2 Act, the Nuclear Energy Act and the Electricity Supply Act are all integral parts of the instruments for defining a sustainable and modern Swiss energy policy. In addition to these legal instruments, the energy policies of the federal government and the cantons are also based on the availability of future energy supply and demand scenarios as well as on strategies, implementation programs and the evaluation of energy-related measures at the municipal, cantonal and federal levels.

Since 1990, all cantons have drawn up their own energy legislation and regulations, and with the enactment of the Federal Energy Act and the Federal Energy Ordinance on 1 January 1999, the Federal Council has complied with the mandate received through the adoption of the Energy Article of the Swiss Federal Constitution. A CO_2 Act entered into effect on 1 May 2000, in which Switzerland defined binding targets for the reduction of the greenhouse gas, CO_2. The targeted reduction is primarily to be achieved through voluntary measures on the part of companies and private individuals, as well as measures relating to energy, environment, transport and financial policy.

17.2.3 Progress Towards National Targets

National targets comprise:

- In accordance with the CO_2 law, the goal of Switzerland's climate policy is to reduce CO_2 emissions by 10% over the period 2008-2012 and to stabilize other greenhouse gas emissions compared to their values of 1990. This translates into an 8% reduction in greenhouse gas emissions according to the Kyoto Protocol.
- The reduction of the rate of growth of electricity consumption (at most 5% more consumption in 2010 compared to 2000),
- And more uptake of renewable energies for electricity production (+0.5 TWh in 2010 compared to 2000) and heat production (+3 TWh in 2010 compared to 2000).

Owing to a 14.1% rise in the consumption of transportation fuels, Switzerland's CO_2 emissions have, by the end of 2009, declined by only 2.7 % when compared to 1990. In 2009, Switzerland's electricity consumption amounted to 56.6 TWh, about 12.1% more than in the year 2000 (52.4 TWh), of which new renewable energy sources (excluding hydropower) contributed to a production of 1,308 GWh. The latter figure compares to 847 GWh for the year 2000. In 2009 12,272 GWh of heat were derived from renewable energy sources compared to 8,915 GWh in 2000.

17.2.4 Government Expenditure on Geothermal Research and Development

For this purpose, government expenditures cover not only research and development (R&D) in the strict sense, but also contributions to pilot and demonstration projects. The Swiss Federal Office of Energy, the Swiss State Secretariat for Research and Education, the Board of the Swiss Federal Institutes of Technology, the Swiss Innovation Promotion Agency, and the majority of individual Swiss cantons have contributed funds to a number of R&D and pilot and demonstration projects. Although not a member state, Switzerland has a range of bilateral agreements with the European Union (EU) that includes research activities and allow cooperation with, and integration into, EU-wide R&D activities.

Figures for 2009 are not yet available with the exception of funds that have been provided by the Swiss Federal Office of Energy; for Research and Development some CHF 1.0 Million, for pilot and demonstration projects some CHF 1.2 Million, and for support of the Swiss Geothermal Association some CHF 0.5 Million.

17.2.5 Industry Expenditure on Geothermal Research and Development

It is not possible to obtain reliable figures. In many instances industry R&D funds are co-mingled and include all energy related R&D. Actual expenditures are likely to range from CHF 35-40 million. The funds derive mostly from Switzerland's main utility companies and their joint research vehicle, swiss*electric* research, member funds used for Switzerland's Laboratory for Geothermics based at the University of Neuchâtel, funds that small and medium sized enterprises contribute, and funds from semi-private regional and local utility companies. The significant increase in 2009 compared to 2008 owes to the funds committed to the deep exploration well (some CHF 22 million) drilled by Zürich's utility company, ewz, and some CHF 12 million in total expenses for a 3-D seismic reflection survey performed by the utility company of the city of St. Gall in eastern Switzerland.

17.3 Current Status of Geothermal Energy Use in 2009

17.3.1 Electricity generation

There was no power production from geothermal resources in 2009. A number of hydrothermal projects are in the planning phase which, if suitable resources are encountered, may eventually lead to power production from hydrothermal or enhanced geothermal systems. Significant stimulus is provided by the success of hydrothermal systems in related play concepts in southern Germany, the possibility to obtain attractive feed-in tariffs, a federal risk guarantee scheme, and the obligation of several local utility companies to explore and, if possible, develop geothermal resources.

17.3.2 Direct Use

The Swiss Geothermal Association (www.geothermie.ch) publishes annual statistics on the use of geothermal energy in Switzerland (Signorelli et al., 2010, in preparation). In 2009, some 2.1 TWh of heat was produced from geothermal systems (Table 17.1), of which 1.6 TWh was directly attributable to geothermal energy. The compound annual growth rate since 2000 has been a highly satisfactory 8%, attesting to the maturity of the technology, the uptake in the market place and the popularity among consumers. Noteworthy was the continued very high uptake of borehole heat exchanger coupled systems, which together with groundwater heat pumps, have a total share of some 86% of heat production and continue to enjoy high growth rates both in terms of installed capacity and heat produced. Thermal spas continue to contribute around 0.2 TWh of produced heat in Switzerland (Figure 17.2).

17.4 Energy and CO_2 Savings

The total heat production of 2,128 GWh (7.7 PJ) in 2009 corresponds to saving of some 182,400 toe/yr. Assuming an emission factor of 3.18 (metric) tonnes of CO_2 per ton of heating oil, emission of an estimated 580,000 tonnes of CO_2/yr has been avoided. This figure is likely to be an upper bound to the actual figure. Of the 580,000 tonnes, an estimated 30% is from the use of geothermal energy in renovated building stock and some 70% has been avoided owing to newly constructed buildings that otherwise are likely to have been heated using heating oil.

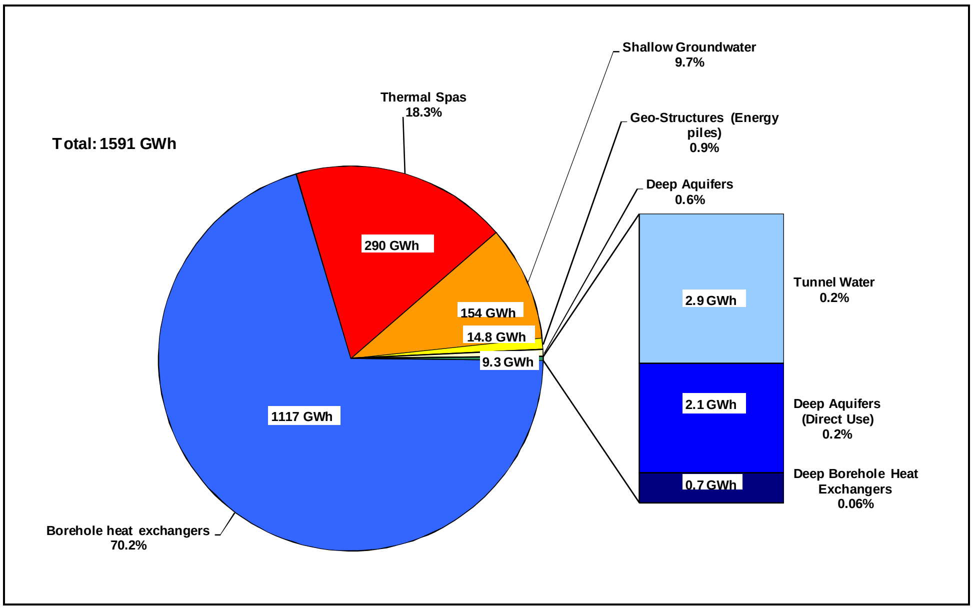

Figure 17.2 Utilization of geothermal heat in Switzerland in 2009.

Switzerland's own electricity production (~60 % hydro, ~40 % nuclear) is almost free of CO_2 emissions. But, there is very active pan-European power trading which on occasion results in the import of fossil-fuel derived electricity. This contribution would actually lower the amount of reduced and avoided CO_2 emissions. The amount of CO_2 not emitted and attributable to the use of geothermal heat alone is estimated at ~440,000 tonnes (or the equivalent of 138,100 tonnes of heating oil).

Table 17.1 Installed capacity for direct use and associated total heat production for 2009.

Geothermal System	Installed Capacity 2009 (MW_{th})	Compound annual growth rate (2000-2009)	Annual total heat production (GWh) – 2009	Compound annual growth rate (2000-2009)
Heat pumps with borehole heat exchangers, horizontal collectors	981.2	12%	1642.2 (of which geothermal 1176.1)	11%
Groundwater heat pumps	159.7	5%	224.1 (of which geothermal 158.9)	5%
Energy piles (geostructures)	11.9	14%	24.7 (of which geothermal 16.9)	15%
Deep borehole heat exchangers	0.2	0%	0.8 (of which geothermal 0.5)	0%
Deep aquifers for district heating	4.9	0%	15.5 (of which geothermal 10.8)	0%
Tunnel waters	2.4	1%	4.1 (of which geothermal 2.8)	2%
Spas, wellness facilities	28.6	-3%	238.3	-7%
Total	1057.0	10%	2151.5 (of which geothermal 1606.1)	8%

Source:http://www.geothermie.ch/data/dokumente/miscellanusPDF/Publikationen/GeoStatisikCH_2009.pdf.

17.5 Market Development and Stimulation

17.5.1 Support Initiatives

2009 saw a continuation of the boom in the utilization of geothermal heat pumps (Figure 17.3). During the years 2000-2009, borehole heat exchanger systems were deployed mostly in newly constructed real estate. However, as most of Switzerland's building stock is old and in need of renovation, the rate of deployment in renovated building stock has correspondingly accelerated over the last few years.

To ensure the widespread uptake of geothermal energy utilization, the Swiss Geothermal Association (www.geothermie.ch) provides educational activities at universities, colleges and technical colleges and further education seminars on a regular and as-needed basis. A few hundred technical and engineering professionals have taken part in those activities. In addition the Swiss Geothermal Association was instrumental in the revamped industry standard for borehole heat exchanger coupled systems (SIA 384/6) and contributed to the development and implementation of quality standards and certificates for the Swiss geothermal industry.

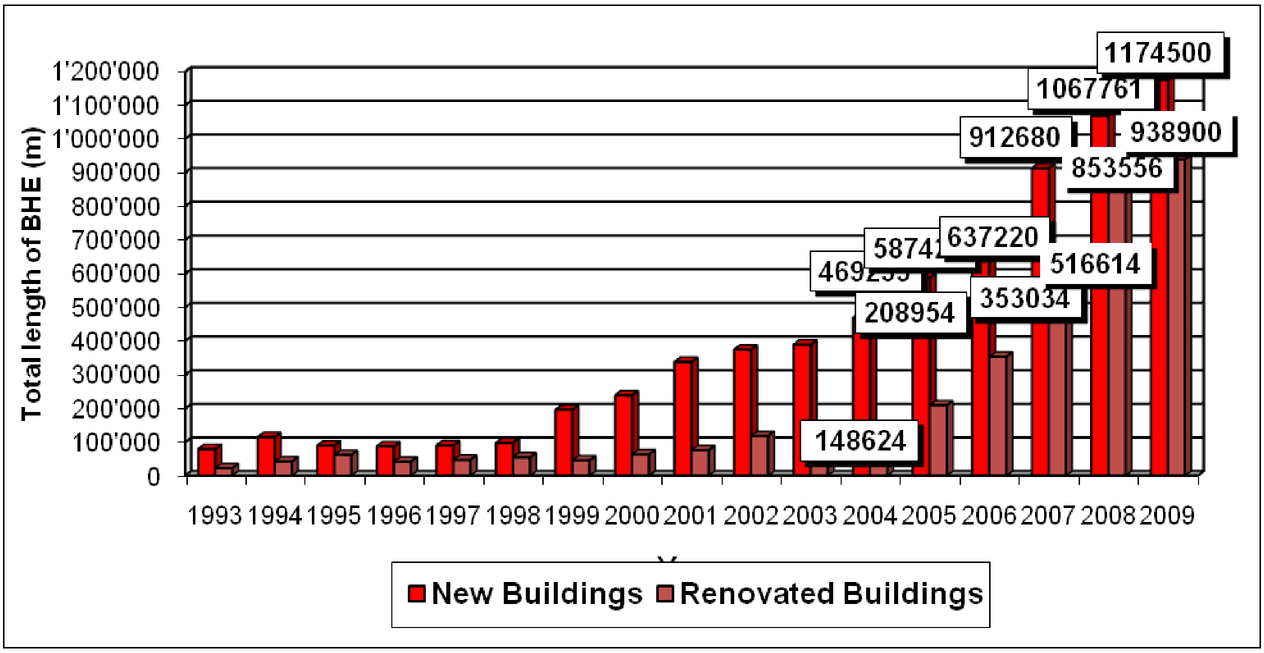

Figure 17.3 Annual total length of borehole heat exchangers installed (source: fws.ch, values 2009 estimated).

The Electricity Supply Ordinance and the revised Energy Ordinance detail the implementation of the legal provisions for liberalization of the electricity market for large consumers as well as the introduction of compensatory feed-in tariffs. Since 1 January 2009, an annual charge of up to 0.6 Swiss cents/kWh has been levied on high-voltage grid transmission costs, resulting in up to CHF 320-340 million/yr of funds available for feed-in tariffs and the risk guarantee for geothermal power projects.

Total feed-in allocations are limited for individual renewable energy technologies to prevent costly technologies from draining a disproportionate share of the overall feed-in funds to ensure that the ultimate objective of adding 5.4 TWh of renewable electricity by 2030 is not at risk. Almost 8,900 applications for feed-in tariffs have been submitted. In 2009, about 391 GWh of electricity was produced from a cumulative 120 MW capacity installed at 1,800 power projects, of which 59% are PV, 18% hydro, 14% wind and 9% biomass projects. The power production accounts for a total of 7.2% of the targeted 5,400 GWh by 2030.

Table 17.2 *Feed-in Tariffs for electricity produced from geothermal resources. The tariffs apply to net production of the facility and tariffs decrease by 0.5%/yr from 2018 on (US$ 1 ~ 1 CHF).*

Nominal capacity (MWe)	Tariff (CHF/kWh)
≤ 5	0.40
≤10	0.36
≤20	0.28
>20	0.227

Source: http://www.admin.ch/ch/d/sr/7/734.71.de.pdf

In addition to the feed-in tariffs there exists a "commitment to guarantee" for geothermal power projects. The purpose of this instrument is to encourage potential investors in geothermal projects by sharing the risk of finding suitable subsurface resources. If boreholes fail to deliver agreed targets, a maximum of up to 50% of the total subsurface costs may be reimbursed. The costs include, for example, well pad construction, drilling and completion for production, injection and observation wells, borehole geology, logging and instrumentation, production, injection and circulation tests, reservoir stimulation, chemical testing, etc.). The process is described in detail in attachment 1.6 of the Swiss electricity supply ordinance (http://www.admin.ch/ch/d/sr/7/734.71.de.pdf). In 2009, no projects applied for the risk guarantee.

17.5.2 Development Constraints

Geothermal heat pump systems have a high market penetration for new buildings, and increasingly are considered for larger systems (>100 kW capacity). The high density of buildings poses, at times, an accessibility constraint if geothermal heat pump systems are planned for building stock undergoing renovation.

Currently, there are a number of hydrothermal projects (direct use of hot aquifers and, if suitable, power production) in the planning stage. Since there has been no recent experience in designing and building a hydrothermal project in Switzerland, project maturation is comparatively slow. The adverse publicity caused by the felt induced seismicity of the Basel EGS Project causes project developers to involve a wide range of stakeholders and pursue a long-term, sustained communication and consultation process. Concern about potential hazards associated with induced seismicity in drilling and geothermal operations, and environmental concerns about water are some of the key obstacles to speedy execution and operation of planned projects. Another factor which makes the development of deep geothermal projects difficult and risky is the lack of underground data in large parts of the country.

EGS projects are currently on-hold. Subsequent to a 1-year study on risks associated with induced seismicity at the Basel site, the government of Basel-City has decided to stop the Basel project. Currently the project owners are in discussion about the future of the Basel well. No other EGS project is in the planning phase.

17.6 Economics

As in prior years, the installation cost of geothermal systems did not significantly decrease in 2009. Geothermal systems are perceived to be local in nature, and thus contribute to energy supply security. Energy contracting for geothermal heat pump systems is increasingly popular (the local electric utility builds, owns, and operates the system and the building owner receives monthly bills for heating, cooling and warm water). There is a ground price depending on the installation size and a variable price for heating, cooling and warm water delivery. Neither unit technical costs nor retail prices are known.

