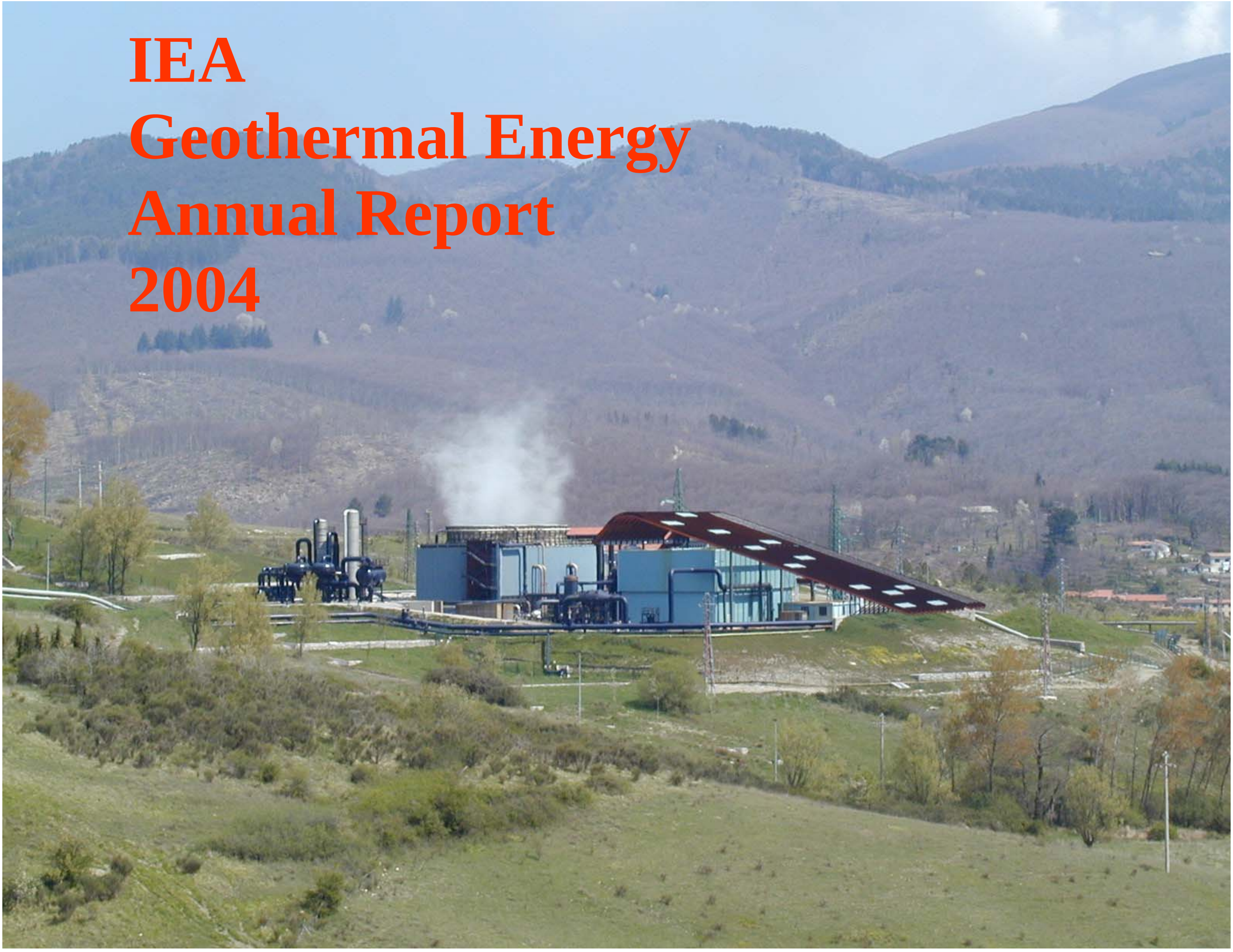
IEA Geothermal Implementing Agreement

INTERNATIONAL ENERGY AGENCY

IEA
Geothermal Energy
Annual Report
2004



International Energy Agency (IEA)
Executive Committee for the
Implementing Agreement for
Cooperation in
Geothermal Research and Technology

August 2005

CONTENTS

Website for further information on the IEA GIA: http://www.iea-gia.org/

Cover Photograph: The 20 MW_e Bagnore 3 geothermal power station in Tuscany, Italy. The facility at the left is the AMIS abatement system for H_2S and mercury removal. (Photo by Aldo Baldacci)

I. EXECUTIVE SUMMARY

MESSAGE FROM THE CHAIR

The Executive Committee (ExCo) of the Geothermal Implementing Agreement (GIA) initiated the year 2004 with a revised strategic plan, which sets its general objectives and strategies to the end of the GIA's current term and possibly beyond. While the joint planning and execution of R&D programmes remain the core of its activities, substantial attention will be given to other means of promoting the worldwide utilization of geothermal resources for primary energy.

In the R&D front, specific projects included in the various Annexes reported very important accomplishments during the year 2004. Annex I to the GIA, which covers the first area of concern agreed to be addressed jointly, namely the environmental issues associated with the exploitation of geothermal resources, completed the compilation of papers to be published in a Special Issue of *Geothermics* in early 2005. Another Special Issue with results derived from Annex I was published by the same journal in 2000. In another line of research, the Hot Dry Rock (HDR) project at Cooper Basin, Australia, where a reservoir at *ca* 4.4 km depth and temperatures of about 250 ^{o}C is being characterized, has scheduled a circulation test early on 2005. Likewise, the HDR Soultz-sous-Forêts project reported important advances in the development and characterization of the deep reservoir/heat exchanger (*ca* 5000 m depth) with measured temperatures in the order of 200 ^{o}C. These two projects look very promising and their success could herald a new era of Enhanced Geothermal Systems (EGS) that would expand the use of geothermal energy.

In 2004 the ExCo decided to address a new area of concern, namely that of seismic risk arising from fluid injection in EGS. As a result a new subtask was formally incorporated into Annex I, with participation of the European Commission, the USA and Italy. In addition, a new subtask dealing with field studies of EGS reservoir performance was initiated in Annex III. While other GIA efforts to promote the utilization of geothermal energy are no more important than the above R&D results and initiatives, perhaps they are more noteworthy because they represent steps taken along the new dimensions of the strategic plan.

During 2004, the GIA completed the revision and installation of its primary instrument for reaching the interested public, namely the GIA Webpage at: www.iea-gia.org. Through this website the GIA will make accessible information on its organization, activities and achievements; as well as make available a wide range of geothermal publications. In addition, the ExCo has made arrangements for the production of a GIA Brochure, which will be ready for distribution at the GIA booth in the Exhibition Area of the World Geothermal Congress 2005 being held in Antalya, Turkey, in April 2005.

Also along the new dimensions of the strategic plan, an informal partnership is evolving between GIA, the IEA Secretariat and the IEA Renewable Energy Working Party. The IEA receives the input of the GIA in the form of reliable and up to date information on geothermal technology and practices; conversely, the GIA utilizes IEA publications and forums to disseminate information and to put forward its recommendations for furthering the utilization of geothermal energy. Through this partnership, the common goal of justly and accurately portraying geothermal as a clean, competitive source of primary energy will be better accomplished.

David Nieva
Chairman IEA GIA

I. EXECUTIVE SUMMARY

INTRODUCTION

The IEA's involvement in geothermal energy began in 1978, with the launching of the "Man-Made Geothermal Energy Systems" Project (MAGES) Implementing Agreement (IA) in the IEA Energy Technology Collaboration Programme (ETCP). One year later, the "Geothermal Equipment Testing" IA began. However, upon the completion of these two 3-year long studies, there was a hiatus in geothermal activities until the IEA Secretariat in Paris initiated an effort to revive them in 1995.

In May 1995, an *ad-hoc* meeting was convened in Florence, Italy, in conjunction with the World Geothermal Congress'95, where representatives of 14 countries expressed general interest in international collaboration under the IEA ETCP umbrella. An IEA Geothermal Expert Panel was formed specifically to prepare the IA Annexes. The legal text and three technical Annexes of the IEA Implementing Agreement for a Cooperative Programme on Geothermal Research and Technology, or Geothermal Implementing Agreement (GIA), were formulated in two subsequent meetings in Paris (November 1995, April 1996) with significant assistance from the IEA Secretariat. The GIA officially went into effect on 7 March 1997, with an initial operating period of five years. In late 2001, the Agreement was extended for a second 5-year term, to 31 March 2007, with the approval of the Renewable Energy Working Party (REWP) and the IEA Committee on Energy Research and Technology (CERT).

The GIA provides an important and flexible framework for broad international cooperation in geothermal R & D, which seeks especially to overcome barriers to the development of geothermal energy utilization. Important national programmes are brought together with a focus on assembling specific know-how and generating synergies by establishing direct cooperative links among geothermal experts in the participating countries (Table ES1).

GIA activities are directed primarily toward the coordination of the ongoing national activities of the participating countries, and encompass a range of geothermal topics, from "traditional" uses such as power generation and direct use of heat, to new technologies pertinent to enhanced geothermal systems (EGS) and deep resources. New activities are also initiated and implemented when needs are established.

THE OBJECTIVES AND NEW STRATEGIC PLAN

The GIA's first Strategic Plan, produced at its formation in 1997 as a guide for the first 5-years of operation, identified the organization's goal as: *to encourage and support the worldwide use of geothermal energy*. To attain this goal, major objectives were set and included: to *conduct international collaborative efforts to compile and exchange improved information* on worldwide geothermal energy research and development concerning existing and potential technologies and practices; to *develop improved technologies* for geothermal energy utilization; and to *improve the understanding of the environmental benefits* of geothermal energy and methods to avoid or ameliorate its environmental drawbacks.

Though these efforts kept the GIA on track for its initial years, the dynamic nature of its operating environment became apparent, and was a major consideration in the design of the GIA's second term (2002-2007) Strategic Plan (accepted in 2003). The new Plan reflects the actions underway, and those being considered, by the GIA in response to market, management and government policy dynamics, as well as technological advances. It specifies the mission for the second term as being: *to advance and support the use of geothermal energy on a worldwide scale by overcoming barriers to its development*. To do so, the original objectives were augmented with additional ones specifically focused on: expanding R&D collaboration, increasing the number of participants, increasing outreach to non-Member countries with large geothermal energy potential; evaluating market stimulation mechanisms, improving dissemination of information about geothermal energy and leveraging limited R&D funding through association with the IEA.

I. EXECUTIVE SUMMARY

NATIONAL PROGRAMMES

The foundation for the cooperative IEA geothermal activities is the national geothermal programmes of the participating countries. These programmes are directed toward the exploration, development and utilization of geothermal resources. Summaries of the current situation and progress in geothermal activities for each of the participating countries and the EC are provided in Chapters 8-17.

During 2004, Contracting Parties from nine countries and the European Commission (EC) participated in the IEA GIA. The member countries were: Australia, Germany, Iceland, Italy, Japan, Mexico, New Zealand, Switzerland and the United States. In addition, China, France, the Philippines, South Korea, Sweden and Turkey were actively encouraged to join, with Turkey and the Philippines already participating on an informal basis in Annex I. The GIA is also investigating extending participation in the programme to Russia.

COLLABORATIVE ACTIVITIES

Participants in the 2004 IEA GIA worked on four research tasks, specified in Annexes I- Environmental Impacts of Geothermal Energy Development, III- Enhanced Geothermal Systems, IV- Deep Geothermal Resources and VII- Advanced Geothermal Drilling Techniques. Three of these annexes (I, III and IV) were part of the original GIA and have continued programmes into the second term, as has the fourth (VII), which was started in 2001. In addition, a fifth annex, Annex VIII- Direct Use of Geothermal Energy, was accepted in September 2003, with the 2004 efforts directed toward setting up the programme. Three additional tasks have been identified as new areas for cooperative research, and the relevant annexes have been drafted (see Table 1.1 for Annex status details).

The involvement of the participants in the Annexes is shown in Table 1.2. It should be noted that participants take part only in those Annexes that are relevant to their current national research and development programmes. The tasks in each Annex are divided into Subtasks, and not all participants are active in all Subtasks of those Annexes in which they participate.

It is anticipated that the second term of the GIA will operate under the task-sharing mode of financing (as it did during the first term) with the possible exception of Annex VIII- Direct Use, which may also include cost-sharing Subtasks. The actual amount of work conducted under the auspices of the GIA has not been quantified, though it can be assumed that most countries have an involvement amounting to somewhere on the order of one to several man-year(s).

A review of the geothermal situation and progress made by each Contracting Party is provided in Chapter 7, with details reported in individual Country Reports in Chapters 8-17. The title, brief description, status and list of highlights for each of the Annexes are provided here, with more complete details available in the Annex Reports included in Chapters 2-6. More information about the GIA's activities may be obtained by contacting the Operating Agent for the Annex of interest listed in the Annex Reports, the GIA Secretary at: mongillom@reap.org.nz or iea-giasec@gns.cri.nz; or by visiting the new GIA website at: www.iea-gia.org.

ANNEX SUMMARIES

Summaries of the GIA Annexes, including those in draft form and one now closed, are presented here. Detailed discussions of objectives, results and work planned for 2005 are provided for the five active Annexes as Annex Reports in Chapters 2-6.

ANNEX I - Environmental Impacts of Geothermal Energy Development

In order to expand the use of geothermal energy, possible environmental effects need to be clearly identified and methods devised and adopted to avoid or minimize their impacts. The main activities of this Annex are directed toward these issues and divided into four subtasks: to investigate the impacts of development on natural features; to study the problems associated with discharge and reinjection of geothermal fluids; to examine methods of impact mitigation and produce an environmental manual; and to examine the occurrence of significant induced seismic events in conjunction with EGS reservoir development or subsequent extraction of heat from underground (see Chapter 2). The last listed subtask, dealing with induced seismicity, is a new area of study initiated in October 2004.

The work on this Annex began in 1997 and was extended by the ExCo in 2001 to continue through 2005.

Highlights of 2004 Annex I Activities

The second Special Issue of Geothermics containing seven articles describing Annex I work in New Zealand, the Philippines and Turkey was completed and submitted for publication. A new Subtask D was initiated, which investigates induced seismicity in enhanced geothermal systems, and a workshop was organized for January 2005. A collaborative study among Iceland, Italy and New Zealand was begun to study natural CO_2 emission. Mitigation policy recommendations were developed for future optimum operation of geothermal resources.

Many of the Annex results have been presented at international conferences, and several scientific papers describing these results are in press or have been published.

The Operating Agent for this Annex is the Institute of Geological and Nuclear Sciences, Limited (IGNS), New Zealand. Chris Bromley (IGNS, Wairakei) is the Task Leader.

ANNEX 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.

ANNEX III - Enhanced Geothermal Systems (EGS)

The objective of this Annex is to investigate new and improved technologies that can be used to artificially stimulate a geothermal resource to allow commercial heat extraction (see Chapter 3 for details). The work in this Annex is divided into four subtasks: to review the use and/or modification of conventional geothermal technology for the development of enhanced geothermal systems; to collect information necessary for decision making, design and the realization of a commercial EGS energy producing plant; to review and evaluate geochemical and modelling techniques for determining reservoir characteristics; and to conduct field studies of EGS reservoir development and performance with the intent of understanding reservoir behaviour and the sustainability of energy recovery. The last subtask was approved in October, with work currently being planned. A fifth subtask, to evaluate the economics of hot dry rock systems, was successfully completed in 2001 (Details are provided in *IEA Geothermal Annual Report 2002*, Chapter 3).

Work on this Annex started in 1997 and was extended by the ExCo in 2001 for another 4 years to 2005.

Highlights of 2004 Annex III Activities

An air-driven high-temperature downhole drilling motor, successfully tested at the Geysers geothermal field, will be useful for drilling directional wells where conventional drilling fluids might damage the reservoir. A new heat flow map for North America was prepared and published, and will be useful for locating geothermal reservoirs that need enhancement. Studies are underway to adapt recent advances in petroleum tracer test interpretation methods to EGS, for estimating fluid flow paths, sweep efficiency, reservoir surface area and fluid velocities in fractured geothermal reservoirs. A new high-temperature acoustic televiewer has been developed and will be useful for obtaining fracture information in geothermal reservoirs.

The first version of the EGS-PMDA, or Project Management Decision Assistant, was completed and disseminated for review. The compilation of data for the Hijiori and Ogachi geothermal fields continues and a review of the Hijiori data was completed, with a portion useful to the subtask to be published in English in early 2005.

Many of the results from Annex III were presented at international workshops and conferences including the 2004 Annual Meeting of the Geothermal Resources Council (GRC); the Annex III meeting at AIST in Tsukuba, Japan; and the Workshop on Geothermal Reservoir Engineering, Stanford, USA. Ten scientific papers describing the results were also published.

The Operating Agent is the New Energy & Industrial Technology Development Organization (NEDO), Japan. I. Matsunaga (AIST, Tsukuba) is Task Leader.

ANNEX IV - Deep Geothermal Resources

This Annex addresses issues necessary for the commercial development of deep geothermal resources at depths greater than about 3,000 m. The activities have been divided into three subtasks: research on exploration technologies and reservoir engineering for deep, hot reservoirs; investigation into drilling and logging techniques; and exchange of information and establishment of a database on fluid chemistry, material properties and corrosion issues, together with field-testing (Chapter 4).

The work of this Annex is very closely related to that in Annex III (EGS) because enhanced geothermal systems studies are being pursued in several regions where the desired high temperatures are reached at much greater depths (> 4,000 m) than in the "normal" high-temperature geothermal fields. Consequently, some of the projects "cross-over", with activities being pursued in both Annexes. This overlap of project work within the two Annexes is currently being addressed.

Work on this Annex began in 1997 and was extended in 2001 by the ExCo for another 5 years to 2006.

Highlights of 2004 Annex IV Work

The second deep geothermal well to be drilled in the Cooper Basin, Australia, was successfully completed to a depth of over 4,350 m, with pressure communication established with the first well during the drilling. As part of the European Soultz project, a fourth well and the designated second production well, was successfully drilled and hydraulic stimulation tests initiated. As part of the German deep geothermal project at Groß Schönebeck, reprocessing of seismic data in conjunction with acoustic televiewer and fullbore micro-imager information identified local stress features; and stimulation experiments have been successful in significantly increasing flow rates over those initially obtained. As part of efforts in Mexico to rigorously simulate mass and heat transport in hydrothermal reservoirs, results from the calculation of thermodynamic properties of single and binary fluids in the system H_2O-CO_2-CH_4 compared well with those published for water, carbon dioxide and methane, as well as their binary mixtures. In addition, studies of Mexican geothermal fields under exploitation continued, with investigation of the evolution of thermodynamic properties of reservoir fluids defining the response: first is a pressure decrease and enthalpy increase in wells, and in the longer term: decrease in both pressure and mass flow rate, boiling, cooling, steam production.

Results obtained in the Annex work were presented at the Workshop on Geothermal Reservoir Engineering, Stanford, USA, and published as 12 reports and papers in international journals.

Project Management Organization Jülich, Germany, is the Operating Agent. Dieter Rathjen is the Task Leader (Project Management Organization Jülich).

ANNEX V - Sustainability of Geothermal Energy Utilization

The objective of this Annex is to study the important aspects of energy production from geothermal resources with the view of determining the long-term economic sustainability of such production.