The average retail electricity price in Switzerland for 2009 was CHF 146/MWh (US$ 1.00 ~1 CHF). This price is an average value obtained from 107 companies in the power sector and is therefore deemed as an accurate number.

There continue to be no statistical data about employment in the Swiss geothermal sector. Previous estimates are likely to remain unchanged with some 150-200 people working in the sector, most of them in drilling, engineering or consulting companies.

17.7 Research Activities in 2009

17.7.1 Focus Areas

Shallow geothermal energy has proven to be successful in the market place and is therefore deemed less of a priority in terms of R&D. Instead, public funds for research and development of geothermal energy are increasingly focused on advancing hydrothermal systems for direct use and power, and on pursuing further research into Enhanced Geothermal Systems (EGS).

17.7.2 Publicly Funded Research and Development into Geothermal Energy

Only a subset of publicly funded R&D activities is listed in this section. A number of smaller research projects focus on measurement campaigns associated with large and complex geothermal ground source heat pump systems, and establishing best practice manuals regarding the use of borehole heat exchangers both for heating and cooling. Notable was the completion of an improved version of a low-cost software tool for public offices to evaluate ground water heat pumps. Two larger scale projects have been initiated; one at the Zürich University of Applied Sciences to reduce the power consumption of ground source heat pumps and thus increase the coefficient of performance by 20% compared to the technology available in 2009 (www.erdsondenoptimierung.ch). The second project underway at the Federal Institute of Technology at Lausanne (EPFL) deals with the impact of geotechnical effects on dimensioning of heat exchanger piles, since today the lack of incorporating interactions of mechanical properties of the soil-foundation system, temperature and pore water into design concepts, results in costly, less efficient heat exchange piles.

Hydrothermal projects have continued to mature in all three major geothermal regions of Switzerland: (1) the Alpine Rhone Valley of the cantons of Vaud and Valais in southern and south-eastern Switzerland (Figure 17.4); (2) the Swiss Molasse Basin that traverses the country from the Lake of Constance in the north-east, bordering Germany and Austria to the Lake Geneva region in the south-west, bordering France; and (3) the Upper Rhine Graben in the north-west of the country in the region of Basel, a region separated by the Jura Mountains from the Swiss Molasse Basin.

17.7.2.1 AGEPP- Alpine Geothermal Power Plant

The project AGEPP is located in the Rhone valley near the community Lavey-les-Bains, some 20 km south of the lake of Geneva. Today, geothermal water of 67°C is produced from a 600 m deep well and used for a nearby spa and heating. Chemical analyses of the water have indicated a potential of geothermal water of up to 120 °C in this area. A project for combined heat and power generation has been set up that would generate power and deliver heat to existing and planned district heating systems of nearby villages from 2012/13. A combination of a geothermal and a biomass power plant is expected to improve efficiency and economics of the project. In 2009, the promoters were able to secure the financing and set up an appropriate project organization. They also applied for getting the feed-in tariff. The project is strongly supported by the cantons of Vaud and Valais, local utilities and several communities of the region.

17.7.2.2 Brigerbad

This project is located in the upper part of the Rhone valley in the canton Valais. Also, in this region, there are historical hot springs used for spas that suggest a potential for geothermal power. In a first phase, near the Brigerbad spa, two wells have been drilled to a depth of 300 and 500 m. Bottom hole temperatures of 50 °C in the deeper well have been encountered and have led the developers to continue planning for a deep exploration well in the years to come. Near the site, the cities of Brig and Naters are potential customers for heat and power.

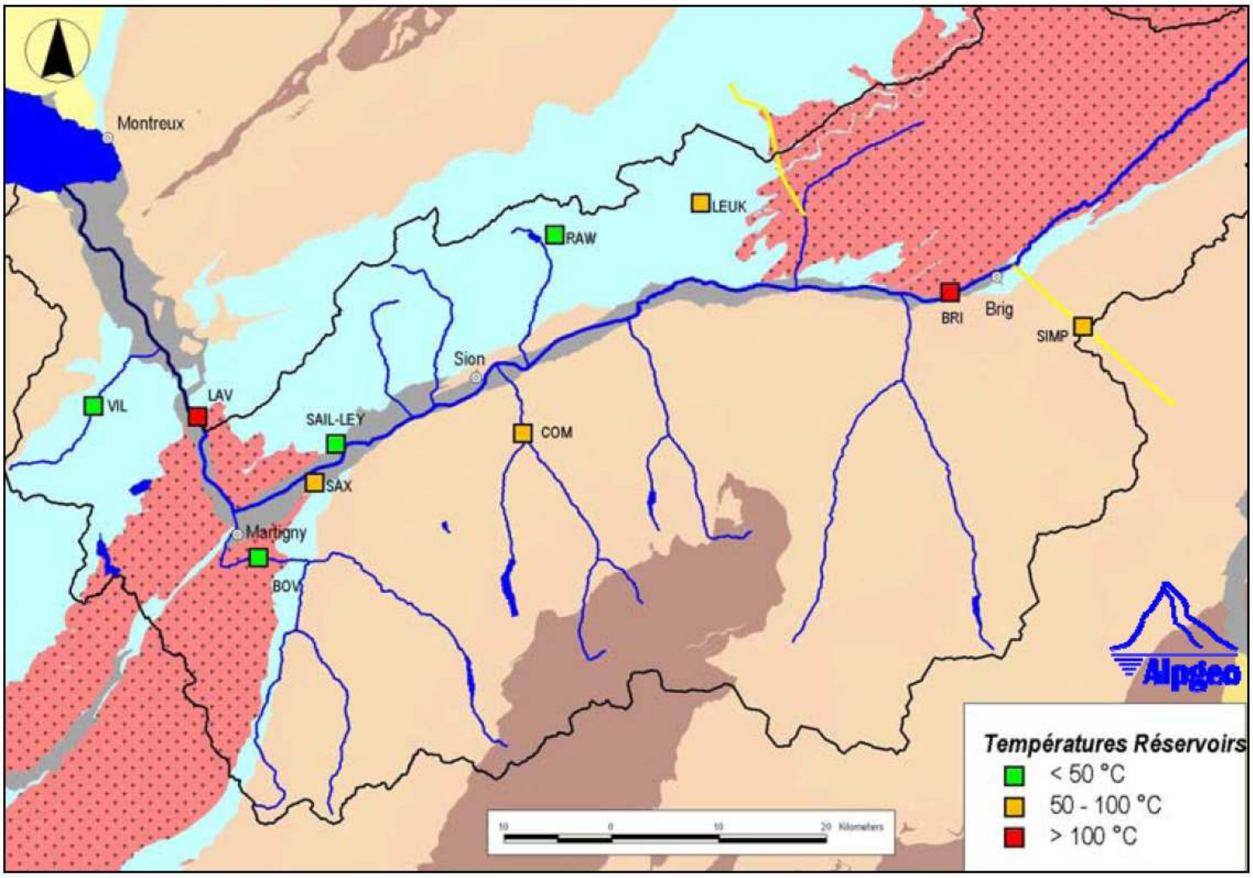

Figure 17.4 Geothermal springs in the upper Rhône valley and estimated reservoir temperatures.

17.7.2.3 St. Gallen

The city of St. Gallen, in the north-east of Switzerland, through its city-owned utility company received a local government grant of CHF 12 million to perform a 3-D reflection seismic survey to be executed in the first quarter 2010. The implementation of the strategy for long-term energy supply of the city of St. Gall, *Energy Concept 2050,* resulted in the local utility receiving a mandate to increase the share of renewables in the city's heat and power supply, and, if possible, avoid fossil fuels.

A number of additional cities and communities have initiated feasibility studies on the use of geothermal resources located in the Swiss Molasse Basin.

17.7.2.4 GP La Côte - Géothermie profonde sur la Côte lémanique (VD)

In the south-west of Switzerland and its Molasse Basin, in the region Aubonne-Etoy (located between the cities of Lausanne and Geneva), developers initiated an exploration program in 2009 to augment existing 2-D seismic reflection surveys with additional surveys in 2010. The primary objective is to identify possible exploration targets (deep fault structures in a sedimentary basin) and accordingly rank a portfolio of possible projects.

17.7.2.5 Enhanced Geothermal Systems (EGS)

In 2009, the *Deep Heat Mining* EGS Project, Basel saw only limited activity on the well Basel-1. A temperature log was acquired that reconfirmed a bottom hole temperature at the casing shoe (along hole depth of 4630 m) of 174 °C. Hydraulic measurements confirmed the strong effect of the stimulation on the injectivity of the borehole (Figure 17.5). For 2010, an attempt will be made to mill out an obstruction at an along hole depth of 4,682 m in the open hole section.

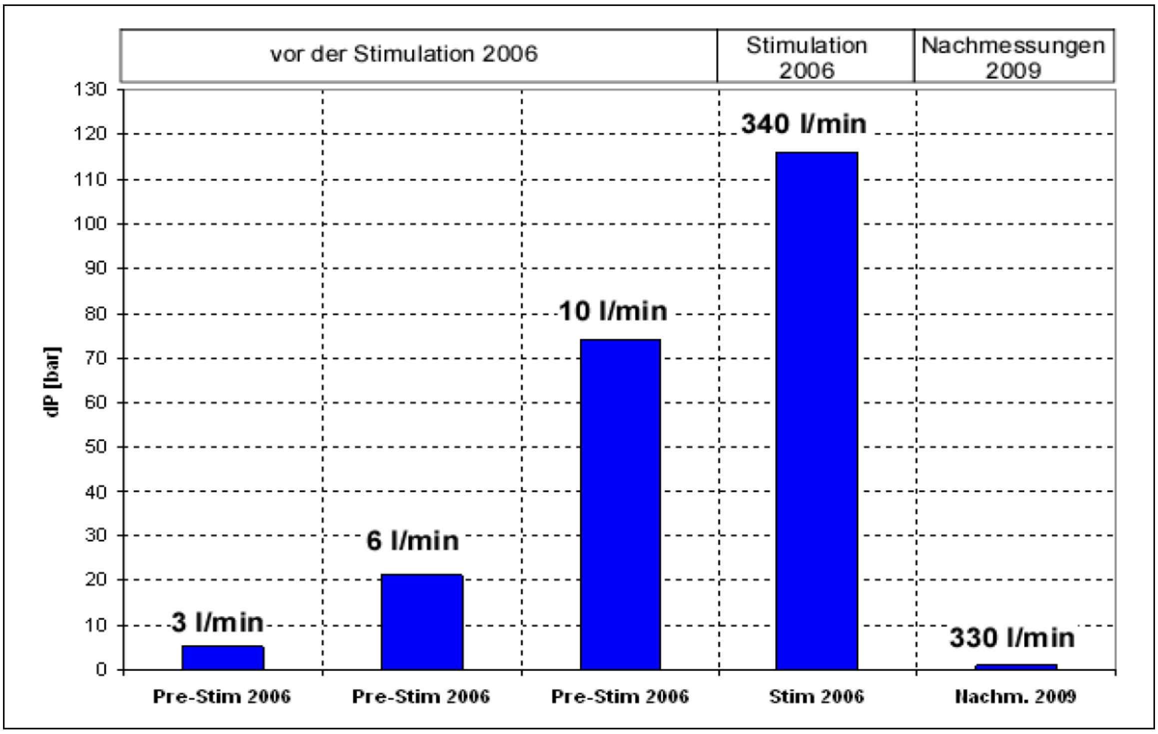

Figure 17.5 Development of the injectivity at the Basel EGS borehole, before, during and after (low rate, low volume test in 2009 with limited scope for interpretation) stimulation.

In addition, a large scale R&D program (*GEOTHERM:* www.cces.ethz.ch/projects/nature/geotherm) ramped up its activities in 2009. The objective of *GEOTHERM* is to help facilitate the exploitation of the vast energy resources that lie at practically drillable depths through the construction of EGS. The development of this technology to maturity would allow geothermal to make a significant contribution to the global energy mix. *GEOTHERM* consists of five modules: Reservoir geomechanics (Module 1); microseismicity studies of the permeability creation process and seismic hazard (Module 2); development of a hydro-thermal-mechanical-chemical coupled numerical code for reservoir simulation (Module 3); fluid-rock interaction (Module 4); and optimal use of geothermal resources in an urban environment (Module 5). The project was initially conceived as providing basic scientific support to the Basel EGS project. The premature termination of this project due to felt earthquakes has given added importance to the geomechanical and seismological studies that are underway, and has provided impetus to strengthen the Swiss Federal Institute's engagement with other EGS projects that can provide data on reservoir circulation. In addition, Swiss researchers continue to work at and contribute to the EGS project at Soultz.

For more information on the R&D program of the Swiss Federal Office of Energy please refer to: http://www.bfe.admin.ch/forschunggeothermie/02484/index.html?lang=de

In addition, Swiss universities and small and medium-sized enterprises participate in R&D programs that are publicly funded by foreign jurisdictions (e.g., GEISER, funded by the European Commission's 7th EU Framework Program, and R&D related to EGS funded by the US-American Department of Energy):
(http://www1.eere.energy.gov/geothermal/pdfs/egs_program_review_report.pdf)

17.7.3 Industry Funded Research and Development into Geothermal Energy

As no reliable figures are available, we provide only an estimate for 2009. The bulk of industry-funded R&D into geothermal energy is from the expenditures related to drilling of an exploratory well at the Sonnengarten location within the city of Zürich. ewz, Zurich's utility company, has committed some CHF 25 million to drilling for and utilizing geothermal energy in 2009 and 2010. Other industry funded R&D is estimated to another CHF 5-10 million in 2009.

17.8 Geothermal Education

A large part of geothermal education in Switzerland is managed by the Swiss Geothermal Association (www.geothermie.ch). Continuing education courses have been held at a large numbers of universities and technical colleges in the German, French and Italian-speaking regions of Switzerland. The University of Neuchâtel has initiated a joint Master's program in Hydrology and Geothermal Energy and now offers university-level courses related to geothermal energy.

17.9 International Cooperative Activities

Since Switzerland perceives geothermal energy (and EGS in particular) to be an increasingly important energy source in the coming decades, Switzerland strives for international cooperation in developing geothermal resources and geothermal technology. On a policy level and on issues related to Switzerland's federally sponsored and coordinated geothermal activities, the Swiss Federal Office of Energy now aims for a tight cooperation and integration into the IEA's Geothermal Implementing Agreement. Similarly, Switzerland strives to pursue the development of its geothermal resources and on research and development within the European Union. Switzerland has continued to contribute to the EGS Project in Soultz-sous-Forêts (France) and to

European research projects funded by the European Commission and member states (e.g., GEISER, EGS related R&D in Germany and France) and the US Department of Energy.

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National Activities
Chapter 18
United States of America

Figure 18.4 *The 18.6 MWe Enel Salt Wells Plant in Fallon, Nevada (Photo courtesy of Enel North America).*

18.0 Introduction

18.0.1 Background

In February of 2009, the United States passed the American Recovery and Reinvestment Act (ARRA). In total, ARRA was a $787 billion piece of legislation. $16.8 billion of that supported the development of clean energy through the Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE), including almost $400 million for geothermal energy. In 2009, a total of 151 projects were selected for award, anticipated to create 3,675 jobs. Note that while projects were selected in 2009, many awards were not made until 2010. The projects will continue through 2013-2015. Through these awards, DOE's Geothermal Technologies Program (GTP) expanded its focus from Enhanced Geothermal Systems (EGS) to encompass initiatives in innovative exploration technologies and low temperature geothermal. Specifically, these goals include to:

- Reduce high upfront risk associated with geothermal development
- Support discovery of the 30 GWe of undiscovered geothermal resources in Western United States identified by the US Geological Survey (USGS) in 2008 (Williams et al., 2008)
- Demonstrate cutting edge technology to advance geothermal energy production from oil and gas fields, geopressured fields, and low to moderate temperature geothermal resources

- Conduct research and development, and demonstration to establish EGS as a major contributor for baseload electricity
- Address market barriers to increase the deployment of ground source heat pumps
- Address authorizations under the Energy Independence and Security Act of 2007 (EISA) not previously funded

Successful development and deployment of EGS technologies will set the stage for a nationwide expansion of geothermal energy deployment. While high-temperature resources offer long-term benefits, near-term gains in geothermal expansion will come from co-produced fluids and the deployment of low temperature technologies to reach resources once considered non-economical. Additionally, an emphasis on the development of exploration technologies will aid in the development of more hidden hydrothermal resources in the near-term.