There was no significant activity towards the development of this Annex during 2004.

ANNEX 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 has been prepared, though no further consideration was given to it in 2004. The ExCo has agreed that it would be implemented as soon as two or more participants agreed to join.

ANNEX VII - Advanced Geothermal Drilling Techniques

This Annex pursues advanced geothermal drilling research and investigates all aspects of well construction with the aim of reducing the costs associated with this essential and expensive part of geothermal exploration, development and utilization. The investigation is divided into three subtasks: the compilation of geothermal well drilling cost and performance information that is maintained on a database; production of a geothermal drilling best practices handbook; and monitoring and exchange of information on drilling technology development and new applications (Chapter 5).

This study began in 2001 and will continue through 2005.

Highlights of 2004 Annex Activities

The working group for this Annex held two meetings at which subtask objectives and specific activities performed in 2004 were discussed. Two posters describing the Annex’s work were prepared for the World Geothermal Congress 2005 and thirteen papers and reports produced.

The Operating Agent is Sandia National Laboratories, USA. Ed Hoover was Task Leader for the first half of 2004, followed by Jack Wise, who was replaced in early 2005 by Steve Bauer (all three from Sandia Labs).

ANNEX VIII - Direct Use of Geothermal Energy

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

This study will continue through 2007.

Highlight for 2004

The Direct Use of Geothermal Energy Annex is the most recent annex to be included in the GIA. Though it officially began in September 2003, work was held up by lack of confirmed participation. However, in early 2005, Iceland, Japan, New Zealand, Switzerland and the USA confirmed their membership; and work is expected to begin soon.

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

ANNEX IX - Geothermal Market Acceleration

Though geothermal electricity production and direct heat use are well developed and economically viable in many parts of the world, there are large untapped resources in many countries. The ExCo has been exploring ways to hasten geothermal energy development, or market acceleration, in these countries for the last few years, and decided that a more pro-active approach was needed and might include: 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, a market acceleration Annex was drafted.

However, in 2004, the IEA decided to proceed with the development of its own market acceleration Implementing Agreement. Consequently, at the October 2004 ExCo meeting, it was unanimously decided to cancel this Annex.

EXECUTIVE COMMITTEE ACTIVITIES

Officers

Dr David Nieva (Mexico) served as Chairman for 2004. Dr Ladislaus Rybach (Switzerland) and Dr Allan Jelacic (USA) served as Vice-Chairs for Policy and Administration, respectively, in 2004.

Membership

There were two changes in the ExCo composition in 2004: Helga Tulinius replaced Sveinbjörn Björnsson as Iceland's Member; and Yumi Kiyota replaced Satoshi Kubo as Alternate Member for Japan.

The list of ExCo Members and Alternates for 2004 is provided in Appendix D.

I. EXECUTIVE SUMMARY

Meetings

The ExCo held two Meetings in 2004 to discuss and review ongoing tasks and plan future activities.

The 11th ExCo Meeting was held on 18-19 March 2004, in Paris, France, and was hosted by the International Energy Agency (IEA) Headquarters. There were 22 attendees, including eight ExCo members and three Alternate Members, three ExCo Observers (Annex members), two NEDO representatives and five IEA staff members, plus the GIA Secretary. The ExCo approved unanimously the election of David Nieva as Chairman and Allan Jelacic and Ladislaus Rybach as Vice-Chairmen. Reports were presented on the progress made in each of the Annexes and on the national geothermal situation in the participating countries. The "overlap" of work in Annexes III and IV was considered. The ExCo discussed the IEA's request for modification of the GIA and the IEA Deputy Chief Legal Council described these changes and their consequences to the meeting. Participation by the GIA in the World Geothermal Congress 2005 was debated. There was further discussion on proposed Annex V- Sustainable Geothermal Energy Production and Annex IX- Market Acceleration, and it was noted that the IEA might initiate a programme that could supplant the latter. The issue of "growing" the GIA through new membership was examined. The Secretary provided a report on the operation of the Secretariat for 2003 and for the beginning of 2004, presented a work plan for 2004, and gave an update on the Common Fund. Issues related to the Common Fund (i.e. payment times, amounts, etc.) were discussed. The ExCo unanimously decided that the GIA Secretariat should be kept in New Zealand until the end of the second term (March 2007). The IEA Secretariat presented a report describing how they could assist the GIA and invited GIA's participation in the Bonn, Germany Renewable Energy Conference and requested a contribution from the GIA for its new IA Highlights book (to be published in 2005).

The 12th ExCo Meeting was organized and hosted by ENEL, Pisa, Italy, on 14-15 October 2004. There were 19 attendees, including eight ExCo Members and four Alternates, three ExCo observers (Annex members), one NEDO member, two IEA staff members, and the GIA Secretary. The idea of cost-sharing for certain projects was discussed, however, it was decided that the primary funding mode for the Annexes would remain task-sharing, though the GIA will continue to search for other funding opportunities. The revised IEA GIA framework was discussed and it was reported that the EC would probably accept it soon, paving the way for the GIA to adopt it. Participation in the World Geothermal Congress (WGC) 2005 was discussed and it was decided to hire a booth to promote the GIA via posters, PowerPoint presentations and distribution of documents. The Secretary reported that the IEA Geothermal Annual Report 2003 was completed and submitted to the IEA, a paper describing the GIA was written for the WGC2005, GIA material was provided for the IEA Geothermal Side Event (Bonn Renewable Energy Conference, 1-4 June 2004), a GIA highlights document was submitted for the IEA 2003-2004 Highlights booklet and the new GIA website was operational. The Secretary's work plans for the remainder of 2004 and for 2005 were presented and accepted by the ExCo. Annex work and Country Reports were presented and reviewed. Again, the issue of "overlap" between Annexes III and IV was discussed, concluding that Annex IV should remain unchanged for the time being. Discussion of Annex V- Sustainability resulted in the decision that the GIA would produce a policy statement and position paper on the topic in 2005. Two new subtasks were also initiated, one in Annex I, and the other in Annex III. Issues relating to increasing GIA membership were discussed and due to South Korea's interest in joining, an "official" invitation will be sent to them. Again, it was clear that cost matters (i.e. the ExCo Common Fund) remained a stumbling block to the GIA's membership growth. Greece's withdrawal due to their Contracting Party's inability to meet their Common Fund contribution obligation was accepted. The IEA Secretariat presented a report mentioning the success of the Geothermal Side Event in Bonn and inviting the GIA to participate in an IEA RD&D

Seminar to be held in March 2005. The GIA ExCo agreed to participate in the seminar. On the day prior to the ExCo meeting, our Italian hosts conducted a fieldtrip to some of Tuscany's historic geothermal areas and geothermal electricity generating facilities, ending with a visit to the Larderello Geothermal Museum.

Conference Participation

The ExCo recognizes the importance of promoting the GIA and its activities in order to encourage geothermal energy use as well as increase membership in the organization. As a part of these efforts, a paper describing the GIA: *The IEA Geothermal Implementing Agreement - Its Goals, Status, Achievements and Prospects*, was written and accepted for presentation as a keynote address at the World Geothermal Congress 2005 to be held in Antalya, Turkey in April 2005. The paper will also be published in the WGC 2005 proceedings.

COSTS OF THE AGREEMENT

In March 2003, a dedicated GIA Secretariat was established in order to conduct the planned increased activities of the GIA, including: production of GIA documents, papers and brochure(s), creation and maintenance of a new GIA archive and website, maintenance of timely communication among the Members, *etc*. The expenses for running the GIA Secretariat, including the Secretary's salary and travel, and other common costs of the ExCo, are met from an Executive Committee Common Fund. This Fund is administered by a Custodian, presently the National Renewable Energy Laboratory (NREL) (USA), who also provides regular accounting reports to the ExCo.

To support the Common Fund, the IEA has provided general guidance on a fair apportionment of monetary contributions in the form of shares assigned to different Member States of the OECD. Based on current membership, the apportionment for the GIA is shown in Table ES1.

Table ES1 Common fund share apportionment among the GIA Members as of December 2004.

Australia	2	Japan	4
European Commission	4	Mexico	1
Germany	4	New Zealand	1
Iceland	1	Switzerland	2
Italy	2	United States	4
Total = 25 shares			

The ExCo has set the present cost per Common Fund share at US$ 2,500/year. With the addition of new members, or the withdrawal of current ones, the total number of shares may increase or decrease, affecting each member's contribution. Contributions are made annually on a calendar year basis. The number of shares assigned to new members who are non-Members of OECD will be determined by the ExCo acting in unanimity.

PLANS FOR 2005 GIA

The GIA will continue to strive to improve and enhance the visibility of its work and results, and to encourage the use of geothermal energy worldwide. We recognize the importance of explaining geothermal energy, and the local and worldwide contributions it can, and is making, especially to non-experts, particularly decision makers. The GIA's 2002-2007

Strategic Plan continues to provide a guide for collaborative technology development, deployment and information dissemination that will help achieve these goals.

As part of its efforts in 2005, he GIA will participate in an IEA seminar on renewable energy research and development to be held in Paris, France, in early 2005. The first GIA brochure will also be produced.

The GIA will participate in the very important World Geothermal Congress in April 2005 by presenting papers describing the GIA's activities and Annex research, and by hosting an exhibition booth in which GIA work will be presented in posters and computer presentations. Several GIA documents, including a new GIA brochure will also be distributed and members will be available for discussions with booth visitors.

The GIA also plans to produce the first of its policy statements and position papers, which will deal with sustainability of geothermal energy use.