18.1 Major Highlights and Achievements from 2009

18.1.1 BLM Opened 190 Million Acres to Geothermal Power

The U.S. Department of Interior's Bureau of Land Management (BLM) opened more than 190 million acres of federal lands for leasing and potential development of geothermal energy resources. The newly issued Record of Decision amended 114 BLM resource management plans and allocated about 111 million acres of BLM-managed public lands as open for leasing. An additional 79 million acres of National Forest System lands are also legally open for leasing (U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2009a). In a separate action, BLM invested $41 million in ARRA funds to streamline the permitting process for renewable energy projects on Federal land and reduce the backlog of waiting permit applications (U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2009b).

18.1.2 Economic Stimulus Act Extends Renewable Energy Tax Credits

The tax section of ARRA provided a three-year extension of the production tax credit (PTC) for renewable energy facilities, and offered expansions on and alternatives for tax credits on renewable energy systems. The extension keeps the wind energy PTC in effect through 2012, while keeping the PTC alive for municipal solid waste, qualified hydropower, and biomass and geothermal energy facilities through 2013. In addition, a two-year extension of the PTC for marine and hydrokinetic renewable energy systems will keep that tax credit in effect through 2013. The PTC provides a credit for every kilowatt-hour produced at new qualified facilities during the first 10 years of operation, provided the facilities are placed in service before the tax credit's expiration date. For 2008, biomass facilities fueled with dedicated energy crops ("closed-loop biomass"), as well as wind, solar, and geothermal energy facilities earned 2.1 cents/kWh, while other qualified facilities earned 1 cent/kWh (U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2009c).

18.1.3 Federal Government Announced nearly $400 Million in ARRA Funding for Geothermal Energy Projects

On May 27, 2009, President Obama announced the availability of over $350 million in ARRA funds to expand and accelerate the development, deployment, and use of geothermal and energy throughout the United States. ARRA funding was available to support projects in four crucial areas: geothermal demonstration projects; Enhanced Geothermal Systems (EGS) research and development; innovative exploration techniques; and a National Geothermal Data System, Resource Assessment and Classification System (U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2009d). On June 2, 1009, DOE Secretary Steven Chu announced an additional $50 million for geothermal heat pump projects. The projects focused on three key areas: Innovative Technology Demonstrations; Life Cycle Cost Tools; and a National Certification and Accreditation Program (U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2009e).

18.1.4 DOE Announces Geothermal Research Initiative

On Oct 2, 2009, DOE announced a new collaboration between the Office of Fossil Energy and the Geothermal Technologies Program to demonstrate low temperature geothermal electrical power generation systems using oilfield fluids produced at the Rocky Mountain Oilfield Testing Center (RMOTC). The objective of this multi-year collaboration is to demonstrate the versatility, reliability, and widespread deployment capabilities of low temperature geothermal electricity production systems that work off of the co-produced water from oilfield operations. The electricity produced powers field production equipment, which offsets purchased electricity; other applications are being explored (U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2009f).

18.1.5 DOE and Partners Demonstrate Mobile Geothermal Power System at 2009 Geothermal Energy Expo

DOE, Pratt & Whitney Power Systems, and Chena Power LLC demonstrated the PureCycle® mobile geothermal power generation unit at the October 2009 Geothermal Energy Expo in Reno, Nevada. This was the second stop on a demonstration tour that will end in a Florida oil and gas field. The unit will be used in operation at the Quantum Resource Management LLC-owned field to continue demonstrating the unit's value (U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2009g).

18.1.6 Department of Energy Awards $338 Million to Accelerate Domestic Geothermal Energy

In response to the ARRA funding opportunity announcements, the DOE received over 500 applications for geothermal projects, of which 426 were compliant. Review of these projects involved nearly 100 geothermal experts from both the U.S. and abroad.

On October 29, Secretary Steven Chu announced up to $338 million in Recovery Act funding for the exploration and development of new geothermal fields and research into advanced geothermal technologies. These grants, supporting 123 projects in 39 states, will be matched more than one-for-one with an additional $353 million in private and non-Federal cost-share funds.

"The United States is blessed with vast geothermal energy resources, which hold enormous potential to heat our homes and power our economy," said Secretary Chu. "These investments in America's technological innovation will allow us to capture more of this clean, carbon free energy at a lower cost than ever before. We will create thousands of jobs, boost our economy and help to jumpstart the geothermal industry across the United States." (U.S. Department of Energy, Geothermal Technologies Program, 2009h).

18.2 National Policy

18.2.1 Strategy

In 2009, GTP expanded its geothermal program to encompass a broader portfolio of technologies than in previous years. In addition to EGS, GTP now has programs in low temperature geothermal and innovative exploration technologies. GTP was able to undertake this expansion as a result funding from ARRA. In the near-term, GTP will pursue resources that are lower temperature, coproduced with oil or gas, and geopressured (from high-pressured subsurface wells) to increase installed geothermal capacity. Additionally, GTP will develop tools to locate undiscovered hydrothermal resources that show limited-to-no surface expression. As a long-term goal, GTP is committed to demonstrating the technical feasibility of high-risk, high-payoff EGS.

GTP has a goal of demonstrating the technical feasibility of EGS technology by 2020 through cooperation with industry. The success of EGS is essential to the commercial viability of the technology and realizing the potential of geothermal energy in the United States as a baseload and geographically flexible renewable energy source.

18.2.2 Legislation and Regulation

The American Recovery and Reinvestment Act- President Barack Obama signed the American Recovery and Reinvestment Act of 2009 (ARRA), a $787 billion piece of legislation, on February 17, 2009 (Figure 18.1). $16.8 billion of that supported the development of clean energy through EERE. The funding was a nearly tenfold increase for EERE, which received $1.7 billion in fiscal year 2008. While the bulk of the new EERE funding supported direct grants and rebates, $2.5 billion supported EERE's applied research, development, and deployment activities, including $800 million for the Biomass Program, $400 million for the Geothermal Technologies Program, and $50 million for efforts to increase the energy efficiency of information and communications technologies. An additional $400 million supported efforts to add electric technologies to vehicles. Separate from the EERE budget, $400 million supported the establishment of the Advanced Research Projects Agency- Energy (ARPA-E), an agency to support innovative energy research, modeled after the Defense Advanced Research Projects Agency (DARPA) (U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2009i).

Figure 18.1 *President Obama signs the American Recovery and Reinvestment Act of 2009. (from Ruth Fremson, The New York Times, 17 February 2009)*

18.2.3 Progress towards National Targets

Funding for geothermal projects in the United States increased dramatically in 2009 as a result of ARRA. The funding marks a significant step towards the U.S. goal of demonstrating the technical feasibility of EGS technology by 2020 through cooperation with industry. Additionally, the United States has made early but notable progress in reducing geothermal exploration risk and in transforming low-temperature geothermal into a viable near-term energy source.

18.2.4 Government Expenditure on Geothermal Research and Development

DOE invested a total of $65.1 million in geothermal projects in 2009 including ARRA and regular appropriations. Note that many projects selected under ARRA were not actually awarded until after 2009.

18.2.5 Industry Expenditure on Geothermal Research and Development

Industry expenditure for 2009 totaled $636.6 million (Bloomberg New Energy Finance, 2010).

18.3 Geothermal Energy Use in 2009

18.3.1 Electricity Generation

In 2009, 97% of geothermal installed capacity was located in California and Nevada. However, geothermal generation is showing potential to expand both geographically and in terms of geothermal resources used. In 2009, the first power plant in Oregon, a 0.28 MW binary system, was brought online at the Oregon Institute of Technology (Figure 18.2). All five plants added in 2009 are binary systems, showing the growing interest in lower-temperature geothermal resources which could expand the geographic impact of geothermal energy.

Figure 18.2 *The geothermal combined heat and power (280 kW) plant at the Oregon Institute of Technology is the first in Oregon and provides the first geothermal power in the state. (Photo courtesy of Geo-Heat Center)*

18.3.1.1 Installed Capacity

Geothermal electric power was generated in nine U.S. states in 2009: Alaska, California, Hawaii, Idaho, Nevada, New Mexico, Utah, Oregon and Wyoming (Table 18.1). Total installed capacity was 3168 MW_e (Lund et al., 2010).

18.3.1.2 Total Electricity Generated

According to the Energy Information Administration (EIA), the electricity generation within the United States for 2009 from geothermal totalled 15.009 TWh (EIA, 2010a).

Table 18.1 *Existing geothermal installed capacity by state (MW_e)(ibid.).*

State	Total Installed Capacity (MWe)
Alaska	0.73
California	2,620.80
Hawaii	35.00
Idaho	15.80
Nevada	447.56
New Mexico	0.24
Oregon	0.28
Utah	47.00
Wyoming	0.25
Total	3,167.66

Table 18.2 *New power plants online in 2009 (Lund, 2010).*

State	Power Plant	Nameplate (MW_e)	Additional Information
Nevada	Enel North America Stillwater	47.3	Construction began in 2007 with full commissioning in April 2009. Plant uses Atlas Copco binary system (Enel Green Power, 2009).
Nevada	Enel North America Saltwells	18.6	Construction began in 2007 with full commissioning in April 2009. Plant uses Atlas Copco binary system (Enel Green Power, 2009).
Nevada	Nevada Geothermal Power, Inc. Blue Mountain Faulkner	49.5	This project was placed online in October 2009, four months ahead of schedule (Nevada Geothermal Power, 2010).
Oregon	Oregon Institute of Technology Klamath Falls	0.28	This project is expected to meet 20% of the electricity demand on campus (Pratt and Whitney, 2009).
Utah	Hatch	14.0	Uses 50 binary units, in April 2009 power supply to Anaheim started (Raser Technologies, 2009).
California	North Brawley	50.0	While it was anticipated that this project would be completed in 2009, this project was delayed to early 2010 (Ormat Technologies, 2010).

18.3.1.3 New Developments during 2009

Land Lease Sales- In 2009, 127 parcels (338,622 acres) were offered for lease by the BLM in two auctions. An auction in July resulted in 98 leases for 255,347 acres, which sold for more than $9 million in revenue. In November, BLM opened an additional three parcels totaling 3,780 acres for $209,257 (The Bureau of Land Management, 2010).

New Geothermal Plants for 2009- In 2009, an estimated 126 MW_e of nameplate capacity was installed online within the United States (Table 18.2; Figures 18.3 and 18.4 [Chapter photo]).

Figure 18.3 *The 47.3 MW Enel Stillwater Poant in Fallon, Nevada. (Photo courtesy of Enel North America)*

18.3.1.4 Rates and Trends in Development

As of April 2010, the GEA reports that 188 confirmed and unconfirmed projects with up to 7,875.16 MW_e under development. The GEA reports that approximately 987-1509 MW_e are in phase III of development (in the process of securing final permits and power purchase agreements) and 161 MW_e is in phase iv (facility in construction) (Jennejohn, 2010a). In addition, the following areas will likely see future growth as a result of investment by the federal government:

Innovative Exploration Technologies- In 2008, the USGS estimated that there is a mean 30 GW_e of undiscovered hydrothermal resources in the 13 western states alone (Williams et al., 2008). Under ARRA, up to $98.1 million was invested in 24 projects to improve technologies to confirm hydrothermal resources with no surface expression. These technologies are expected to lower the risks and cost of exploration, while locating new hydrothermal resources.

Low Temperature, Coproduced and Geopressured Resources- Under ARRA, up to $20.7 million was awarded to 11 projects to demonstrate the economic and technical feasibility of power production from low temperature, coproduced and geopressured resources. These demonstrations will widely expand the range of geothermal energy production including new installations in Louisiana, Texas and North Dakota, states without previous geothermal use.

EGS- In 2009, the DOE expanded its focus from EGS to new technologies, but also made substantial investments in EGS, including up to $51.4 million to fund three EGS demonstration projects and up to $105.2 million for component R&D including drilling, reservoir characterization and power plant technologies. These technologies will not only accelerate the commercialization of EGS, but will contribute to lowering the cost of electricity for all geothermal resources.

For the complete list of projects funded by the Geothermal Technologies Program, see the project database online at: http://www1.eere.energy.gov/geothermal/projects/

18.3.1.5 Number of Wells Drilled

Bloomberg New Energy Finance estimates that in 2009, 119 total geothermal wells were drilled. This number is up from 65 in 2007, and 100 in 2008. Of the 119 wells drilled in 2009, 63 were exploration and production, 11 for injection, 15 for observation and workover, and 30 were for thermal gradient wells (Taylor, 2010).

18.3.1.6 Contribution to National Demand

In 2009, the nameplate capacity totaled 1,025,400 MW_e for all energy types. Geothermal electricity generation was 15.0 TWh, which was 0.38% of the total U.S. electrical generation of 3,949.7 TWh. Geothermal electricity generation was 3.6% of all renewable production, which was 417.2 TWh, including conventional hydropower (EIA, 2011).

18.3.2 Direct Use

18.3.2.1 Installed Thermal Power

The installed direct use capacity in 2009 was 12,611.46 MW_t and had an annual energy use of 56,551.8 TJ/yr (15,709 GWh/yr) (Lund, 2010).

18.3.2.2 Thermal Energy Used

All direct uses in the U.S. combined have been estimated to have a capacity factor of 0.14, according to Lund (2010) in "The United States of America Country Update 2010".

The U.S. installed geothermal heat pump capacity in 2009 was 12,000 MW_t and had a capacity factor of 0.13. The energy consumed totaled 47,400 TJ/yr (13,177 GWh/yr).

In 2009, the installed capacity for direct uses, excluding heat pumps, was estimated to be 611.46 MW_t with an annual consumption of 9,151.8 TJ/yr (2,544 GWh/yr). All non-heat pump direct uses had a calculated capacity factor of 0.47, according to Lund (2010).

18.3.2.3 Categories of Use

Geothermal energy is used for numerous direct use applications within the United States, including for space heating, cooling, greenhouses, fish farming, industrial processes, snow melting and swimming pools (Lund, 2010).

18.3.2.4 New Developments during 2009

Under ARRA, up to $61.9 million was announced for ground-source heat pump (GSHP) technologies in the categories of data gathering and analysis, development of a National Certification Standard and technology demonstration. The award breakdown is as follows:

- Technology Demonstrations: awards to demonstration projects (50 ton minimum size) at a wide variety of buildings including an ice rink, a poultry cooling facility, a detention facility and many universities and schools (approximately $60 million).
- Analysis and Data Projects: awards to universities and private sector consultants to improve models and gather and analyze data (approximately $1 million).
- Installer Certification: one award to develop standards for the entire GSHP system installation (approximately $1 million).

Through these projects, DOE aims to address market barriers that have prevented heat pumps from reaching their full commercial potential. These projects will provide high-quality performance and cost data to consumers, architects and engineers, increase consumer confidence and awareness, reduce installation costs through demonstrations, R&D and incentives, and will demonstrate new financing opportunities.

In December 2009, the first well of a heat pump demonstration funded by the DOE was drilled at the National Renewable Energy Laboratory in Golden, Colorado Figure 18.5). System performance will be closely monitored and will include an interactive real-time display. This system will be used to evaluate heat pump system design and performance, assisting researchers, industry, consumers and policy makers evaluate the technology more accurately.

Figure 18.5 *Drilling for the NREL GSHP demonstration project.*
(Photo courtesy of Devin Egan, NREL Communications)

18.3.2.5 Rates and Trends in Developments

According to Lund (2010), while direct use in the United States has been constant or decreasing, the installation of GSHPs has experienced a rapid increase (an annual rate of increase of 13% over the past five years). This may be a result of the lack of funding incentives for traditional direct-use applications compared to GSHPs (ibid.). In addition to state and local incentives, the federal government offers a 30% credit (including installation costs) for GSHPs placed in service by December 31, 2016 (U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2010). Additionally, ClimateMaster, a GSHP manufacturer, reports that in 2008 GSHPs were installed in 1 out of 38 new homes (Ellis et al., 2009). This rate of development is expected to increase with the continued financial incentives and improved consumer confidence resulting from ARRA project initiatives.

18.3.2.6 Number of Wells Drilled

Lund estimates approximately 200,000 geothermal heat pump wells (assuming a vertical depth of 75 m) and 10 wells (assuming a depth of 4 km) for direct use were drilled in the US from 2005-2009 (Lund, 2010).