CHAPTER 1

The Implementing Agreement

1.1 Activities of IEA Geothermal Research and Technology Programme

Geothermal research and technology cooperation under the auspices of the IEA began in its present form in March 1997, with the signing of the Implementing Agreement for a Cooperative Programme on Geothermal Research and Technology (IEA GIA). This programme revived the IEA geothermal research collaboration that had lapsed with the completion of two earlier Implementing Agreements: the "Man-Made Geothermal Energy Systems" (MAGES) Project (1978-1980) and the Geothermal Equipment Testing Project (1979-1981).

In late 2001, near the conclusion of its first 5-year term of operation, the GIA recognized that though the organization's efforts had been quite successful, the basic environment in which it worked had altered (and continues to evolve) as the result of changes in market, management and government dynamics, and technological advances. Consequently, with the extension of the GIA for a second term, to 2007, the GIA modified its mission for the new Strategic Plan: *to advance and support the use of geothermal energy on a worldwide scale by overcoming barriers to its development.*

The original objectives of the IEA Geothermal Research and Technology (R&T) Programme still remain the major guides for the organization and are to:

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

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

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

However, as a consequence of the modified mission, additional objectives were added, specifically focused to:

- **Expand R&D collaboration:** Geothermal energy technology development is progressing and new areas of collaboration are required. Table 1.1 contains a summary of current collaborative efforts under the GIA. The Executive Committee (ExCo) will consider and implement annexes where additional collaboration could be useful.

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

- **Increase outreach to non-Member countries with large geothermal energy potential:** The electricity markets in many countries were opened to competition in the 1990s. As energy markets deregulate, they are driven more by market forces and less by government programmes and intervention. Environmental impacts of energy development have become increasingly important. New regions are opening up as international energy markets expand. The GIA will embrace this opportunity and explore ways to accelerate development of the world's geothermal resources.

- **Evaluate market stimulation mechanisms:** In the ExCo's efforts to expand geothermal heat and power markets in both OECD and non-OECD countries, research actions are clearly important and indeed essential, but they are not in themselves sufficient to open up markets. Market stimulation is also needed to create an expanded market for geothermal energy.

- **Improve dissemination of information about geothermal energy:** The ExCo has recognized its role in promoting the use of geothermal energy, but more emphasis is needed on the open distribution of high quality and attractive information products. The GIA is actively pursuing this issue, and as a part of its effort, is continuing to develop its website, annual reports and a brochure in order to provide information in a more understandable and appealing manner.

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

Table 1.1 Annex Title, Operating Agent and Status of GIA Annexes (as of December 2004).

Annex Number	**Title** **Operating Agent (OA)** **Task Leader (TL); Affiliation; Contact E-mail** **Participants**	**Status**
I	Environmental Impacts of Geothermal Development OA: Institute of Geological and Nuclear Sciences Limited (IGNS), New Zealand TL: Chris Bromley; IGNS, New Zealand; c.bromley@gns.cri.nz Participants: EC, Iceland, Italy, Japan, Mexico, New Zealand, USA	Active since 1997, Continuing through 2005
II	Shallow Geothermal Resources	Closed
III	Enhanced Geothermal Systems OA: New Energy & Industrial Technology Development Organization (NEDO), Japan TL: I. Matsunaga; AIST, Japan; matsunaga-isao@aist.go.jp Participants: Australia, EC, Germany, Italy, Japan, Switzerland, USA	Active since 1997, Continuing through 2005
IV	Deep Geothermal Resources OA: Forschungszentrum Jülich (F-J), Germany TL: Dieter Rathjen; F-J, Germany; d.rathjen@fz-juelich.de Participants: Australia, Germany, Italy, Mexico, New Zealand, USA	Active since 1997, Continuing through 2006
V	Sustainability of Geothermal Energy Utilization	Draft
VI	Geothermal Power Generation Cycles	Draft
VII	Advanced Geothermal Drilling Techniques OA: Sandia National Laboratories, United States TL: Steven Bauer; Sandia National Laboratories, USA; sjbauer@sandia.gov Participants: EC, Iceland, Japan, Mexico, New Zealand, USA	Active since 2001, Continuing through 2005
VIII	Direct Use of Geothermal Energy OA: The Federation of Icelandic Energy and Waterworks, Iceland TL: Einar Gunnlaugsson; The Federation of Icelandic Energy and Waterworks, Iceland; einar.gunnlaugsson@or.is Participants: Iceland, Switzerland (Japan, New Zealand and USA confirmed their participation in March 2005)	Active since 2003, Continuing through 2007
IX	Geothermal Market Acceleration	Draft

Control of the Geothermal R&T programme is vested in the Executive Committee (ExCo), which comprises one member and one alternate from each of the Contracting Parties. There is typically one Contracting Party for each country, which is usually a government department or agency. The ExCo meets in regular session twice each year to exchange information, discuss progress in each of the tasks and in each of the participating countries, and plan future activities. Decisions are made by majority vote, unless otherwise specified in the IA. In 2002, the GIA ExCo decided to increase the scope of its activities. Consequently, it created a dedicated Secretariat, which began operations in March 2003 and is funded by a Common Fund.

The GIA's programme is implemented through the conduct of collaborative projects called tasks, which are described in detail in annexes to the Implementing Agreement (IA) (Chapters 2-6). The Tasks are first approved by the ExCo, and then appended as annexes to the IA. These tasks, referred to by their annex number, are managed by an Operating Agent organization within one of the Member countries. It is estimated that the level of effort spent by each country on GIA activities is on the order of one to several man-years. Up to the end of 2004, all of the GIA annex activities have operated under the "task-sharing" mode of funding. This may change in the near future as a result of some of the activities planned in Annex VIII- Direct Use of Geothermal Energy.
GIA research results are disseminated through participation at international conferences and workshops, and publication in scientific and technical journals and conference proceedings (details in Chapters 2-6). In addition, information is made more widely available on the new GIA website and through promotional material being produced by the GIA Secretariat.

In 2004, 9 countries and one international organization formally participated in this programme (Table 1.2).

Table 1.2 Country participation and funding sources for the current Annexes (as of December 2004).

Participating Country	Annex I (Environment)	Annex III (Enhanced Geothermal Systems)	Annex IV (Deep Resources)	Annex VII (Advanced Drilling)	Annex VIII (Direct Use)
Australia		P	P		
EC	P	P		P	
Germany		P	P		
Iceland	P, I			P	P
Italy	I	I	I		
Japan	P	P		P	
Mexico	P		P	P	
New Zealand	P, I		P, I	I	
Switzerland		P			P
USA	P	P	P	P	

P = Publicly-funded research institute or university; I =Industry

1.2 Future Research Needs for Geothermal Energy Development

The world's population is now 6 billion people and expected to grow by 50% in the next 45 years (USBC, 2004). About one-third of the current population has no electricity and the economies of any of the developing countries are expected to grow very rapidly in the coming decades. We are facing an enormous challenge to provide affordable, clean energy to meet these accelerating needs. The increased awareness of global warming issues and the detrimental effects caused by the use of fossil fuels has also led to a growing desire to use clean, sustainable, renewable energy sources.

In 2002, the total global primary energy use was about 430 EJ (1 EJ = 10^{18} J), with renewables providing about 13%, and about 17% of the global electricity production. Current estimates indicate a total worldwide technical potential of renewable resources of about 7,500 EJ/year. The geothermal potential suitable for future development estimated to be about two-thirds of this, or 5,000 EJ/year [1 EJ = 10^{18} J] (WEA, 2000), with economic exploitation providing about 150 EJ/year for electricity generation and 350 EJ/year for direct uses (Bertani, 2003). Consequently, renewable energy, and geothermal in particular, is capable of making a considerable contribution towards meeting the world's current and future energy needs.

As of 2004, twenty-four countries were utilizing geothermal energy to generate electricity, with a total installed capacity of 8,900 MW_e (Bertaini, 2005) and a growth rate over the past 25 years of about 200 MW_e/year. Approximately 56.8 TWh, or about 0.35% of the 2002 global electricity production of 16,000 TWh was generated. In addition, geothermal direct heat use was reported in over 70 countries, with a worldwide installed capacity of about 27,800 MW_t (with total energy use of 72,622 GWh) in 2004, having doubled almost every five years since 1995 (Lund, *et al*., 2005). Direct heat use is also expected to continue growing into the future, especially with the installation of geothermal heat pumps. Additionally, in 2004, geothermal electricity generation saved the equivalent of 14 million tonnes of oil (Mtoe) and reduced CO_2 emissions by about 47 million metric tonnes (Mt), and geothermal direct use about 14 Mtoe with reduced CO_2 emissions of 45 Mt.

Given the potential and current technology, it is believed that a 45% increase in geothermal electricity generation is possible between 2000 and 2010. The new growth would be expected mainly from existing suitable resources, particularly in the developing countries of Latin America, Southeast Asia and Africa where the demand for electricity is growing rapidly. In addition, there are very good opportunities for increased direct use in Central and Eastern Europe where resources occur near to demand areas. Similarly, the IEA World Energy Outlook 2002 "Reference Scenario" (for OECD countries) forecasts a geothermal electricity production growth rate of 4% per annum during the period 2000-2010, with non-hydro renewable electricity production increasing from 2% in 2000 to about 4% in 2010. The "Alternative Policy Scenario" indicates that if all OECD countries' policies being considered to promote renewables are pursued, non-hydro renewables could provide about 6% of the total generated electricity in 2010.

The IEA GIA can play a significant role in helping attain the abovementioned ambitious targets.

1.3 References

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USBC 2004. United States Bureau of the Census, International Database. Update 30 September 2004. http://www.census.gov/ipc/www/worldpop.html

WEA 2000. World Energy Assessment: energy and the challenge of sustainability. Ed. J. Goldemberg, United Nations Development Programme, UNDECOSOC, WEC, 2000.

WEC, 2000. World Energy Council Statement 2000. Energy for Tomorrow's World- Acting Now. Website: http://www.worldenergy.org/wec-geis/publications/reports/etwan/introduction/introduction.asp

WEC, 2002. Energy for People, Energy for Peace. WEC website: http://www.worldenergy.org/wec-geis/publications/statements/stat2002.asp

CHAPTER 2

Annex I – Environmental Impacts of Geothermal Energy Development

2.1 Introduction

Environmental effects of energy use are a worldwide concern. Geothermal is generally regarded as a benign energy source. There are, however, some environmental problems associated with its utilization. To further the use of geothermal energy, possible environmental effects need to be clearly identified, and countermeasures devised and adopted to avoid or minimize their impact. Task 1 of the GIA was set up to address these issues, and is formulated in Annex I.

The goals of Task I are: to encourage the sustainable development of geothermal energy resources in an economic and environmentally responsible manner; to quantify any adverse or beneficial impacts that geothermal energy development may have on the environment, and to identify ways of avoiding, remedying or mitigating such adverse effects. The term "development" here is used in a broad sense to encompass not only energy production but also use for social and economic purposes such as tourism. These activities have been a part of the GIA since its inception in 1997, and in 2001the Annex was extended to 2005.

The specific objectives of Annex I are:

- To study the effects that existing geothermal developments have had on the environment and determine their cause.
- To identify the most likely and serious adverse effects that geothermal developments can have on the environment.
- To identify the development technologies that have proven to be environmentally sound.
- To publish the results of the studies in international journals and present the results at international forums.
- To improve communications between individuals and organizations in different countries, and between different professional groups involved in geothermal development by involvement in collective presentation of the results in international forums.

During 2004, five countries participated in Annex I: Iceland, Italy, Japan, Mexico, New Zealand, and United States of America. Two other countries that are currently non-Members, Turkey and the Philippines, also made contributions to the Annex.

The Operating Agent for Annex I is the Institute of Geological & Nuclear Sciences Limited (IGNS), a Crown Research Institute owned by the New Zealand Government. The Task Leader is Chris Bromley.

2.2 Subtasks of Annex I

There are four Subtasks in this Annex.

2.2.1 Subtask A- Impacts on Natural Features (Subtask Leader: Chris Bromley, Institute of Geological & Nuclear Sciences Limited, Wairakei, New Zealand)

This Subtask focuses on documenting known impacts of geothermal developments on natural geothermal features such as geysers, hot springs and silica terraces. The aim of this subtask is to provide a sound historical and international basis on which to devise methods to avoid or mitigate the impacts of development on these geothermal features, which often have significant cultural and economic value.

Projects that examine the effects of geothermal developments on natural geothermal features are being conducted in Iceland, Japan, New Zealand and United States of America.

2.2.2 Subtask B- Discharge and Reinjection Problems (Subtask Leader: Trevor Hunt, Institute of Geological & Nuclear Sciences Limited, Wairakei, New Zealand)

Work in this Subtask is focused on identifying and determining methods of overcoming the impacts of geothermal developments on other aspects of the environment. This includes the effects of gas emissions from geothermal power plants, effects of toxic chemicals in waste fluid that is discharged both into the ground and into rivers, effects of ground subsidence, and induced earthquakes.

Projects have been organized which examine the problems associated with disposal of waste geothermal fluids from existing geothermal developments in Iceland, Turkey and New Zealand. The effects of CO_2, Hg and H_2S gas emissions in Italy, New Zealand, Iceland, the USA and Mexico are being investigated. The effects, causes and possible remedies for subsidence are being researched in New Zealand and Iceland.

2.2.3 Subtask C- Methods of Impact Mitigation and Environmental Manual
(Subtask Leader: Chris Bromley, Institute of Geological & Nuclear Sciences Limited, Wairakei, New Zealand)

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

New Zealand, Mexico and the USA are the participants in this Subtask.

2.2.4 Subtask D- Seismic Risk from Fluid Injection into Enhanced Geothermal Systems
(Subtask Co-Leaders: Roy Baria, EEIG Heat Mining, European Commission and Ernie Majer, Lawrence Berkeley National Laboratory, Department of Energy, United States)

This new Subtask, begun in 2004, addresses the issue of the occurrence of significant induced seismic events in conjunction with EGS reservoir development or subsequent extraction of heat from underground. These events have been large enough to be felt by populations living in the vicinity of current geothermal development sites. The objective is to investigate these

Figure 2.1 Bláhver is a silica-rich hot spring in Hveravellir, Iceland. It has deposited a large surrounding sinter terrace (few hectares in area), one of the largest undamaged sinter terraces in Iceland (Photo Sigurður S. Jónsson)

events to obtain a better understanding of why they occur so that they can either be avoided or mitigated. Understanding requires considerable effort to assess and generate an appropriate source parameter model, testing of the model, and then calculating the source parameters in relation to the hydraulic injection history, stress field and the geological background. An interaction between stress modelling, rock mechanics and source parameter calculation is essential. Once the mechanism of the events is understood, the injection process, the creation of an engineered geothermal reservoir, or the extraction of heat over a prolonged period may need to be modified to reduce or eliminate the occurrence of large events.

The active participants in this Subtask in 2004 are the EC, New Zealand and the USA.

2.3 Work Performed in 2004

2.3.1 General

Some of the results of the ongoing environmental work conducted in Annex I were published and presented at international conferences in 2004 (see Output section below).

Comments on the general work pursued for 2004 follow:

- The final draft of the second Special Issue of *Geothermics* journal was completed and submitted to the publishers for publication in 2005.

- Papers on environmental aspects of geothermal development were presented at the 2004 New Zealand Geothermal Workshop and several have been accepted for presentation at the 2005 World Geothermal Congress (WGC 2005) to be held in Antalya, Turkey on 24-29 April 2005.

- Planning and preparation for a two-day workshop on geothermal induced seismicity to be held in conjunction with the Stanford Geothermal Workshop (January 2005).

- New research requirements for induced seismicity, monitoring of natural CO_2 and convective heat flow, classification of thermal feature vulnerability, testing of mitigation and remediation methods and development of bioremediation methods to remove toxic elements from waste water discharges were identified as important longer-term R&D needs based upon discussions with geothermal developers and regulators.

- Planned collaboration among geochemical researchers in Italy, Iceland, the USA and New Zealand to jointly investigate methods for monitoring natural CO_2 emissions from thermal areas in order to quantify the net long-term effects of geothermal development on global warming through CO_2 emissions.

- Annex participants took part in a half-day workshop to discuss progress on the continuing tasks and began planning for the new induced seismicity subtask (Subtask D).

2.3.2 Subtask A- Impacts on Natural Features

Compared changes to thermal features due to geothermal development as experienced in Iceland and New Zealand. Prepared submissions on appropriate geothermal policy changes to help regulators manage effects in a practical manner.

2.3.3 Subtask B- Discharge and Reinjection Problems

The effects of waste water disposal on groundwater and surface water in Iceland were compared to those arising from disposal options identified at Wairakei, New Zealand.

Potential causes of subsidence in geothermal fields around the world were investigated, and methods to improve predictive capabilities of subsidence models were investigated.

2.3.4 Subtask C- Methods of Impact Mitigation

Case studies from the Philippines of the effects of vertical discharges on vegetation and landslide mitigation were analyzed and published

2.3.5 Subtask D- Seismic Risk from Fluid Injection into EGS

The EC, the USA and New Zealand commenced investigations to develop an understanding of the mechanisms, provide strategies and robust hazard assessment methods for large induced earthquakes caused by injection/production in enhanced geothermal systems.

2.4 Highlights of Annex I Programme Work for 2004

The Annex I highlights for 2004 include:

- The second Special Issue of Geothermics containing seven articles describing Annex I work in New Zealand, the Philippines and Turkey was finalized and submitted for publication.

- New Subtask D investigating induced seismicity commenced and workshop organized, with 38 participants from France, Germany, New Zealand and the USA.

- Collaboration among Iceland, Italy and New Zealand on natural CO_2 emission was begun.

- Subsidence issues were addressed
- Mitigation policy recommendations were advanced for future optimum operation of geothermal resources.

2.5 Work Planned for 2005

The 2005 work plan for each of the four Subtasks includes:

2.5.1 Subtask A

- Changes in gas and steam emissions from natural features
- Distinguishing between natural and induced variations in thermal discharges
- Modelling causes of groundwater effects from deep pressure change
- Methods of ranking thermal features and ecosystems for protection
- Classify vulnerability of thermal features to reservoir pressure changes

2.5.2 Subtask B

- Cost-effective H_2S and Hg removal from production steam
- Geothermal CO_2 capture for horticulture or bottling
- CO_2 sequestration by injection or chemical fixing
- Arsenic/boron removal from wastewater by bio-processing
- Protection of potable water aquifers from outfield reinjection effects
- Improved prediction of subsidence and effects avoidance or mitigation

2.5.3 Subtask C

- Produce an environmental policy advice and procedures manual
- Test the use of targeted injection to rejuvenate failed geysers
- Test the use of targeted injection to stop subsidence

2.5.4 Subtask D

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

2.6 Recent Outputs

2.6.1 Annex I Special Issue of Geothermics (ed. Hunt, T.M.) completed and to be published in 2005:

Hochstein, M. and Bromley, C. (2005) Measurement of heat flux from steaming ground.

Mroczek, E. (2005) Contributions of arsenic and chloride from the Kawerau geothermal field to the Tarawera River, New Zealand.

Şimşek, Ş., Yıldırım, N. and Gülgör, A. (2005) Development and environmental effects at Kizildere Geothermal Power Scheme, Turkey.

Leynes, R.D., Pioquinto, W.P.C. and Caranto, J.A. (2005) Landslide hazard assessment and mitigation measures in Philippine geothermal fields.