18.4 Energy Savings

According to the EIA 2010 Energy Outlook, in 2008 41% of CO_2 emissions came from electricity generation. Geothermal power plants have the potential to provide baseload electricity while substantially lowering emissions. Direct use, including GSHPs, contribute by directly avoiding emissions.

18.4.1 Fossil Fuel Savings/Replacement

Power Plants- As previously stated, 15.0 TWh (54,032 TJ) of electricity was generated from geothermal energy in 2009. Assuming that one metric ton of oil equivalent (1 toe) is equal to 0.042 TJ and fuel oil generates electricity at a 0.35 efficiency factor, 1 TJ = 68 toe. The geothermal electricity generated in 2009 would displace about 3.67 million metric tonnes of oil (Mtoe) equivalent.

Direct Use- Annual thermal energy use for 2009 was estimated to be 56,551.8 TJ/yr, which equates to a fuel oil savings of 3.846 Mtoe (3.223 Mtoe from GSHPs and 0.622 Mtoe for other direct use).

18.4.2 Reduced/Avoided Carbon Emissions

Lund calculates that the total electricity produced from geothermal energy is equivalent to 3.35 million tonnes of carbon per year and thermal heating from direct uses (including GSHPs) save 1.76 tonnes of carbon annually.

18.5 Market Development and Stimulation

18.5.1 Support Initiatives and Market Stimulation Incentives

18.5.1.1 Production Tax Credits

The Federal Production Tax Credit (PTC) was 2.1cents/kWh in 2009 for geothermal projects for the first 10 years of operation. ARRA has extended the credit until 2013.

18.5.1.2 Payment in Lieu of Production Tax Credits

ARRA also created a Treasury Department grant program (section 1603) allowing geothermal property owners to apply for cash grants in lieu of PTCs or Investment Tax Credits (ITCs). Geothermal electric production cash grant awards in 2009 are noted in Table 18.3 (Figure 18.6).

Table 18.3 2009 Geothermal electric generation projects under Section 1603 (U.S. Department of Treasury, 2010).

Recipient	Location	Amount	Award Date
Enel Salt Wells, LLC	Nevada	$21,196,478	9/21/2009
Enel Stillwater, LLC	Nevada	$40,324,394	9/21/2009
NGP Blue Mountain I LLC	Nevada	$57,872,513	11/9/2009
TOTAL		$119,393,385	

Figure 18.6 Blue Mountain/Faulkner I Project. (Photo courtesy of Nevada Geothermal Power)

18.5.1.3 Loan Guarantee Program

Through ARRA, Congress established a temporary program under EPAct 2005 that authorizes DOE to make loan guarantees for commercial deployment of certain renewable energy systems, electric transmission systems and leading-edge biofuels projects that commence construction no later than September 30, 2011. Congress appropriated $51 billion from FY 2007 and FY 2009. An additional $48.6 billion was provided under ARRA for conventional renewable energy systems and electric power transmission, which includes $4 billion for credit subsidy. While no guarantees were issued for geothermal projects in 2009, it could be a driver for future development.

18.5.2 Development Cost Trends

In 2009, costs fluctuated considerably due to the global economic climate. Due to the drop in oil and gas prices, the geothermal industry benefited from increased rig availability and decreased drilling costs. Additionally, some oil and gas drillers sought to break into the geothermal market during this period (Taylor, 2010a and Taylor, 2010b).

Sandia National Lab performed an analysis to calculate well construction costs as a function of depth. Using Bureau of Labor Statistics Producer Price Index along with Sandia well cost data, well construction costs were calculated using a "best fit" method. The analysis suggests that well construction costs have not yet stabilized from the economic crisis of 2008. Table 18.4 gives a sense for how geothermal well construction costs (relative to year 2000 and 2004 Q3 baselines) have fluctuated over time. The table shows that well construction costs increased from 2000 until 2006, then fluctuated from 2007 to 2009. This demonstrates that well costs in 2009 have not yet stabilized after the economic downturn.

Table 18.4 *"Best-fit" curves for well construction costs as a function of depth (Mansure and Blankenship, 2010).*

Year	2000	2001	2002	2003	2004	2004 Q3	2005	2006	2007	2008	2009
Multiplier (2000)	1.00	1.246	1.177	1.150	1.261	1.365	1.980	2.971	2.875	2.950	2.562
Multiplier (2004 Q3)	0.732	0.913	0.862	0.842	0.924	1.000	1.457	2.176	2.106	2.161	1.876
Intercept (k$)	750	935	883	863	946	1.024	1485	2,228	2,157	2,213	1,921

According to the IHS- Cambridge Energy Research Associates power plant capital cost index, power plant costs were resilient in the second half of 2009 despite the sharp decline in 2008 and the first two quarters of 2009. In 2009, the North American electricity demand dropped 3% and many new power plants were cancelled or delayed. However, toward the end of 2009 the rate of decline slowed as commodity prices (including steel) increased and economies in Asia recovered. Over the short-term, the index is expected to remain mostly flat (IHS, 2010).

18.5.3 Development Constraints

Geothermal development continues to require high upfront investment and has high exploration risks. As a result the geothermal market relies heavily on federal, state, and local tax incentives to attract investors. Naturally existing hydrothermal reservoirs remain geographically limited to western states where the most desired reservoirs tend to be remotely located and require significant transmission infrastructure. As EGS technologies are developed and deployed the challenges surrounding location are expected to be lessened. However, a new set of challenges surfaces. Vast quantities of water will be needed to create the reservoirs and maintain production. In addition, the processes associated with EGS development have been shown to cause induced seismicity. Permitting and leasing processes are also challenges to geothermal development.

18.6 Economics

18.6.1 Trends in Geothermal Investment

Islandsbanki predicts that the overall investment need for projects in development as of April 2010 is $29 billion. Additionally, while Islandsbanki reports that government stimulus has improved the climate for investing in geothermal projects, it has taken considerable time for companies to secure financing (Islandsbanki, 2010).

Bloomberg New Energy Finance found that opportunities exist to invest in equity for geothermal projects and in financing the drilling stages as short-term equity plays (Taylor, 2010b).

18.6.2 Turbine, Project, Well Drilling and O&M Costs

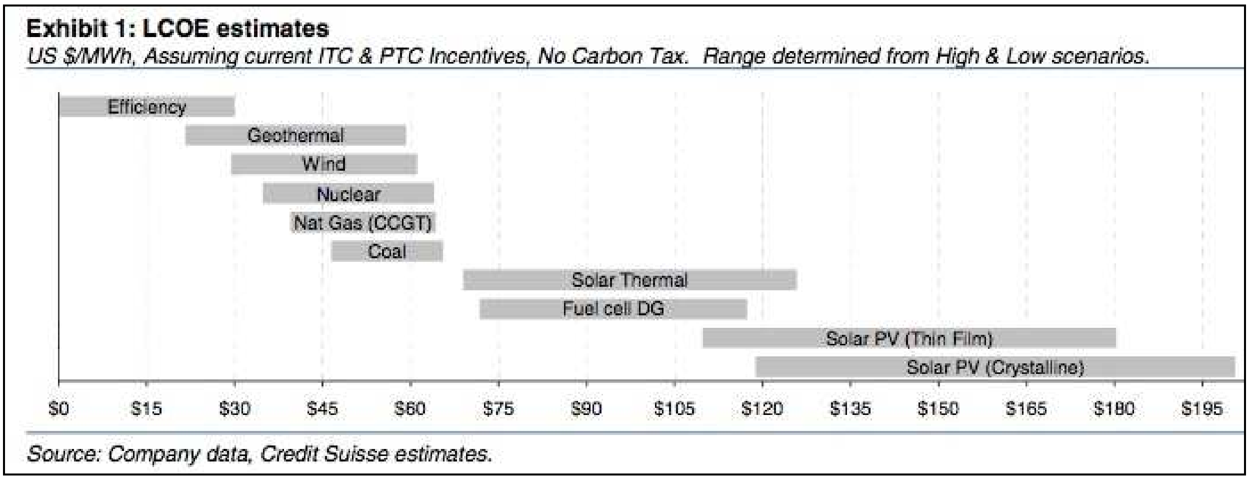
A study completed by Bloomberg New Energy Finance has estimated that the geothermal levelized cost of electricity (LCOE) ranges from $60-90/MWh, but can drop below $40/MWh or rise above $150/MWh depending on the resource. Below is the estimated cost breakdown for a 40 MW flash plant (expansion to existing field) with a resource depth of 1,750 m. While the cost breakdown will vary significantly from site to site, balance of plant and drilling costs are expected to represent the largest portions of geothermal development costs. Annual O&M costs were estimated to be $15/kWh (fixed) and $9/kWh (variable) (Taylor, 2010b).

Table 18.5 *Estimated development costs for a typical 40MW geothermal power plant (ibid.).*

Developmental Stage	Cost ($)	Percentage of Cost
Permitting	$615,000	0.5%
Leasing	$1,353,000	1.1%
Surface Exploration	$1,476,000	1.2%
Balance of Plant	$48,708,000	39.6%
Drilling	$70,848,000	57.6%
Total	$123,000,000	

Additionally, in January 2009, a Credit Suisse analysis found that the LCOE for geothermal ranged from $0.022/kWh to 0.056/kWh, with a base case of $0.036/kWh, lower than coal at $0.046/kWh base case. Geothermal assumptions include a $0.021/kWh production tax credit and that financing is available at an 8% interest rate. O&M costs ranged from $24 and $26/MWh. Additionally, this analysis does not include the cost of exploration (Flannery, et al., 2009).

Table 18.6 *Credit Suisse Alternative Energy Sector Review – LCOE Estimates (ibid.).*



18.6.3 Trends in the Cost of Energy

The levelized cost of electricity is expected to lower as R&D advances by the U.S. DOE's Geothermal Technologies Program reduce exploration, drilling and well field development costs and risks. However, as high-quality confirmed resources are utilized, the remaining geothermal fields will be more expensive to confirm (if they show no surface expression) and economically produce power if the resource is marginal. However, over the long term, with advancements in new technologies including EGS, the country's geothermal reserves will increase dramatically.

18.6.4 Employment in the Geothermal Sector

GEA estimates that the geothermal industry directly employs approximately 5,200. The direct, indirect and induced impact of the US geothermal industry is estimated to be 13,100 full-time jobs (Jennejohn, D., 2010b).

18.7 Research Activities

18.7.1 Focus Areas

With support from ARRA, the research focus in 2009 was expanded to encompass low temperature geothermal and innovative exploration technologies in addition to EGS. Projects focused on component technologies research and development, theoretical modeling and analysis, and systems demonstrations.

18.7.2 Government Funded

U.S. Federal Government funding for geothermal energy was available through DOE. In 2009, DOE invested $42.9 million from annual appropriations in geothermal research, development and demonstration and $22.2 million for ARRA-supported geothermal energy projects.

18.7.3 Industry Funded

Industry funded research activities included cost-shared activities with the DOE. In total, industry invested $636.6 million in geothermal projects in 2009 (Bloomberg New Energy Finance, 2010).

18.8 Geothermal Education

18.8.1 Geothermal Resource Council

The Geothermal Resources Council (GRC) is a tax-exempt non-profit educational association with members in 30 countries. It serves as a primary professional educational association for the international geothermal community, convening special meetings, workshops and conferences on a broad range of topics pertaining to geothermal exploration, development and utilization. In addition, the GRC periodically schedules a basic introductory course about geothermal resources and development.

18.8.2 Geothermal Energy Association

The Geothermal Energy Association (GEA) is a trade association of U.S. companies supporting the expanded use of geothermal energy and developing geothermal resources for electrical power generation and direct-heat uses. In order to achieve this goal, the GEA compiles statistical data surrounding the geothermal industry and conduct various education and outreach projects. In 2008, a number of publications were released for public access providing invaluable information regarding current geothermal technologies and trends in developments.

18.9 International Cooperative Activities

In 2008, DOE signed the International Partnership for Geothermal Technology (IPGT) with Iceland and Australia. The IPGT continued its work in 2009 with the establishment of six working groups in technical areas: lower cost drilling; stimulation procedures; exploration technologies; high temperature tools; zonal isolation and packers; and reservoir modeling.

Additionally, the United States is a member of the International Partnership for Energy Development in Island Nations (EDIN) with Iceland and New Zealand. EDIN aims to advance the deployment of renewable energy and energy efficiency technologies (including geothermal) in islands across the globe (EDIN website, 2009).

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Sponsor Activities

Chapter 19

Canadian Geothermal Energy Association

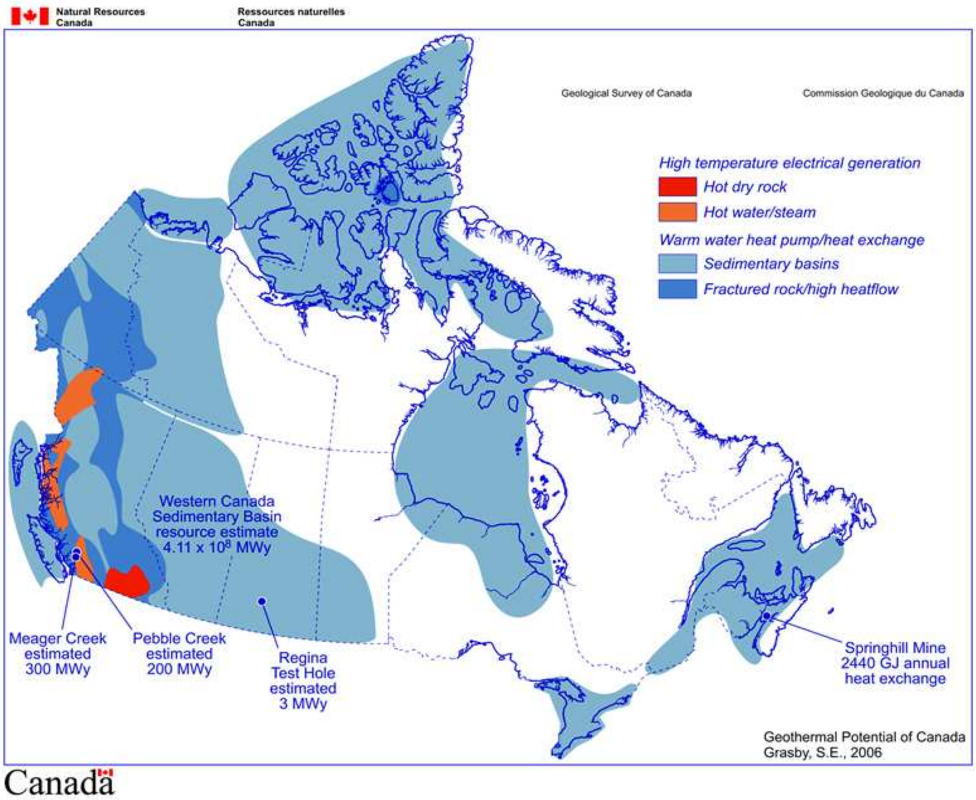

Figure 19.1 Map illustrating the geothermal energy development potential for Canada.

19.0 Introduction

19.0.1 Background

Estimates of Canada's geothermal energy potential have routinely been stated at more than 5,000 MWe of traditional geothermal potential. Enhanced geothermal systems (EGS) multiply this estimate by several times and place geothermal energy in close proximity of nearly all Canadians. The Canadian Geothermal Energy Association (CanGEA) and its members believe that as much as 5,000 MWe of traditional geothermal power could be brought online as soon as 2015.

For the most part Canada's easily accessible geothermal resources are located in the western third of the country. Here there are mountain ranges which grant access to the hot geothermal resources which lie below. This region is akin to the tranche of geothermal resources located in the western United States, Alaska, and Mexico. The interior of Canada is comprised of deep crust referred to as the Canadian Shield making geothermal resources harder to access. Similarly, eastern Canada also has less predominant geothermal resources.

The map provided in Figure 19.1, compiled by the Geological Survey of Canada, illustrates the potential for geothermal energy development across the country. The most favourable regions for development include Alberta, British Columbia, and the Yukon and Northwest Territories – all located in the western third of Canada. In these regions the resource is both significant and relatively easily accessible. There exist hot springs and pools in all of these locations, not to mention extensive geological knowledge gained from mineral and oil & gas exploration activities. These data provide a foundation for geothermal exploration even in the absence of government support for geosciences and mapping.

19.1 Major Highlights and Achievements for 2009

The Canadian Geothermal Energy Association has grown significantly in recent years and at the end of 2009 included 27 members ranging from geothermal developers, equipment manufacturers, and utilities, to firms specializing in the consulting, engineering, construction, financial, and legal aspects of geothermal energy. Together, CanGEA's pure play geothermal producers represent over $1 Billion in market capitalization on the Toronto and Venture Stock Exchange and nearly 2,000 MWe of installed geothermal energy globally, though there is currently no domestic geothermal power production in Canada.

Nevertheless, the Canadian geothermal industry has been proactive in instituting the Geothermal Code for Public Reporting (the Code) to increase investor confidence and provide an accurate means for comparison within the industry. The Code provides a minimum set of requirements for the public reporting of Exploration Results, Geothermal Resources and Geothermal Reserves. Furthermore, the Code will provide a basis for transparency, consistency and confidence in the public reporting of geothermal information.

CanGEA members have an active roster of 76 projects worldwide with 1,470 MWe under development and nearly 2,000 MWe of operating power plants. With such a large breadth of experience Canadian geothermal developers are well suited to tap Canada's vast geothermal resources to provide clean, reliable, base-load power for Canadian and export markets. Furthermore, with such ambitious support from Canadian investors it is clear that the geothermal energy in Canada is sure to play an important role in Canada's energy future.

19.2 National Policy

19.2.1 Strategy

At the federal level there is a poignant lack of both strategy and direction for Canada's geothermal energy industry. Though direct use and geo-exchange applications have seen some support from the federal government the geothermal power sector has been overwhelmingly ignored. Due to Canada's rich energy resources, including vast amounts of hydroelectric, fossil fuel, and nuclear power, there has not been the impetus to explore new alternative energy sources to the same degree as other nations who have sought to attain energy independence.

19.2.2 Legislation and Regulation

Currently only one jurisdiction (British Columbia) has legislation governing the exploration and development of geothermal resources. Other provinces and territories are currently considering the adoption of such legislation and the Canadian Geothermal Energy Association is active in the consultation process to expedite the prudent development of these resources. On the federal front geothermal energy development remains a lower priority in the context of other energy resources such as oil & gas, hydroelectric, wind, and solar power. Through active policy work and advocacy the Canadian Geothermal Energy Association is making headway in attracting interest and progressive policy to advance the industry.

19.2.2.1 British Columbia

The Province of British Columbia is perhaps the most progressive jurisdiction in terms of policy and administration for geothermal energy development. The Province recently held its first tenure permit action since 2004 and has scheduled at least one more auction to take place later in 2010, but has failed to meet its own guidance in the issuance of tenure permits enabling geothermal exploration and development. Nonetheless, this latest auction effectively ends a longstanding period of government inactivity in the geothermal sector and reflects a renewed interest in the industry and its ability to meet the clean energy demands of the Province.

In addition to geothermal tenure permit auctions the Province recently announce the new Clean Energy Act and is undertaking industry consultation to modernize its legislation and regulations for the geothermal industry. The new Act will provide greater Ministerial authority in advancing clean energy projects while streamlining certain processes to expedite project development. The industry is hopeful that the new Act will usher in a flurry of geothermal resource exploration and development for the Province and provide the needed government support to attract further investment in the industry.

19.2.2.2 Alberta, Yukon and Northwest Territories

The remaining western Canadian jurisdictions with strong geothermal resources are also keenly looking at ways to advance the development of their geothermal resources. In Alberta, where electricity generation is largely dependant on fossil fuel generation facilities, policy reform remains a goal of the industry even though current projects are being governed by other legislation such as oil & gas and mineral exploration and extraction. Though there is a lack of tailored policy there is great interest in geothermal energy and a provincial agency has put forth funding for a co-produced fluids geothermal project. As well, there is a financial incentive of $15 per tonne of CO_2 equivalents removed or negated in the power production market. This, in addition to federal incentives, has drawn interest in the geothermal sector in Alberta – especially for co-produced fluids projects symbiotic to the oil and gas and mining industries. In the northern territories there is similar interest in developing geothermal resources for electricity production and also for residential and commercial heating. Typically these northern and remote communities have relied upon fossil fuel and food imports which are both costly and environmentally damaging. Geothermal energy represents a comprehensive solution to these issues and is an ideal alternative worth consideration. The federal government has sponsored one geothermal power pilot project and one geothermal heating project in the Northwest Territories. These projects, combined with the Alberta project, may soon be Canada's first geothermal power plants and generate the country's first megawatts of electric power from the earth's energy.

19.2.2.3 Other Canadian Provinces and Territories

Many other jurisdictions in Canada are pursuing aggressive plans to initiate and develop alternative and renewable means of energy production. Quebec and Ontario, similar to British Columbia, have each adopted progressive energy policies that promote renewable electricity and heat production through incentives and attractive government policies. Geothermal energy has largely been left out of these programs as the resource is either less tangible or insufficient without EGS technology in these regions. However there is also great opportunity for co-produced fluids, geo-pressure, and direct use applications throughout Canada. Ultimately there is great interest in examining future opportunities for geothermal development and the Canadian Geothermal Energy Association is active in promoting this valuable resource throughout Canada.

19.2.3 Progress towards National Targets

The Canadian federal government initiated a target of deriving 90% of Canada's power production from "non-emitting" sources by 2020. Presently, Canada generates 70% of its electricity from "non-emitting" sources, with over 50% of Canada's total power production is derived from hydroelectric generation. It has been made clear through Canadian geothermal interests that geothermal energy could contribute materially towards this national goal. The Canadian Geothermal Energy Association, which represents the high-temperature geothermal industry in Canada, maintains that with proper legislation and support, 5,000 megawatts of geothermal power could be harnessed feasibly by 2015 – roughly seven percent of Canada's current electricity consumption.

19.2.4 Government Expenditure on Geothermal Research and Development

Federal support for geothermal power production has been limited to indirect research on mapping the heat resources of Canada. This research however is lacking in providing hydrological and rock permeability data that is essential to geothermal power projects and development.

19.2.5 Industry Expenditure on Geothermal R&D

As mentioned earlier, the bulk of Canada's geothermal energy industry's progress is taking place outside of Canada – mostly in the United States and South America. 2009 saw very little expenditure on Canadian R&D that would be applied or specific to the Canadian context.

19.3 Current Status of Geothermal Energy Use in 2009

19.3.1 Electricity Generation

19.3.1.1 Installed Capacity

Canada currently has seven active projects under development but is yet to have any geothermal power supplied to the grid (Table 19.1). It is anticipated that this situation may change in 2011 as Canada's first geothermal project (a co-produced fluids joint venture) comes online.

19.3.1.2 Total Electricity Generated

There is currently no geothermal electricity produced in Canada.

19.3.1.3 New Developments during 2009

In 2009 interest in Canada's geothermal industry enjoyed somewhat of a renaissance as membership in the Canadian Geothermal Energy Association (CanGEA) grew significantly and the government of British Columbia proposed a host of permit auctions to take place in 2010.

19.3.1.4 Rates and Trends in Development

Canada's geothermal industry is largely focussed on projects outside of Canada's borders. However, in 2009 the Toronto Stock Exchange (TSX) and Toronto Venture Exchange (TSX-V) continued to attract geothermal developers and service companies from around the world. This trend was supported by the Geothermal Code for Public Reporting which brought transparency and accountability to the industry and further supported investor confidence in the geothermal energy sector.

Table 19.1 Current active projects in Canada.

Project	Proponent	Location	Status
Swan Hills	Borealis Geopower	Alberta	Co-produced fluids project of 2 MW to be online in coming months
Pebble Creek	Gaea Energy	British Columbia	Under development
Canoe Reach	DeepRock Geothermal Inc.	British Columbia	Under development
Knight Inlet	Sierra Geothermal Power Corp	British Columbia	Under development
South Meager	Ram Power	British Columbia	Under development
Ft. Liard	Borealis Geopower	Northwest Territories	Feasibility study for 1 MW pilot project
Con Mine	City of Yellowknife	Northwest Territories	Feasibility study for district heating project

See Figure 19.2 for location of Provinces.

Figure 19.2 Provinces of Canada.

19.3.1.5 Number of Wells Drilled

Canada has yet to see a full-scale system production/injection well come to fruition but does have a number of test, slim-hole, and production wells in addition to active, retired, and abandoned oil & gas wells that are currently being evaluated for co-produced fluids and/or direct use applications. At the Meager Creek complex eight wells have been completed, some of which are productive and may be suitable for injection wells also. As of yet these are commercially unproven and remain inactive in any material capacity. Canada's oil & gas and mineral extraction industries have also left behind a legacy of wells that can provide accurate estimates of temperature gradients and subsurface formations and compositions that can now be employed for geothermal energy development.

19.3.1.6 Contribution to National Demand

It is estimated that Canada has a near-term potential of 5,000 MWe of conventional geothermal resources. With EGS technology this figure may be two to three times greater. Sadly, geothermal power has yet to contribute to the national demand and power production remained at nil for 2009.

19.3.2 Direct Use

In recent years Canada has steadily embraced heat pump technology. It is estimated that up to 50,000 residential and 5,000 commercial systems are currently installed (Thompson, 2010). The cost of installing these units, especially in building retrofits, is often prohibitive for the average consumer; however, federal and local subsidies have encouraged the adoption of such systems. The growth rate is estimated at 13%/yr, with recent rates being as high as 50%.

Heat pump technology has also been used in abandoned mines, starting as early as 1989 in the Springhill Mine of Nova Scotia where the heating and cooling provides savings estimated C$45,000/yr in energy costs. The City of Yellowknife in the Northwest Territories commissioned a study in 2007 to use water from an abandoned gold mine with a heat pump to provide district heating to the community, saving an estimated C$13 million/yr. This project has recently received federal funding in the amount of C$10 million. There are also 12 western hot springs used to heat swimming pools with individual flow rate of 6-32 l/s and total installed capacity of 10-15 MWt, plus a number of naturally occurring hot springs.(Lund et al., 2005).

Since, no specific data were available on the various Canadian geothermal uses, we estimate the following for heat pumps using a COP in the heating mode of 3.5, 3,000 full load heating hours per year, an average residential size of 12 kW, and commercial size of 100 kW, resulting in a total of 1,100 MWt and 8,487 TJ/yr. For the mine water the estimate is 11 MWt and 26 TJ/yr (Jessop, 1995), and for the 12 western swimming pool, 15 MWt and 360 TJ/yr. This gives a total of 1,126 MWt and 8,873 TJ/yr.

In British Columbia the government has lent support to the direct use geothermal energy industry through funding made available under the Innovative Clean Energy Fund (ICE Fund). Fairfield Propagators Ltd. won $1.26M in funding under the program for a unique demonstration project promoting the use of geothermal energy systems. The 12-acre greenhouse facility in Chilliwack - the largest lily and chrysanthemum grower in the province - currently uses natural gas and electricity for winter heating and summer cooling, which generates about 2,900 tonnes of greenhouse gas emissions and costs roughly $500,000/yr. The project will replace the current heating/cooling system with an open-loop geothermal energy heat pump system, using ground water at different temperatures to either heat or cool the buildings, minimizing GHG emissions and providing lower-cost energy. The project includes a demonstration component – the Geothermal Technology-Transfer Centre in order to showcase the process for greenhouse growers, businesses and institutions.

19.4 Market Development and Stimulation

19.4.1 Support Initiatives and Market Stimulation Incentives

Presently, financial incentives exist in Canada for the installation of low-temperature heat pump systems in homes and businesses, however there have been no measures aimed at stimulating growth in high-temperature geothermal power projects.

In an effort to improve the efficiency of heating older buildings, a homeowner or small business may qualify to have up to 25% of the cost of a heat pump system reimbursed by the federal government, to a maximum of C$50,000. Several Canadian financial institutions also offer favourable loan programs to finance the installation of heat pump systems, in consideration of the amount of time required to recuperate the initial investment cost.

Several federal and provincial government programs have been conducted in recent years to subsidize the production of electricity from renewable sources. Qualified producers of wind power, for example were eligible to receive a $10/MWh direct subsidy from the Federal Government, which has paid out C$254 million between 2002 and 2007. As of 2009, geothermal power had not been recognized in any of these subsidy programs, and the establishment of equal subsidy for geothermal power is a priority initiative in the Canadian geothermal community. To date the Wind and Solar industries have received in excess of $1.3B in government funding while proportional support for geothermal energy is yet to be seen.

19.4.2 Development Cost Trends

There is very little data available in Canada to derive trends in costs for drilling, exploration, and development. As more projects take shape more data will be available to support trends and provide industry averages.

19.4.3 Development Constraints

Currently there are a number of constraints to the development of Canada's geothermal energy resources. Perhaps most notable is the lack of education and awareness for the geothermal power sector which remains somewhat of a foreign concept to both Canadian citizens and politicians. Unlike other nations who have embraced geothermal energy for decades, the industry is still new to Canadians and holds a lower priority in the context of rich fossil fuel and hydro resources, not to mention a focus on wind and solar energy sources in the renewable energy sector. Transmission and power purchase agreements will likely also be a major concern for project development and affect project financings. The Canadian Geothermal Energy Association is working to pave the way for progressive policies in transmission access and clean power calls to enable the development of geothermal resources.

19.5 Economics

19.5.1 Trends in Geothermal Investment

2009 saw very little funds invested in geothermal research and development. It is anticipated that 2010 may see stronger support from federal and provincial governments under the Clean Energy Fund which is likely to fund one or two pilot projects for the industry.

19.5.2 Trends in the Cost of Energy

Energy prices vary widely across Canada ranging from 7-30 cents (US$) per kilowatt-hour. The top end of this range represents isolated power grids in Northern Canada where fossil fuels are flown in for power generation and heat. In other regions such as Labrador there is an overwhelming excess of power generation, much of which is exported to other provinces and/or the United States. The average price per kilowatt-hour is roughly 11 cents (US$).

19.5.3 Employment in the Geothermal Sector

Employment data for the geothermal industry has not been thoroughly evaluated. In the geothermal power sector there may be roughly 100 full time positions whereas the direct-use geothermal sector may approach 1,000 full, part-time, and contractor positions. In Canada there is a large discrepancy between the development of the near mature direct-use geothermal industry and the still infant geothermal power industry. This accounts for the large difference in employment statistics.

19.6 Research Activities

19.6 1 Focus areas

To date much of the research focus has been in regard to the heat resources of Canada with little attention paid to other factors such as hydrological or rock composition criteria which may be crucial to resource development. Going forward the industry will have to work with governments to focus their efforts on prominent areas of research that will benefit the industry's growth.

19.6.2 Government Funded

Canadian governments, both provincial and federal, have intermittently supported geothermal resource development for over 100 years. The first such projects supported through government initiatives related to direct use applications such as hot springs along the Canadian western railroad dating back to the late 1800s. As the railroad progressed west several naturally occurring hot springs were discovered and subsequently developed into world renowned tourist attractions. For much of the 20th century the focus would remain on developing hot springs for direct use applications for recreational and therapeutic use.

In the early 1980s, as energy prices soared, governments turned their attention to finding new and renewable source of energy. As such the Canadian federal government, through the Ministry of Natural Resources and the Geological Survey of Canada, initiated studies to explore Canada's geothermal energy potential for electricity production. Unfortunately, as energy prices returned to affordable levels this early exploratory work was abandoned and no formal report was published. For the most part Canada's geothermal power sector lay dormant for much of the following two decades while interest in the industry continued to grow outside of Canada's borders.

Today governments of all levels are keenly interested in examining the many benefits of adopting geothermal energy to meet increasing power and heating demands across the country. Three geothermal projects have recently received government funding for pilot demonstration projects and research initiatives.