White, P. and Hunt, T.M. (2005) Simple modelling of the effects of exploitation on hot springs, Geyser Valley, Wairakei, New Zealand.

Scott, B.J., Gordon, D.A. and Cody, A.D. (2005) Restoration of Rotorua Geothermal Field, New Zealand: progress, issues and consequences.

Tuyor, J., de Jesus, A., Medrano, R., Garcia, J., Salinio, S. and Santos, L. (2005) Impacts of geothermal well testing on exposed vegetation Northern Negros geothermal project, Philippines.

2.6.2 Proceedings of the 26th New Zealand Geothermal Workshop, December 2004, Taupo, New Zealand:

Werner, C., Hochstein, M.P. and Bromley, C.J. (2004) CO_2-flux of steaming ground at Karapiti (Wairakei), New Zealand.

Bromley, C.J., Manville, V., Currie, S. and Allis, R. (2004) Subsidence at Crown Road, Taupo, latest findings.

2.6.3 World Geothermal Congress 2005, April 2005, Antalya, Turkey

Bromley, C. J. (2004) Advances in environmental management of geothermal developments.

Bromley, C.J. and Hochstein, M. (2004) Heat discharge of steaming ground at Karapiti (Wairakei), New Zealand.

2.6.4 Other

Kristmannsdóttir, H. and Armannsson, H. (2004) Groundwater in the Lake Myvantn area, northern Iceland: chemistry, origin and interaction. *Aquatic Geology Journal*, 38.

Bromley, C. J. (2004) Submissions on environmental geothermal policy in New Zealand.

Bromley, C. J. (2004) Wairakei resource consent- submissions for future optimum operation.

2.7 Website Related to Environmental Impacts Work

A website for describing Annex I work is continuing development.

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Contact: Chris Bromley: c.bromley@gns.cri.nz

CHAPTER 3

Annex III – Enhanced Geothermal Systems

3.1 Introduction

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

The countries and organization that participated in Annex III in 2004 were: Australia, Germany, Italy, Japan, Switzerland, USA and the EC.

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

3.2 Annex III Subtasks

The work undertaken in Annex III is divided among three Subtasks. Note that Subtask A, involving the evaluation of the economics of EGS systems, was successfully completed in 2001. The resulting computer economic model can be downloaded from the Internet at: http://web.mit.edu/hjherzog/www/

A new Subtask directed at pursuing field studies of EGS reservoir performance was proposed by the United States and the EC, and accepted in October 2004.

3.2.1 Subtask B- Application of Conventional Geothermal Technology to Enhanced Geothermal Systems (EGS) (Subtask Leader: Joel Renner, Idaho National Engineering and Environmental Laboratory, USA)

Subtask B is aimed at evaluating new and future developments such as horizontal drilling, fracture detection and mapping, and pumping in conventional geothermal energy, and their applications to EGS technology.

3.2.2 Subtask C- Data Acquisition and Processing (Subtask Leader: Thomas Mégel, Geowatt AG, Switzerland)

This Subtask 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. The relevant results and parameter values will be successively collated into a spreadsheet-like synoptic package, ready for use in the decision and design processing or, where necessary, to await further refinement and completion.

During the past 30 plus years EGS research projects in various countries has led to particular scientific, technical and organizational knowledge that points the way towards the industrial construction of EGS power plants. It is very important, at this stage of transition from R&D to commercial exploitation, for new project teams to have access to a synthesis of all the basic knowledge and experience acquired to ensure a successful and unimpeded project start.

It was decided to attempt the assembly of a tool to give an overview of what has been achieved and how, without including all the technical details. Compiling an easy to understand management decisional tool for new EGS project teams, with no compromises in accuracy and clarity is a huge task. Nevertheless, it is an integrated part of every development process in the field of enhanced technologies.

Thus the development of a tool in the form of a collection of relevant information has been planned. Its aim is to provide an information framework for the project planning and construction of first generation commercial EGS plants. The tool, that is to say the resulting information collection, will be assembled to create what we have named a Project Management Decision Assistant (PMDA).

The concept includes documenting the availability of special tools and services and assembling an overview of data, data analyses and experiences (in the way of lists of reports and publications with their abstracts) gained at the major EGS projects worldwide since the early 1970's.

Four fields of activity have been planned:

- Because of the long gestation time of the EGS technology, it was believed useful to document the experiences of the various R & D projects, both past and present, in the field.

- Create a list of literature references with abstracts wherever possible.

- Produce an index of potential suppliers, service operators and consultants with relevant experience.

- An overview of data requirements during planning and construction of a commercial EGS plant would be given using the idea of a Generic Project as a vehicle for presentation. This is based on a project plan. However its presentation does not show activities as such, but only the data requirements for completing project milestones.

3.2.3 Subtask D- Reservoir Evaluation (Subtask Leader: Tsutomu Yamaguchi, AIST, Japan)

The overall objective of Subtask D is to compile and make clear what kinds of methods, techniques, and tools are effective for reservoir evaluation; and then establish the evaluation method that can be applied to develop a new EGS site. An Internet questionnaire was developed and used in 2002 to obtain this information. Unfortunately, the answers, especially from countries other than Japan, were not sufficient to complete this task. Thus, in Subtask D, efforts will be focused on compiling Japanese data from the Hijiori and Ogachi fields.

3.2.4 Subtask E- Field Studies of EGS Reservoir Performance (Subtask Leaders: Roy Baria, EEIG, EC; and Peter Rose, EGI, University of Utah, USA)

This is a new Subtask, accepted into Annex III in October 2004.

The objective of Subtask E is to conduct field studies of EGS reservoir development and performance with the intent of understanding reservoir behaviour and the sustainability of energy recovery. This topic covers a broad area and includes subjects such as hydraulic stimulation, fracture mapping, tracer analysis, geophysical methods and geochemistry.

Participants in this subtask will conduct cooperative work at one or more EGS site undergoing development and suitable for field studies. Staff exchanges will occur in support of this Subtask. As needed, equipment will be made available after mutual agreement among the participants. Each participant will be responsible for its own staff and equipment provided for field studies at an EGS site, including salary, insurance, transportation, subsistence and other essential expenses.

3.3 Work Performed in 2004

3.3.1 Subtask B- Application of Conventional Geothermal Technology to EGS

Enhanced Geothermal Systems (EGS) are engineered reservoirs that have been created to extract economical amounts of heat from otherwise unproductive geothermal resources. The US Department of Energy (DOE) has sponsored several activities using hydrothermal technology for enhanced geothermal systems. In addition, several projects initiated in response to research needs of the hydrothermal community are being implemented in geothermal fields with ongoing EGS projects.

Drilling

The geothermal drilling industry recently completed a study of new directional drilling technology. A test of an air-driven high-temperature downhole drilling motor was recently conducted at the Geysers geothermal field. The tool will be useful for drilling directional wells in geothermal environments where the introduction of conventional drilling fluids might damage the reservoir.

Extended Heat Flow Studies for EGS

Heat flow studies initiated for hydrothermal exploration have been extended to the search for areas of the United States suitable for EGS. The DOE continues to fund heat flow studies in order to better delineate targets for both hydrothermal and EGS development. A new map of the heat flow of North America, prepared by the Southern Methodist University Geothermal Group, was published in June 2004 by the American Association of Petroleum Geologists. The map covers traditional hydrothermal areas as well as
areas that will need enhancement

Figure 3.1 A high temperature televiewer is being tested at the Coso geothermal field, California, USA. (Credit: US DOE)

Petroleum Tracer Test Methods for EGS

The DOE researchers are investigating ways to apply petroleum tracer test interpretation methods to EGS. The research will provide new methods to estimate fluid flow paths, sweep efficiency, reservoir surface area and fluid and temperature velocities in fractured geothermal reservoirs. Papers describing the methodology were presented at the Geothermal Resources Council (GRC) 2004 Annual Meeting and the 30th Stanford Geothermal Workshop (February 1, 2005).

High Temperature Instrumentation

A new high temperature acoustic televiewer has been developed with cooperative funding from the DOE and US Navy. The televiewer has been tested at the Coso geothermal field at temperature up to about 235 ºC. The tool is designed for a maximum temperature of 275 ºC. The tool will be used to obtain fracture information in both hydrothermal and enhanced geothermal systems.

Geochemical Studies

The DOE is funding researchers to characterize the effects of injecting liquid into the vapour-dominated reservoir at The Geysers. These studies include heat transfer, injection/production induced seismicity and chemical changes in the produced steam. Researchers also continue to extend rock-water interaction studies in hydrothermal systems to EGS. Several rock-water interaction papers were included in the 2004 GRC Annual Meeting. These papers describe work initiated for hydrothermal systems and now applied to EGS.

Parametric Analysis of Required Reservoir Properties

Recently, researchers have initiated a parametric study of temperature, depth, reservoir surface area (matrix and fracture), productivity, well-bore friction and drilling costs to determine approximate boundaries for commercial development. A paper discussing the results will be presented at the Geothermal Resources Council 2005 annual meeting

3.3.2 Subtask C- Data Acquisition and Processing

The worldwide experience gained from some of the major EGS research and development projects within the last 30 years was compiled into a first version of a Project Management Decision Assistant (PMDA) in 2003. This handbook shall provide new project teams with the access to a synthesis of the available information to support a successful and unhindered project start.

In 2004, the first version of the EGS-PMDA classifier was disseminated to 8 participants of Annex III for a review. The EGS-PMDA was presented at the Annex meeting during the 12th GIA ExCo Meeting in Pisa in October 2004 and at the Annex III meeting at AIST in Tsukuba, Japan, in November 2004.

The diagram in Figure 3.2 gives an overview of the scope of this data-orientated management aid. In principle, it indicates which items of data and information must be obtained during a project in progress ("Project planning") and where to obtain those data and experiences already available ("Sources of Know-How").