19.6.3 Federally Funded Geothermal Projects

19.6.3.1 Ft. Liard, Northwest Territories

The Ft. Liard community-based geothermal demonstration project is a collaborate effort supported by the federal government, the Acho Dene Koe First Nation, and Borealis GeoPower Inc. The project is the first of its kind in Canada and is funded through the Natural Resources Canada Clean Energy Fund. Using existing well data from nearby abandoned oil & gas projects the project aims to generate both heat and power for the community of roughly 600 residents. This project will demonstrate how a northern community can use a geothermal resource to generate electricity and heat, thereby reducing the entire community's fossil fuel demand and energy costs. A successful demonstration will provide a model for other northern and First Nations communities with available geothermal resources. Federal project funding is in the amount of $10–$20 million. For additional information see; http://www.nrcan.gc.ca/media/newcom/2010/201001a-eng.php

19.6.3.2 Yellowknife, Northwest Territories

The Con Mine project continues forward on extensive preliminary studies that were conducted in 2007 to provide heat from the abandoned Con Gold Mine to the nearby city of Yellowknife. The City of Yellowknife, with support from the federal government is moving forward with the project and is now in the advanced stages of project engineering and planning. Using the relatively hot thermal resource of the deep mine the city plans to install a district heating system that will greatly reduce dependence on fossil fuel imports for residential and commercial heating. The project will be instrumental in paving the way for similar projects utilizing deep ground source and aquifer thermal resources to provide heat for the surrounding community. Federal project funding is in the amount of $10–$20 million. For additional information see; http://www.nrcan.gc.ca/media/newcom/2010/201001a-eng.php

19.6.4 Provincially Funded Geothermal Projects

19.6.4.1 Swan Hills, Alberta

The Swan Hills project is a collaborative effort between Borealis GeoPower, Free Energy, and the Alberta government. The project goal is to research the effective utilization of geothermal energy from deep oil and gas wells in the Canadian Foothills for the production of electrical power. Relatively hot fluids being extracted from the well are sent through a heat exchanger to harness the thermal energy of the well to generate electric power. The Alberta Energy Research Institute has contributed $2.6 million to the project under the Clean Air and Climate Change Technology and Innovation Program. This pilot project could have major benefits for Alberta's many active and retired oil & gas wells as well as the oil sands. Provincial project funding is in the amount of $2.6 million. For additional information see; http://www.borealisgeopower.com/expertise/details/co-production-geothermal-from-waste-water/

19.6.4.2 Whitehorse, Yukon Territory

Yukon Energy and the City of Whitehorse have initiated a project to examine the potential for geothermal energy exploration and development for the City and Territory. Funded in part by the Yukon Cold Climate Innovation Centre and Yukon Energy the project will look at opportunities to utilize the surrounding naturally occurring hot springs and reservoirs to provide heating and/or power for the community of Whitehorse. The project will test the use of remote sensing satellite imagery and infrared thermal sensors to find sites where geothermal resources exist. This research will help narrow the search for the best possible drill sites and most economically feasible projects which could result in major cost savings for the City and the Territory in the future. For more information please see http://www.yukonenergy.ca/news/releases/archive/77/.

19.6.5 Industry Funded

N/A

19.7 Geothermal Education

Education and awareness continues to be a major focus for the industry and the Canadian Geothermal Energy Association. In 2009 the Association participated in a number of outreach activities to support this effort in partnership with communities and provincial administrations.

19.8 International Cooperative Activities

The Canadian geothermal industry was active in a number of international conferences and summits in 2009 and also hosted the Second Annual Geothermal Conference in Vancouver in April 2009. Going forward the Canadian geothermal industry will continue to leverage the experience and developments of more progressive nations to help foster the development of Canada's domestic geothermal resources.

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Sponsor Activities

Chapter 20

Geodynamics

Figure 20.3 1 megawatt power station at Habanero (see turbine in Figure 20.4).

20.0 Introduction

Geodynamics Limited is a public company limited by shares, incorporated and domiciled in Australia. It listed on the Australian Securities Exchange on September 2002. Geodynamics has a specific focus on the economic extraction of heat from hot rocks using enhanced geothermal systems (EGS) technology. Geodynamics' vision is to become a world-leading Australian geothermal energy company, supplying competitive zero-carbon energy and baseload power.

Geodynamics is Australia's most advanced geothermal energy developer. While the Company holds geothermal exploration licences in South Australia, New South Wales and Queensland, the majority of efforts are currently focused on extracting heat from its geothermal tenements near Innamincka in South Australia, where high-heat-production granite buried 3.6-4 km beneath the Cooper and Eromanga Basins approaches temperatures of 280°C at 5 km depth.

20.1 Highlights for 2009

Savina 1 well was drilled into granite at a depth of 3,615 m and intersected an overpressured fracture at 3,700 m. Testing of the fracture pressure indicated that the overpressure was quite similar to that at the Habanero field 19 km to the east (34 MPa at surface with a water column) and the fluid composition was also similar, being high in elements associated with fractionated granites (Li, B, Rb, Cs). Unfortunately the high overpressure resulted in the drill string becoming differentially stuck in normally pressured sediments higher up the well. Eventually the drill string had to be parted immediately above the bottom hole assembly, and the well had to be suspended with cement plugs.

In March 2009, Geodynamics announced "Proof of Concept" after demonstrating its ability to extract heat from hydraulically stimulated hot fractured rock to create power. The achievement was a major landmark, and marked the completion of Stage 1 of the Company's business plan. In achieving "Proof of Concept" the company has demonstrated the following key elements:

- Resource definition
- Ability to drill and complete wells
- Ability to hydraulically stimulate fractures
- Ability to develop a substantial enhanced reservoir volume
- Achievement of well productivity and injectivity
- Confirming fluid circulation between production and injection wells
- Forecasting resource degradation
- Mitigation of currently identified operational constraints
- Absence of adverse environmental impacts

The closed loop test reported in the 2008 Annual Report was the culmination of 6 years of work by Geodynamics in demonstrating all of the above elements.
On 24 April 2009 at 10:48:44 UTC the casing of the Habanero 3 production well failed close to the surface (Figures 20.1 and 20.2). The well was killed with mud and then cemented on 21 May 2009. An external review of the failure suggested that hydrogen embrittlement of the high strength casing occurred in the top 6 m of the well. The failure resulted in the deferral of activities on the Pilot Plant and a long delay to further activities in the other two locations in the Innamincka area at Jolokia and Savina.

Figure 20.1 *Habanero 3 well failure April 2009.*

Figure 20.2 Habanero 3 kill operation May 2009.

Figure 20.4 1 megawatt power station at Habanero.

Construction of the Innamincka 1 MW Pilot Plant (Figures 20.3 and 20.4) was completed in April 2009, and "Hot commissioning" was due to commence on 27 April, three days after the Habanero 3 production well failure. Work on the overhead power line between the 1 MW Pilot Plant and the township of Innamincka was completed. Geodynamics received a grant of A$ 560,000 in relation to the construction of the power line, from the Regional Development Infrastructure Fund, an initiative of the South Australian Government.

On 6 November 2009, the Australian Government informed Geodynamics that the Company's application for A$ 90 million (M) funding under the Renewable Energy Demonstration Program (REDP) was successful. The funding will be staged over the life of a Commercial Demonstration Plant (CDP) with the final grant payment to be received following the commissioning of a 25 MW geothermal power plant in the Cooper Basin. The principal objective of this CDP is to demonstrate cost-effective technology at a commercial scale to give lenders confidence to finance the commercial roll out of subsequent units and transmission lines. The REDP grant provides 30% funding for the cost of drilling six wells, a 25 MW power plant, and its connection to the wells. There is currently no commercial load for such a plant and Geodynamics is actively considering a number of options for power off-take. One of these options is to build a co-located computer data centre.

On 14 December 2009, Geodynamics announced that the Australian Government had awarded A$ 7 M in funding under Round 2 of the Geothermal Drilling Program. The funding has been granted for the development of the Company's Hunter Valley geothermal project in New South Wales and is additional to a A$ 10 M grant also received 2009 under the NSW Climate Change Fund Renewable Energy Development Program. The Hunter Valley project envisages two wells drilled into granite below 4,000 m and the construction of a power station connected to those two wells.

The company's cash position at the end of December 2009 stood at A$ 91.9M.

20.2 Status of Company's Geothermal Activities in 2009

Geodynamics spent a considerable time re-assessing its operations in the light of the Habanero 3 well failure. The Jolokia 1 and Savina 1 wells, 9 and 19 km west of Habanero, respectively, proved similar conditions in the granite. Their casings are identical to the failed casing at Habanero 3, and had to be regarded as suspect. The Jolokia 1 stimulation required a re-design.

Apart from securing the Habanero 3 well failure in May 2009, the only field activity carried out in 2009 was the logging of Jolokia 1 in April. The drilling rig was re-deployed at Jolokia 1 to attempt tubing conveyed image logging of the open hole section from 3,750 m to 4,911 m. An aluminium shroud was built so that drilling mud could be circulated approximately 400 mm above the imaging tool window with the window covered by a conventional Teflon mud excluder. The logging tool was rated to 205 °C and it was expected that initial cooling of the well by circulation followed by circulation around the shroud would provide a successful logging outcome. Unfortunately the tool was unable to record below 4,170 m where the temperatures at the shroud exit and the bottom of the tool 900 mm below were 170 °C and 240 °C, respectively.

20.3 Planned Activities for 2010 and Beyond

The Company focus is now on Stage 2 of its three stage business plan delivering power through the commercial scale demonstration plant (CDP). The power produced through the commercial demonstration plant may be used to power up a co-located data centre. Following that, Geodynamics is targeting production of more than 500 MW by 2018 (Stage 3 of the business plan). Eventually output could reach 10,000 MW giving the Innamincka granite a justifiable claim as a great Australian resource.

The drilling rig remained set-up on site at Jolokia 1 after the operations in 2009, in preparations for further logging, the setting of a liner across the upper part of open hole to a depth of 4,350 m and the stimulation of the well below 4,350 m to be carried out in 2010.

The stimulation of Jolokia is designed to take place at two levels and relies significantly on the results for the stimulations at Habanero where the reservoir developed as a sub-horizontal layer approximately 3 km by 1.5 km in the granite at 4,250 m as determined by microseismic returns. The first reservoir will be developed during the Jolokia 1 stimulation in 2010, and the second reservoir is expected to be developed from Jolokia 2 unless packers or other isolation methods are qualified for the temperatures and pressures in Jolokia 1.

There is also a requirement by the market and the government to bring the 1 MW power station into operation as soon as possible. The company is considering the most cost-effective way to achieve this requirement.

20.4 Comments on the Geothermal Market Opportunities and Constraints

20.4.1 Marketing Initiatives and Market Stimulation Incentives

The Federal Government's Renewable Energy Demonstration Program, and its Geothermal Drilling Program have stimulated geothermal activity in 2009, but the results of these programs have not yet come to fruition.

20.4.2 Development Cost Trends

In a rather subdued year Australian geothermal suffered two setbacks in 2009, the first was related to the Habanero 3 well control incident, and the second was the failure of the Copenhagen Climate Change summit. There were no major operational advances in geothermal programs other than the drilling of the Petratherm Paralana 2 well. Cost reduction, particularly drilling costs, still remains the focus so that EGS becomes competitive with fossil fuel electricity generation.

20.5 Company's Research Activities (where they can be disclosed)

In April 2009, Geodynamics announced it would provide A$ 5 M over 5 years for technology advancement. This has been called its Geothermal Technology Plan. Sub-surface technologies of drilling performance improvement, high temperature logging, fracture understanding and stimulation optimization are a focus. However, a number of surface technological improvements to increase generation efficiency are also being targeted.

The following technologies are being developed/deployed over the next 18 to 24 months:

- High temperature image logging for prospective fracture zone identification
- Preferential stimulation (controlling where stimulation occurs) including the science behind fractures and frequency of fractures within the granite
- Down hole isolation
- High temperature elastomers

- Multi-fracture drilling in overpressured environment
- Drilling technologies such as impact drilling and thermal spallation

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Sponsor Activities

Chapter 21

Geothermal Group-
Spanish Renewable Energy Association

21.0 Introduction

21.0.1 General Description of Organization and its Activities

The Spanish Renewable Energy Association, APPA, is a National Association that represents close to 500 producers, businesses and other associations in the Spanish renewable energy sector. Its role is to coordinate, to represent and to defend the interests of the sector in politics, civil society and the media, as well as to participate in the development of Spanish energy and environmental policy.

APPA is divided in nine departments, covering all the renewable technologies: Biofuels: Bioethanol and Biodiesel, Biomass and Biogas, Wind Energy, Small-scale Wind Installations, Solar Photovoltaic, Solar Thermoelectric, Hydropower, Marine Energy and Geothermal Energy (High and Low Enthalpy).

At the beginning of 2007, APPA set up the High Enthalpy Geothermal Department, and since 2008 is setting up the Low Enthalpy Geothermal Department. The creation of both departments is a result of the interest shown by private entities in the Spanish geothermal potential. Now the High Enthalpy Geothermal Department has 11 companies as members and the Low Enthalpy Geothermal Department has 18.

21.0.2 Mission Statement and Strategic Objectives

According to APPA companies these are the strategic objectives broken down into both departments:

- Low Enthalpy Geothermal Department objectives:
  - To boost and to spread geothermal technologies in institutions
  - To coordinate the different Spanish Autonomous Regions with the aim they have similar requirements
  - To maintain contact with other European associations
  - To normalize the different types of implementation technologies
  - To make geothermal energy attractive to electricity companies and electricity consumers
  - To contribute in a positive way to electricity demand
- High Enthalpy Geothermal Department objectives:
  - To study Spanish geothermal resources status
  - To define basic exploration lines to improve the resource knowledge
  - To define specific investigation lines, feed-in tariffs and financing mechanisms to make geothermal business attractive in Spain
  - To study the legal framework applicable to the geothermal development
  - Spanish Geothermal RAP objectives

21.1 Highlights for 2009

2009 is the year prior to the publication of the new 2011-2020 Spanish Renewable Energy Plan (PER) and the new National Renewable Energy Action Plan (PANER). Each EU Member State must develop an Action Plan which must be submitted to the European Commission before the 30 June 2010. In Spain, the development of the new PER coincides with the National Action Plan.

The new PER 2011-2020 will go in depth into consolidated areas and it will incorporate other new ones, such as geothermal energy and its concrete objectives (thermal and electric objectives) by 2020.

It's an important priority for APPA to influence the Spanish Government to include geothermal objectives in the next PER 2011-2020 and in the PANER. Therefore, the APPA departments of High Enthalpy Geothermal and Low Enthalpy Geothermal departments have worked on proposals that reflect their position.

The APPA Low Enthalpy Geothermal Department makes its position and proposals following the analysis of the main problems hampering the development of low enthalpy geothermal energy use, classifying the problems related to resource use in those linked to energy conversion:

- Barriers to exploiting the resource
- Economic barriers

- Technological barriers
- Regulatory barriers

The APPA High Enthalpy Geothermal Department appointed GeoThermal Engineering GmbH (GeoT) and Sinclair Knight Merz (SKM) to undertake a study of the status of the geothermal resources in Spain and a detailed analysis of the support mechanisms which would stimulate the Spanish geothermal industry (Figure 21.1).

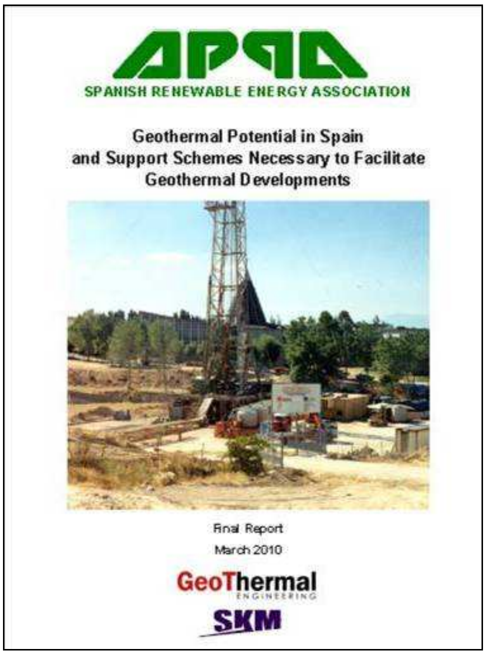

Figure 21.1 The APPA report on geothermal potential and necessary support schemes to facilitate geothermal developments in Spain.

The overall objective of the report is to propose appropriate and adapted support schemes suitable to stimulate the Spanish geothermal market in a way that can considerably contribute to Spain's climate goals by 2020.

21.2 Status of Organization's Geothermal Activities in 2009

21.2.1 APPA Low Enthalpy Technical Document

The APPA Low Enthalpy Geothermal Department produced a technical document, which analyzed in detail:

- Current status of the sector in Spain and Europe
- Analysis of geothermal resource
- Technological aspects
- Legal aspects
- Environmental issues
- Socio-economic aspects

- Barriers and measures associated with them to promote development
- Objectives 2020: power and energy data, avoided emissions and generating employment and investment partners
- The industrial sector in Spain
- Strategic research Lines

In order to provide this information to the Ministry of Industry, Tourism and Trade (MITYC) developed and agreed for the same low-enthalpy geothermal sector. The APPA Low Enthalpy Geothermal Department believes that the main activities within the sector should aim to achieve the following objectives:

- Consolidation of technology as a realistic alternative to conventional energies commonly accepted. To do so, such acceptance should be extended to all actors in the value chain that will require custom reasons based on the criterion of profitability that can be applied to each.
- Standardization of the technology base is founded on the application of geothermal energy, for which it is necessary to have legislation and specific technical standards for such technology.
- Regulation of the methodology to be applied by connecting all actors in the chain, which is essential for systems with certification.
- Training of all actors in the value chain, as a means towards achieving excellence in technology implementation, in order to generate confidence in it by all players: potential users, governments and others.
- Create and promote "know how" by the engineers, builders and rigs.
- Ensure the existence of after-sales service in Spain for all components (especially heat pumps) that are imported from other countries.
- Explanation of the technology to developers of buildings to create demand. Here also, as responsible for both infrastructure development and the associated financial risk, should be tax incentives (incentives, rebates, etc.). To encourage the installation of technology in all new construction work.
- Grants and support policies by the state and the autonomous communities to stimulate the market.

21.2.2 Study Undertaken by SKM and Geo-T

The study undertaken by SKM and Geo-T on behalf of APPA High Enthalpy Geothermal Department has the following main conclusions:

- **Geothermal Resources in Spain-** The geothermal resources in Spain are of three broad types:
  - High enthalpy (that is, high temperature, high pressure) active volcanic resources in the Canary Islands
  - Low enthalpy hydrothermal resources (sometimes referred to as Hot Sedimentary Aquifers) in a number of locations across the Mainland
  - Petrothermal resources, or EGS (Enhanced or Engineered Geothermal Systems), (where energy is stored in rock) at selected locations on the Mainland

  It is important to note that Spain's geothermal resources are currently not sufficiently well characterized to provide robust estimates of the country's geothermal potential. Therefore, adequate support measures to stimulate the geothermal sector should be designed to encourage increased exploration activity and improve the resource knowledge.

- **Support Measures to Stimulate the Spanish Geothermal Sector**

In Spain, power generation from geothermal resources is currently promoted through either a guaranteed feed-in tariff of 73.56 €/MWh for the first 20 years and 69.50 €/MWh thereafter, or a guaranteed premium which is paid on top of the spot market power price, the premium being 41.04 €/MWh for the first 20 years and 32.67 €/MWh thereafter. It is to be noted that currently there is no geothermal power generation and 20 MW_{th} of geothermal heat is produced in Spain.

The guaranteed feed-in tariff of 73.56 €/MWh in Spain is less than the EU-average for geothermal feed-in tariffs of 98 €/MWh and less than half that in countries such as Germany and the Czech Republic whose feed-in tariffs are 160 €/MWh and 173 €/MWh, respectively. It is to be noted that the feed-in tariff in Germany can be increased through a number of different bonuses: 40 €/MWh for plants which go into operation before year 2016; 30 €/MWh for Combined Heat and Power plants; and 40 €/MWh for plants that utilise petrothermal resources.

In order to determine the feed-in tariff that would stimulate the geothermal sector in Spain, the study estimates associated capital and operating costs and determines the feed-in tariff that would make the projects financially viable.

The analysis suggests that the feed-in tariffs required for geothermal projects to become financially viable are:

- 85 €/MWh for projects utilising high enthalpy resources
- 370 €/MWh for projects utilising low enthalpy resources
- A bonus of 40 €/MWh for petrothermal projects.

However, feed-in tariffs alone will not stimulate the geothermal sector. This is because tariffs cannot fully address the costs and risks associated with the drilling of the exploration wells necessary to prove that adequate resource exists to justify the development of a geothermal project.

A number of countries around the world (including Germany, France, USA and Australia) have developed exploration risk mitigation schemes to address these issues. Results to date indicate that these schemes have successfully stimulated activity in the geothermal sector.

In addition to an appropriate feed-in tariffs insurance scheme, the study recommends other support measures including: the development of between 5 and 10 demonstration projects which would be 50% grant-funded by Government; drilling grants for pure heat projects; research and development programs; and improvements to the regulatory regime.

- **Geothermal Potential of Spain by Year 2020**

If the support measures described above were implemented it is estimated that there would be about 1,050 MW_e power generation and about 700 MW_{th} heat production by 2020. Geothermal power generation by 2020 is expected to comprise ~260 MW of plants utilising high enthalpy resources, ~550 MW of plants utilising low enthalpy resources, and ~240 MW of EGS projects.

It is to be noted that these figures are consistent with the upper estimates for geothermal energy across EU Member States in 2020 that have been developed by the European Geothermal Energy Council.

21.3 Planned Activities for 2010 and Beyond

The Geothermal Department of the Spanish Renewable Energy Association, APPA, will continue working on the key aspects that will enable the development of geothermal energy in our country in agreement with the objectives considered. These aspects are:

- Promotion of geothermal energy through its inclusion in the new 2011-2020 Spanish Renewable Energy Plan (PER) and National Action Plan with the adoption of precise regulatory measures and the definition of pilot programs
- Updating and permanent management of the knowledge pertaining to the Spanish geothermal potential
- Development of RD&D programs that are adapted to the particularities of the sector in Spain, aimed at strengthening the innovation capacity through facilitating significant reductions in generation costs and increasing system efficiencies
- Development of training and certification model that covers the different spheres of geothermal energy

A number of different barriers have hindered the implementation of low enthalpy geothermal technology which has positioned us almost 20 years behind the most advanced European Union nations. Lower thermal demand and energy costs in Spain explain part of this lag behind other countries. The APPA Low Enthalpy Geothermal Department will work on this to achieve increased investment in low enthalpy geothermal energy so as to enable the development of projects that are economically viable, with the goal of reaching maturity in the sector.

The consultants' recommendation is for APPA High Enthalpy Geothermal Department to discuss the findings of the study with its members and with the Spanish Government in order to build support for a package of well-designed support measures (comprising feed-in tariffs, an insurance scheme, grant-assisted demonstration projects, drilling grants for heat projects, R&D programs and improvements to existing regulations) which will stimulate the geothermal sector and lead to strong growth in both geothermal power and heat by 2020. The APPA High Enthalpy Geothermal Department will begin working this year in that regard trying to show to different government bodies that high geothermal enthalpy can play a significant role on the Spanish energy mix if the above described support mechanisms are implemented within the next years and are included on the new renewable energy regional and national plans.

21.4 Comments on the Geothermal Market; Opportunities and Constraints

21.4.1 Marketing Initiatives and market Stimulation Incentives

From the Low Enthalpy Geothermal Department's point of view, the potential in the field of low enthalpy geothermal energy has an enormous reach. It is a renewable energy that is available, initially, at any site in which a building is planned for construction. The limitations that hinder the development of this technology in the market are mainly economic and are associated with the costs of implementation of the geothermal exchange system, the building's energy demand and energy prices.

The regional and national administrations must design and implement policies to promote and support the use of energy from renewable sources in heating and cooling, as established by the European Renewable Energy Directive (*Directive 2009/28/EC of the European Parliament and Council of April 23, 2009 on the promotion of the use of energy from renewable sources*).

These policies should aim to get more and more integration of geothermal energy in buildings so effective regulatory and remuneration frameworks must be promoted, stable over time and homogeneous for the different regions. They should also promote the general knowledge of the technology among professionals from the heating and cooling sector, the banks financing renewable projects, and civil society in general as end users.

From the High Enthalpy Geothermal Department's point of view, the geothermal resource potential of Spain is a great opportunity and it is stimulating companies to apply for geothermal exploration and investigation licenses in the country (more than 50 have being applied on the last years). Companies have undertaken important efforts in the last two years to develop exploration and investigation activities such geochemistry and geophysics, preparing projects for the drilling phase (some drilling activity is expected in Canary Islands for the middle of 2011).

On the other hand, the current lack of incentives for geothermal investigation in Spain and the administrative barriers on the mining licensing and environmental reporting application processes constitute significant barriers and therefore big constraints to the development of the industry. As explained above, the main Market challenge is to convince the institutions about the necessity of support mechanisms in the early stage of the investigation to stimulate the industry to develop the research activity prior to the project development.

21.5 The Organization's Research Activities

21.5.1 Spanish Geothermal Technology Platform- GEOPLAT

In recent times, a great interest in geothermal energy has awoken again in Spain. Aiming at identifying and developing sustainable strategies for the promotion and marketing of geothermal energy in Spain, and after taking the first steps at the end of 2008, the Spanish Geothermal Technology Platform- GEOPLAT (http://www.geoplat.org) was officially launched on 11 May 2009.

GEOPLAT is a scientific-technical sector coordination group consisting of all relevant stakeholders in the geothermal energy sector in Spain. All the activities carried out within the Spanish Geothermal Technology Platform, aim at providing a framework within which, all sectors involved in the development of geothermal energy, lead by industry, work together in a coordinated way to ensure the commercial acceptance of this renewable energy and its continuous growth, in a competitive and sustainable form.

GEOPLAT covers all R&D activities in terms of identification and evaluation of resources, as it covers the use of this renewable energy and its technology.

The activities of the Spanish Geothermal Technology Platform are subsidized by the Spanish Science and Innovation Ministry. Also, it has the support of the Spanish Institute for Diversification and Saving of Energy- MITYC (IDAE) and the Spanish Center for Industrial Technology Development (CDTI). The GEOPLAT Secretariat is managed by the Spanish Renewable Energy Association, APPA, within its two geothermal departments (High and Low Enthalpy Geothermal Departments).

In 2009, GEOPLAT was set in motion, and as the number of participating entities gradually increased, they started to work hard to meet their objectives. To that end, the Spanish Geothermal Technology Platform, in the same manner as other technology platforms, has set a work programme over its first months of existence consisting of the elaboration of two important documents: one on the state of the art of the Spanish geothermal sector and the vision for 2030, and following this, the other defining the Strategic Research Agenda for geothermal energy in Spain.

Throughout this year, each GEOPLAT Working Group has contributed to the elaboration of the *Document of Vision for 2030*. It provides an exhaustive analysis of the Spanish geothermal sector (background and current situation, potential, technologies, etc.), and points out the most relevant challenges and opportunities for the future. Moreover, two vision scenarios are presented for 2020 and 2030.

GEOPLAT is also taking part in collaborative activities with other technology platforms in Spain and Europe. The most GEOPLAT-linked Spanish technology platforms are the CO_2 Spanish Technology Platform (PTE-CO_2), the Energy Efficiency Spanish Technology Platform (PTE-EE) and the Construction Spanish Technology Platform (Construcción 2030).

Furthermore, GEOPLAT is playing important roles in the European geothermal scene, collaborating from the beginning with two technology platforms, helping to define their structures and design their strategic research guidelines, contributing with contents and supporting all the important initiatives they lead.

In addition, at about the same time GEOPLAT was founded, the Renewable Heating & Cooling European Technology Platform (RHC-ETP) was launched, promoted by the Energy and Transport General Directorate of the European Commission. There are four panels in the RHC-ETP: biomass, solar thermal, geothermal and cross-cutting panels. In 2009, GEOPLAT achieved the Vice-Presidency of the Geothermal Panel.

GEOPLAT also participates actively in the Geothermal Electricity Platform GEOELEC (promoted by the European Geothermal Energy Council- EGEC) since it was created at the end of 2009.

The objective of these platforms is to provide a framework within which all the different stakeholders involved in renewable heating & cooling and also electricity generation from geothermal resources can work together in order to identify their needs on RD&D and convey their conclusions to the European Union administrations so that they will be taken into account in R&D plans design, research funding, etc.

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Sponsor Activities

Chapter 22

Green Rock Energy

Figure 22.1 *Drilling to 1000 m to heat pool in Perth.*

22.0 Introduction

Green Rock Energy Limited is a public company listed on the Australian Securities Exchange with a focus on developing geothermal energy in Australia and abroad. In the near term, the Company aims to develop two commercial demonstration projects from geothermal energy recovered from sedimentary aquifers. One project is in the central Perth Basin (direct uses) in Australia and the other in Hungary (electricity and direct uses).

For both projects there is evidence from previous petroleum wells that suitable temperatures can be obtained at reasonable target depths. The main challenge for both projects involves proving there is sufficient permeability at those depths to recover geothermal energy at a commercial flow rate for over 20 years. To assist in resolving these issues Green Rock Energy is participating in GIA Annexes III (Enhanced Geothermal Systems), VII (Advanced Geothermal Drilling Techniques) and VIII (Direct Uses).

22.1 Commercial Demonstration Projects

22.1.1 Perth Basin, Western Australia

Green Rock's first project in the Perth Basin is located at the main campus of the University of Western Australia within permit GEP1, the first geothermal exploration permit to be granted in the State of Western Australia. The permit is located in Perth. This commercial demonstration project is designed to air-condition the University campus by replacing a substantial portion of the University's electrical powered compression chillers with geothermal powered absorption chillers. Subject to proving commercial viability, the Company plans to be in production in 2012. This will be the first step towards replicating the concept on a larger scale throughout the metropolitan area of Perth where the Company holds exclusive geothermal rights over an area totalling around 685 km^2.

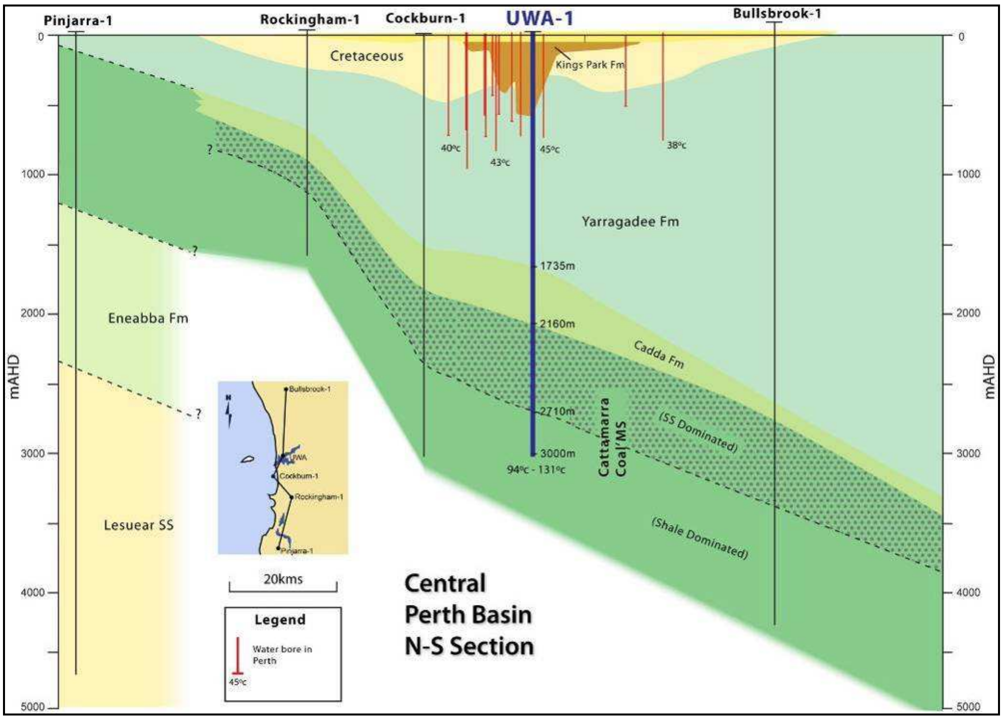
Perth is in an advantageous location. It is Australia's fastest growing city and the main logistical hub for Australia's burgeoning mining and petroleum industries. Perth is located within the Perth Basin where geothermal water at suitable temperatures for commercial scale air-conditioning and district heating is likely to be contained in hot sedimentary aquifers at depths less than 3 km. This geothermal heat has the potential to be employed on a substantial scale across the city.