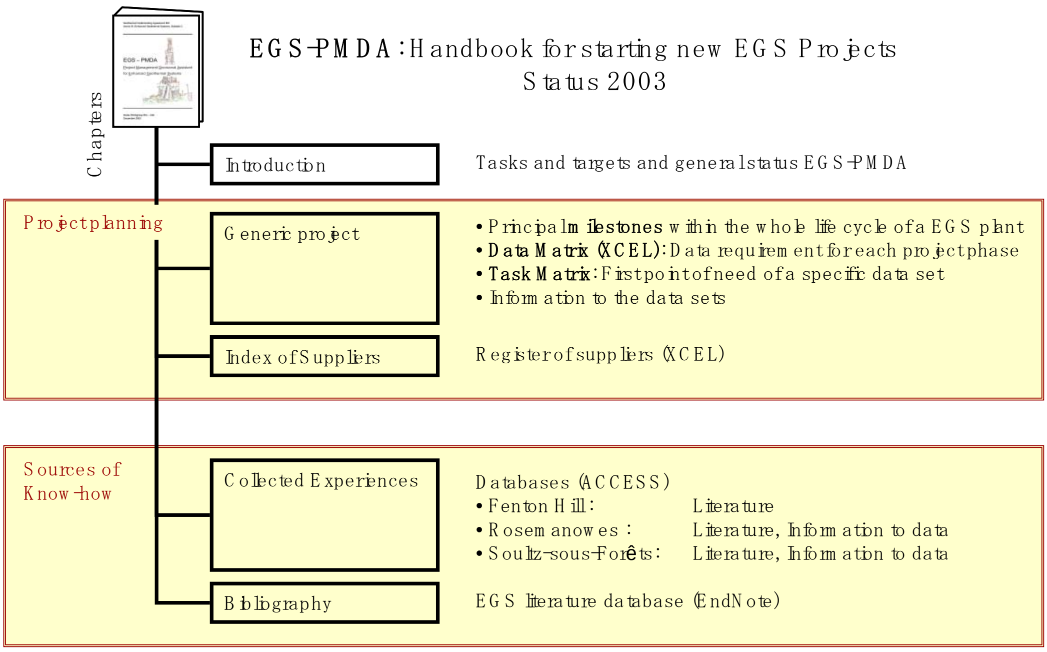

Figure 3.2 Overview of the scope of the PMDA.

3.3.3 Subtask D- Reservoir Evaluation

The questionnaire was completed, however, the response (especially from countries other than Japan) was not sufficient to complete the task. Thus, Subtask D will focus efforts on compiling Japanese data from Hijiori and Ogachi fields.

Apart from the activity of Subtask D, a review program chaired by Prof. Niitsuma of Tohoku University has compiled a review of Hijiori project from October 2002 to March 2004. The review mainly covers: overall system design, field characterization, reservoir creation, circulation and heat extraction, and monitoring (Figure 3.3).

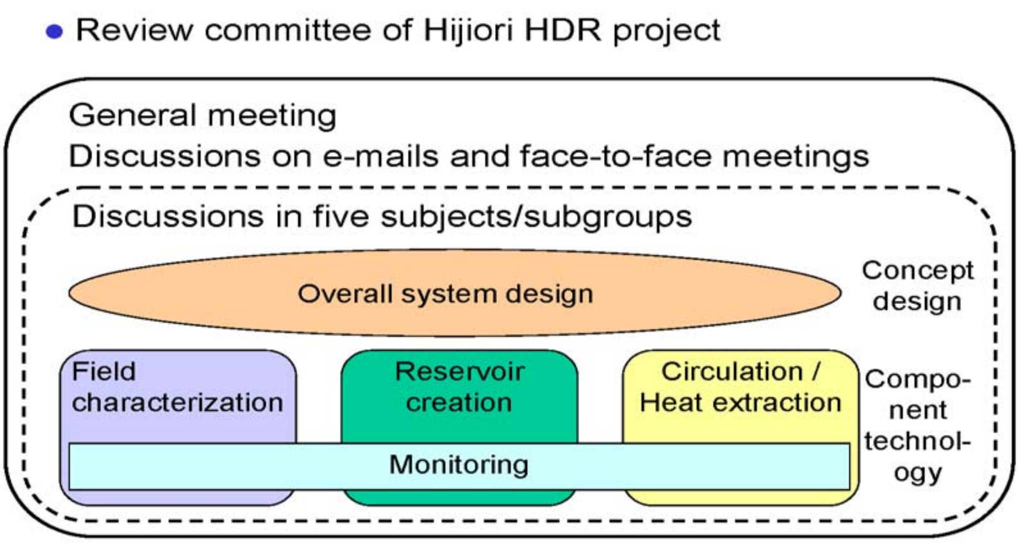

Figure 3.3 Review of the Hijiori EGS project.

The most essential parts of the review related to Subtask D are circulation and heat extraction and monitoring. Since Subtask D participants believe that these parts of the review will be useful for countries other than Japan, it will be translated from Japanese into English by March 2005.

3.4 Work Planned for 2005 and Beyond

3.4.1 Subtask B- Application of conventional Geothermal Technology to EGS

- The major US activities in 2005 are a long-term flow test of the enhanced reservoir at the Coso geothermal field; preliminary flow testing at Desert Peak, Nevada; evaluation of well bore stimulation experiments, analyses of flow test at the Geysers; and chemical stimulation at Glass Mountain.

- An analysis of EGS reservoir testing at foreign and domestic sites will be conducted for Subtask E activity.

- US DOE funded twelve EGS research projects near the end of 2004. Several of these projects seek to transfer technology developed for hydrothermal resources and for oil and gas to EGS; studies of petroleum industry stimulation technology and mining and civil engineering rock fracturing, use of shear-wave splitting for real-time fracture identification, testing of SP to monitor fracturing, and joint inversion of MT and micro-seismic data.

- DOE will continue to fund research that provides tools for both hydrothermal and EGS, including improved tracer test interpretation and coupled reservoir simulators (fluid flow – geochemistry – stress)

3.4.2 Subtask C- Data Acquisition and Processing

- The EGS-PMDA is a handbook to support new teams to start an EGS project. It is therefore of paramount importance to advertise the EGS-PMDA and to make it available for teams who are as yet unidentified within the "geothermal community".

- In 2005, no principal budget will be available for major activities. However, it is foreseen to advertise the EGS-PMDA via the Internet. Appropriate websites with the advertisement will be evaluated at the beginning of 2005. A further possibility of announcement will be the World Geothermal Congress 2005 in Antalya, Turkey. After the dissemination of the first version EGS-PMDA, an update and/or an extension of the classifier could be appropriate. This will depend on the experiences in 2005.

3.4.3 Subtask D- Reservoir Evaluation

- In 2005 Subtask D will continue the work without principal budget to compile and organize the answers of the Internet questionnaire.

- The summary of the report “Overall compilation and review of Hijiori HDR experiments” under a NEDO contract will be presented at the World Geothermal Congress 2005.

- Subtask D will distribute the results of questionnaire and summary using a CD-ROM at the end of the task.

3.4.4 Subtask E- Field Studies of EGS Reservoir Performance

Work in this new Subtask is currently in the planning stages.

3.5 Outputs

Adams, M.C. (2004) Use of natural-occurring tracers to monitor two-phase conditions in the Coso EGS project. *Proceedings Twenty-Ninth Workshop on Geothermal Reservoir Engineering*, *SGP-TR-175*, Stanford, California, January 26-28- 30.

Asanuma, H., Kumano, Y., Izumi, T., Soma, N., Kaieda, H., Aoyagi, Y., Tezuka, K., Wyborn, D., and Niitsuma, H. (2004) Microseismic monitoring of a stimulation of HDR reservoir at Cooper Basin, Australia by the Japanese team. Transactions Geothermal Resources Council, 28, 191-195.

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Robertson-Tail, A., Luts, S.J., Sheridan, J., and Morris, C.L. (2004) Selection of an interval for massive hydraulic stimulation in well DP 23-1, Desert Peak east EGS project, Nevada. *Proceedings Twenty-Ninth Workshop on Geothermal Reservoir Engineering*, *SGP-TR-175*, Stanford, California, January 26-28- 30.

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Wannamaker, P.E., Rose, P.E., Doerner, W.M., Berard, B.C., McCulloch, J., and Nurse, K. (2004) Magnetotelluric surveying and monitoring at the Coso Geothermal Area, California, in support of the Enhanced Geothermal Systems concept: Survey parameters and initial results. *Proceedings Twenty-Ninth Workshop on Geothermal Reservoir Engineering*, *SGP-TR-175*, Stanford, California, January 26-28- 30.

3.6 Websites Related to EGS Studies

Bad Urach project, Germany: http://www.geotermie.de/badurach2.html

Coso stimulation Project, USA: http://www.egs.egi.utah.edu

Deep Heat Mining, Switzerland: http://www.dhm.ch

DOE technical projects: http://www.eere.energy.gov/geothermal

GeneSys-Project, Germany: http://www.bgr.de/

Germany's Resources: http://www.tab.fzk.de/

Hijiori Project, Japan: http://www.nedo.go.jp/chinetsu/hdr/hijiorinow/html

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

Author: Isao Matsunaga, AIST, Tsukuba, Japan
Contact: Isao Matsunaga: matsunaga-isao@aist.go.jp

CHAPTER 4

Annex IV – Deep Geothermal Resources

4.1 Introduction

The Deep Geothermal Resources Task was started in 1997 as a four-year international collaborative program under the IEA Geothermal Implementing Agreement (GIA). In 2001, the GIA Executive Committee approved the continuation of this Annex to 2006.