The Perth Basin is a 1,000 km long extensional rift, or half graben, containing a thick pile of sediments in places over 15 km thick. Heat flows are highest in the northern Perth Basin. In the central Perth Basin, near the city of Perth, the sediments are around 10 km thick and include a number of extensive hot sedimentary aquifers. Low temperature geothermal energy, at temperatures of around 40 to 45 °C, extracted from Yarragadee sandstones from depths of 750 m to 1000 m is being recovered and used to heat a number of Olympic sized swimming centres in permit GEP1 (Figure 22.1, introductory Chapter photo). But it is the medium temperature

Figure 22.2 *Broad Absorption Chiller Package.*
(Photo courtesy of ETS)

geothermal resources that make exploitation of geothermal energy from the central Perth Basin attractive for commercial scale cooling and district heating. Temperatures of around 80 to 100 °C are expected from formations at depths around 2500 to 3000 m near Perth. This is sufficient to power absorption chillers directly for air-conditioning on a commercial scale (Figure 22.2).

The challenge is to prove sufficient permeability at these depths. While there is evidence of good permeability from petroleum wells located on the outskirts of Perth, the deepest drilling in Perth only extends to around 1,300 m. Green Rock Energy plans to drill one production and one injection well at the Crawley campus of the University of Western Australia (UWA) to around 2 to 3 km deep to recover geothermal energy from sandstone aquifers. Aquifers will be assessed in sandstones from the Yarragadee, Cadda and Cattamurra formations.



For this purpose the Company has been offered a grant of A$ 7 million (M) under the Australian Government's competitive bidding process, to assist it to drill the wells and carry out flow testing. Site work and well design will commence once the Company executes the agreement in 2010, with the Australian Government to enable this drilling to be carried out in the first half of 2011.

22.1.2 Hungary

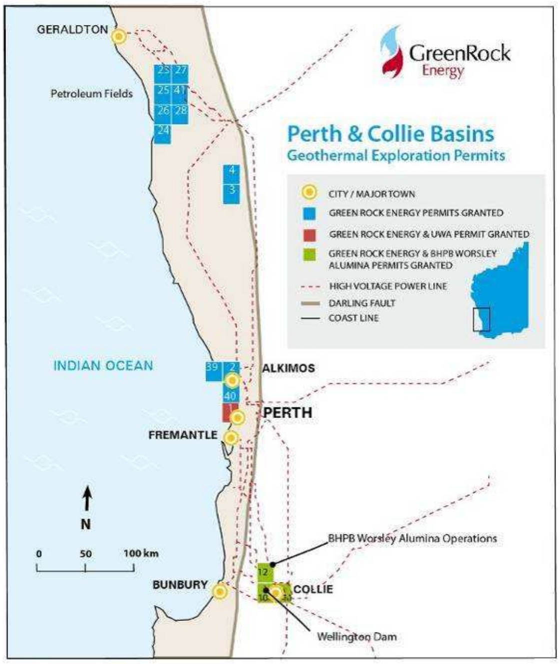
Well testing planned for October 2010 targets the first commercial project for Green Rock Energy in Hungary. A petroleum well drilled in recent years which recovered water around 140 °C has been selected by Central European Geothermal Energy (CEGE) for testing for geothermal water production for electricity generation and direct heat use. CEGE is a company in which Green Rock and its co-venturer MOL, Hungary's largest company, each hold a 50% interest. The well testing program was designed for CEGE by Green Rock's director Dr Jörg Baumgärtner.

Testing of the well is planned for October 2010. The geothermal water to be tested occurs in Triassic carbonate sediments at a depth of around 2,500 m where geothermal water temperatures are sufficient for commercial electricity production in Hungary. This could lead to Hungary's first commercial scale geothermal powered electricity generation. Given success with the well testing, a second well will be designed and drilled to maximise geothermal energy production and the electricity generated from both wells from around mid-2012 will be sold into the nearby power grid under Hungary's feed-in tariff system without the need for any power purchase agreement. In Hungary, a feed-in-tariff applies to electricity produced from geothermal energy and a network of transmission lines is well established in Hungary. In contrast to this project, most existing geothermal energy production in Hungary is generally from shallower Pannonian age sediments where reservoir temperatures typically do not exceed 100 °C and is only used for direct heat purposes.

22.1.3 Other Activities

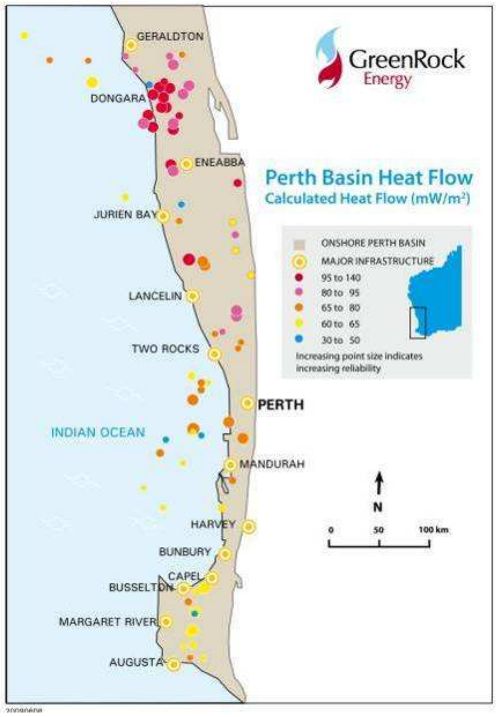
22.1.3.1 Northern Perth Basin, Western Australia

In the northern Perth Basin where the Company holds 9 Geothermal Exploration Permit areas totalling 2,637 km^2, Green Rock Energy aims to generate electricity from geothermal water recovered from hot sediments. Surface heat flows in excess of 100 mW/m^2 occur in these Permits. Temperatures in excess of 150 °C are expected in these areas at depths between 3,000 and 4,000 m, and should be suitable for commercial generation of electricity provided sufficient permeability can be proven. Since the Permits were granted in mid-2009, Green Rock Energy has been analysing temperature profiles from existing petroleum wells and re-entering deep water bores to determine heat flows and identify heat anomalies in the Permits. During the next year the Company will concentrate on measuring and mapping permeability within the regions of highest heat flows with a view to selecting drilling locations near existing power transmission lines for easy access to market.



22.1.3.2 Collie Basin, Western Australia

Exploration for geothermal energy resources commenced in the three geothermal exploration permits held in Collie Basin with BHP Billiton Worsley Alumina. Field work was mainly concentrated on locating and measuring sources of heat. This work will continue over the next year.



22.3.1.3 Olympic Dam, South Australia

At the Company's 100% owned Olympic Dam EGS project in South Australia, Green Rock has drilled into a massive inferred heat resource contained in hot granites and shown that hydro-fracturing will open up fractures in the extensive granite body. The Company plans to drill one production and one injection well and carry out fracture stimulation to connect them at depths ranging from 3.5 to 5 km in the thermally anomalous granite near our Blanche No 1 well. Green Rock Energy is seeking funding by way of a farm-in before it commences the deep drilling, fracture stimulation and flow testing for this proof-of-concept project.

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Sponsor Activities

Chapter 23

Ormat Technologies, Inc

27.5 MW gross Galena III Geothermal Power Plant, installed in 2008. Part of the 104 MW gross Steamboat Complex, owned and operated by Ormat, which supplies sufficient electricity for all households in Reno, NV. (Photo courtesy of Ormat Technologies)

23.0 Introduction- Ormat Technologies, Inc.

Ormat Technologies (NYSE:ORA) is a leading vertically integrated company engaged in the geothermal and recovered energy power business. The company has over four decades of ORC experience and 25 years of geothermal applications.

Ormat explores, develops, designs, builds, owns and operates clean, environmentally friendly geothermal and recovered energy-based power plants. In addition, Ormat also designs, manufactures and sells power units and other power generating equipment for geothermal and recovered energy-based electricity generation for third parties.

As of November 2010, Ormat owns and operates approximately 538 MW of geothermal (including the 50 MW North Brawley project in California, which currently operating at an average of about 25 MW) and recovered energy generation (REG) facilities including approximately 367 MW of geothermal and 53 MW of REG in the United States. In total, Ormat has built approximately 1,300 MW of geothermal, REG, and solar installations worldwide, in 24 countries. Geothermal represents over 90% of the total installation.

In the U.S, Ormat has deployed approximately 70% of the geothermal capacity installed since 2000.

Figure 23.1 *Fall 2009: 49.5 MW Faulkner I "Blue Mountain" Geothermal Power Plant – Humboldt County, Nevada. EPC Contractor- Ormat; Owner & Operator- Nevada Geothermal Power Company. (Photo courtesy of Ormat Technologies)*

Ormat has grown to a team of over 1,000 employees worldwide, with approximately 470 in the United States.

23.1 New Projects

Ormat is well positioned for future growth and plans to continue building a geographically balanced portfolio of geothermal, recovered energy assets, solar photovoltaic (PV) systems and remote power solutions, while maintaining its position as a leading sustainable energy manufacturer, product innovator and service provider.

In 2008 and 2009, Ormat added approximately 240 MW of gross geothermal capacity and 67 MW of gross REG capacity worldwide; approximately 60% of which is owned and operated by Ormat.

Ormat's current portfolio drives profitable operations and financial stability. As of November 2010, Ormat owns a total of 538 MW of geothermal and recovered energy generating capacity in the United States, Nicaragua, Kenya, and Guatemala. Between 120 and 130 MW are currently under construction, and additional 138 MW are currently under various phases of development. Ormat also plans to add 38 MW from solar PV installations.

The same type of ORMAT ORC power technology is used for both geothermal and REG. Examples of some of the 2008 and 2009 projects are shown below in Figures 23.2 and 23.3.

Figure 23.2 *35 MW net Phase II of Olkaria III Geothermal power plant at Kenya, installed in 2008. (Photo courtesy of Ormat Technologies)*

Figure 23.3 *OREG 2- Recovered Energy Generation power plant in North Dakota. (Photo courtesy of Ormat Technologies)*

23.2 Revenues

2009 was a successful year for Ormat led by record revenues and exceptionally strong results from our Product Segment business, and consistent results from our Electricity Segment. More specifically, total revenues increased year-over-year by 20% to US$ 415.2 million (M), which included $159 M in revenues from our Product Segment (Figure 23.4).

While we do not expect Product Segment revenues to continue at this level in 2010, we continue to see growth opportunities in that segment in the years to come.

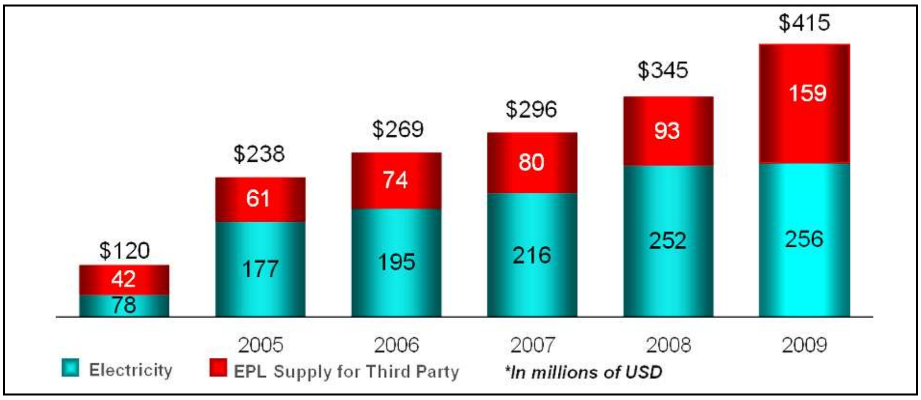

Figure 23.4 *Ormat's revenues continue to grow.*

Figure 23.5 *The Dora 2 Geothermal Power Plants, in Salavatli, Turkey; Ormat supplied the generating unit and technical assistance for Dora 1and 2, while Mege built, commissioned and operate the two units. Dora 1, 7.35 MW, was built in 2006, while Dora 2, 11.2 MW, was built in 2009. (Photo courtesy of Ormat Technologies)*

23.3 Resource and Project Development

Ormat is engaged in the largest effort undertaken by a single company, within the last 20 years, to categorize, map, sample and drill Greenfield prospects in the US.

Ormat has a dedicated staff of geologists, resource engineers and drilling engineers to confirm and develop new geothermal fields.

Ormat has various leases and concessions for geothermal resources of approximately 300,000 acres in 30 sites located in Alaska, California, Nevada, Hawaii, Oregon, Idaho, Utah and Guatemala.

Ormat started or plans to start exploration activity at a number of these sites that will support its future growth.

We are actively pursuing additional land in these and other states where prospective geothermal resources remain untapped.

Ormat's in-house drilling company, GeoDrill, has over 100 employees and four rigs with capability to drill down to 18,000 ft (Figure 23.6).

Figure 23.6 *One of GeoDrill's rigs.*
(Photo courtesy of Ormat Technologies)

23.4 Research and Development

23.4.1 Co-production of Electricity at Oil and Gas Fields

Ormat, in a joint project with the Department of Energy (DOE) at the Rocky Mountain Oil Test Center (RMOTC), validates the feasibility of proven technology already used in Geothermal and REG for the production of commercial electricity using hot water produced during the process of oil and gas field production (Figure 23.7). This project marks the first of its kind by providing on-site fuel free power that will increase the productivity and possibly extend the longevity of existing US oil fields.

The oil fields in the United States could provide an additional 200 to 5,000 MW of electricity through this technology, according to United States Senator Mike Enzi (Wyoming). The Ormat ORC unit being used (Figure 21.6) is similar to the 250 kW_e air-cooled unit that has been producing electricity from 210 °C geothermal water at an Austrian resort since 2001.

Additionally, there are similar units in Nevada (700 kW_e) and Thailand (300 kW_e) which have been in continuous commercial operation without overhaul since 1984 and 1989, respectively.

Figure 23.7 Hot water co-produced from oil wells at the Rocky Mountain Oilfield Testing Center (RMOTC), Wyoming, USA (2008). (Photo courtesy of Ormat Technologies)

23.4.2 Enhanced Geothermal Systems (EGS)

21.4.2.1 Desert Peak

Ormat is also working with research institutions to create an engineered geothermal system (EGS) at our Desert Peak geothermal field in Northern Nevada (Figure 21.8). Ormat currently operates a 14 MW geothermal power plant at Desert Peak. Heat flow through the field is significant and temperatures in excess of 200 °C have been measured at relatively moderate depths. However, these heat anomalies lack interconnectivity with the existing geothermal reservoir. Thus, much of the heat energy in the field cannot be captured through conventional hydrothermal technology. For this reason, this project serves a dual purpose. This project serves to move forward scientific understanding and applied technology by employing and practicing advanced methods to help commercialize EGS technology. Because this project is being tested at an existing geothermal field, a successful EGS could be quickly adapted to additional generation capacity for commercial sale.

23.4.2.2 Brady

The US Department of Energy (DOE) has once more chosen Ormat to demonstrate the viability of Enhanced Geothermal Systems (EGS) with a grant for US $3.4 M to improve hot, non-commercial wells located within a stress environment and in formations favourable for permeability enhancements using EGS techniques.

Ormat, the DOE, GeothermEx Inc. and other stakeholders will apply EGS stimulation techniques at Ormat's Brady facility near Reno, Nevada, to develop fracture networks that will enable currently non-commercial wells to communicate with the productive reservoir and enhance generation.

Ormat technology has been applied to another commercial project with EGS injection in Landau, Germany, where a 3.2 MW power plant has been in operation for more than a year (Figure 23.8).

Figure 23.8 *The 3.2 MW Landau Geothermal Power Plant is the first commercial plant in Germany, and the first implementation of EGS technology in an injection well. (Photo courtesy of Ormat Technologies)*

23.5 Corporate Responsibility

Ormat's main focus is on education; from the primary schools in the communities surrounding our plants in Kenya and Guatemala to our support to students and research initiatives in universities, primarily in Nevada.

Figure 23.9 *Ormat's CEO with the Maasai community member in the inauguration ceremony of the Olkaria III Power plant in Kenya (Photo courtesy of Ormat Technologies)*

Ormat also works at creating long-term, positive relationships with the many stakeholders who have an interest in our geothermal and recovered energy power plants. To encourage ongoing connection, Ormat reaches out to stakeholders with an array of communications tools and initiatives which provide our stakeholders with transparent and timely information about our operations and development plans. Outside the US, Ormat also supports initiatives to improve the livelihood of the communities with support to health, community activities and local organizations (such as fire departments).

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Appendix A- Participants at 21st ExCo Meeting, Madrid, Spain

(Photo courtesy of Yoonho Song)

Appendix B- Participants at 22nd ExCo Meeting, Reno, USA

(Photo courtesy of Hirofumi Muraoka)

Appendix C IEA-GIA Executive Committee as of December 2009

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