The objective of the "Deep Geothermal Resources" Task is to address the issues necessary for the commercial development of deep geothermal resources at depths of about 3,000 m and deeper.

The participants in Annex IV during 2004 were: the Australian National University, Australia; the US Department of Energy (DOE), USA; Enel Green Power SpA, Italy; Forschungszentrum Jülich GmbH, Germany; Institute Geological & Nuclear Sciences Limited, New Zealand; Instituto de Investigaciones Eléctricas, Mexico.

The Australian, EC Soultz and German projects included in this Annex also involve the "creation" of geothermal reservoirs at depths much greater than 3,000 m, i.e. the application of EGS to create deep geothermal resources. Consequently, their work spans both Annex III-EGS and Annex IV- Deep Geothermal Resources. See Chapter 3 for additional details regarding these projects.

The Operating Agent for Annex IV is Forschungszentrum Jülich GmbH, Germany. The Task Leader for 2004 was Dieter Rathjen.

4.2 Subtasks of Annex IV

The investigations in this Task are divided into three subtasks.

4.2.1 Subtask A- Exploration Technology and Reservoir Engineering (Subtask Leader: to be appointed)

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

Four countries, New Zealand, Mexico, Italy and Japan, participated in Subtask A during 2003.

4.2.2 Subtask B- Drilling and Logging Technology (Subtask Leader: to be appointed)

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

There are 13 organizations in the Subtask B network from Australia (1), Italy (2), Japan (4), Mexico (1), USA (4) and Philippines (1).

4.2.4 Subtask C-Reservoir Evaluation (Subtask Leader: to be appointed)

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

4.3 Work Performed in 2004

4.3.1 Australia

Australia is currently involved in a pioneering EGS project in the Cooper Basin. The EGS venture of Geodynamics Limited in the Cooper Basin is working on a venture in an attempt to enable the production of electricity at lower costs than other mainstream renewable energy resources using deep, high temperature rock.

Habanero-2, the second deep geothermal well drilled in Australia, was completed to a depth of 4,358 m in 2005. Habanero-2 will be the production well of the pair, which includes Habanero-1, the injection well. The geothermal resource is one of the hottest in the Cooper Basin, with temperatures in excess of 250 °C confirmed. Pressure communication was established between the two wells during the Habanero-2 drilling phase.

4.3.2 Germany

The deep geothermal projects conducted by and participated in by Germany in 2004 included:

- **Groß Schönebeck**

The Groß Schönebeck study involved the *in-situ* investigation of the low enthalpy, Rotliegend reservoir in the northeast German Basin where thick, low permeability rocks attain temperatures necessary for geothermal power generation at depths of 4,000-5,000 m. This is part of an interdisciplinary project to develop the geothermal technology necessary for extracting existing geothermal fluid for electricity production through hydraulic fracturing to increase permeability in siliciclastic sediments and volcanic rocks of Rotliegend formation. Reprocessing of seismic data on the regional scale, and information obtained from an acoustic televiewer and fullbore formation micro-imager helped identify local stress features and show they agree with regional stress orientation and fault patterns.

Recent analysis of stimulation experiments conducted at Groß Schönebeck have also been successful, with flow rates increased significantly compared to the initial hydraulic state. However, further experiments are needed to stimulate areas farther away from the well and thereby hopefully increasing the flow to economic levels.

- **EC Soultz-sous-Forêts (Alsace, France)**

Germany continued its participation in 2004, with France, Italy, Switzerland and the EC, on the European Soultz-sous-Forêt project to develop a scientific geothermal pilot plant as the first phase. The second production well, GPK-4, was drilled in 2004. Hydraulic stimulation tests were initiated.

4.3.3 Mexico

Activities directed to the rigorous simulation of mass and heat transport in high-temperature hydrothermal reservoirs continue. The thermodynamic properties of single and binary fluids in the system H_2O-CO_2-CH_4 were calculated and compared well with those published for water, carbon dioxide and methane, as well as their binary mixtures.

Studies of Mexican geothermal fields under exploitation were also continued. The response to exploitation at Los Azufres was investigated through the examination of the evolution of thermodynamic patterns of reservoir fluids. Results show that the first response to exploitation was observed as a pressure decrease and enthalpy increase in wells, while the processes for the long term response are: decrease in both pressure and mass flow rate, boiling, cooling, steam production; and in wells affected by reinjection, increase in both pressure and mass flow rate.

Chemical and isotopic studies of the Los Azufres geothermal fluids indicate that changes in the reservoir are due to exploitation. Reservoir boiling and mixing of reservoir fluids with cooler fluids were the most important processes identified up to 2002.

4.4 Work Planned for 2005

The Soultz project is ongoing and will be continuing into 2006, when the pilot power plant is to be completed. Government aid from the EC, France and Germany will continue to provide funding.

The project at Groß Schönebeck runs through 2005 with little funding. The main focus of the work is: reservoir characterization, injection tests and material research. For further use a second borehole is needed. Currently, there is discussion with the ministry about financing the drilling (~ 7 million Euro).

4.5 Outputs

Huenges, E., Holl, H., Legarth, B., Zimmermann, G., Saadat, A. (2004)
The Stimulation of a sedimentary geothermal reservoir in the north German basin: case study Groß Schönebeck. Proc. 29 Workshop on Geothermal Reservoir Engineering, Stanford University, January, 26-28, 2004.
SGP-TR-174-177

Hettkamp, T. et. al. (2004) Energy production from hot rocks. Proc. 29 Workshop on Geothermal Reservoir Engineering, Stanford University, January 26-28, 2004.

Trautwein, U., Huenges, E. (2004) Pore pressure induced changes of permeability reflecting microstructural deformation in Rotliegend Sandstones. Submitted to International Journal of Rock Mechanics 2004

Geothermie Reports des Geoforschungszentrums Potsdam (only in German):

Report 2004/01
Sandsteine im in situ Geothermielabor Groß Schönebeck-Reservoircharakterisierung, Stimulation, Hydraulik und Nutzungskonzepte.

Report 2004/02
Experimente zur Produktivitätssteigerung in der Geothermie-Forschungsbohrung Groß Schönebeck.

Geothermal Reports/Papers for 2004

Baumgärtner, J., Jung, R., Hettkamp, T., Teza, D. (2004) The Status of the Hot-Dry-Rock scientific Power Plant at Soultz-sous-Forêts. Z. Angewandte Geologie 2/2004, 12-16.

Orzol, J., Jatho, R., Kehrer, P., Tischner, T. (2004) The GeneSys-Project- development of concepts fort he extraction of heat from tight sedimentary rocks. Z. für Angewandte Geowissenschaften, 2/2004, 17-23.

Schulz, R., Thomas, R., Jung, R., Schellschmidt, R. (2004) Geoscientific prospecr evaluation fort he Unterhaching geothermal power plant. Z. für Angewandte Geologie, 2/2004, 28-36.

Pape, H., Clauser, C., Iffland, J. (2004) Anhydrite Cementation and Compaction in Geothermal Reservoirs. Submitted to Int. J. Rock Mechanics and Mining Sciences 2004

Wagner, R. et al. (2004) Numerical Simulation of Pore Space Clogging in Geothermal Reservoirs by Precipitation of Anhydrite. Int. J. of Rock Mechanics and Mining Science, accepted 2004.

Geothermischer Fachkongress in Landau/Germany 10–12 November 2004 (only in German).

4.6 Websites Related to Annex IV Work

Australia

Geodyanmics: http://www.geodynamics.com.au

Geodyanmics: www.geodynamics.com.au/IRM/content/05 investor/05.5.html

Italy

Italian National Agency for New Technologies, Energy and the Environment: www.enea.it/com/ingl/default.html

Mexico

Instituto de Investigaciones Electricas: www.iie.org.mx

New Zealand

Institute of Geological and Nuclear Sciences Limited: www.gns.cri.nz

Germany

Bad Urach project: http://www.geotermie.de/bad_urach.htm

International Conference for Renewable Energies, 104 June 2004, Bonn, Germany: www.Renewables2004.de

Federal ministry for the Environment, Nature Conservation and Nuclear Safety: www.bmu.bund.de

Forschungszentrum Jülich, Project Management: www.fz-juelich.de/ptj/

EU-Project in Soultz-sous-Forêt: www.Soultz.net

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Contact: Dieter Rathjen: d.rathjen@fz-juelich.de

CHAPTER 5

Annex VII – Advanced Geothermal Drilling Techniques

5.1 Introduction

The objective of advanced drilling technology is to promote ways and means to reduce the cost of geothermal drilling through an integrated effort which involves developing an understanding of geothermal drilling needs, elucidating best practices, and fostering an environment and mechanisms to share methods and means to advance the state of the art.

Our collaborative effort has shown that drilling is expensive and can account for as much as 50% of total project cost. This observation is confounded because drilling research publications constitute less than 10% of published geothermal papers, indicating that either research and development in drilling is minimal or the time is not being taken to document status and successes. In front of the geothermal community worldwide is the need for lower drilling costs in order to make this energy source more economically accessible.

Improved drilling technology will be critical for development of deeper geothermal resources and 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. For example, if technological advances can be made to result in a decrease in well costs by 25%, a reduction in dry well rate by 25% and an increase in well productivity by 25% then, for a 50 MW_e flash plant a cost-of-electricity reduction of 20% is achievable (Figure 5.1).

Annex VII of the Geothermal Implementing Agreement has been developed to pursue advanced geothermal drilling research that will address all aspects of geothermal well construction. Participants in this Annex in 2004 were: Mexico, Iceland, the European Commission, New Zealand and the United States.

Sandia National Laboratories (USA) is the Operating Agent for Annex VII. Ed Hoover was Task Leader for the first half of 2004, followed by Jack Wise, who was replaced in early 2005 by Steve Bauer (all three of Sandia Labs).

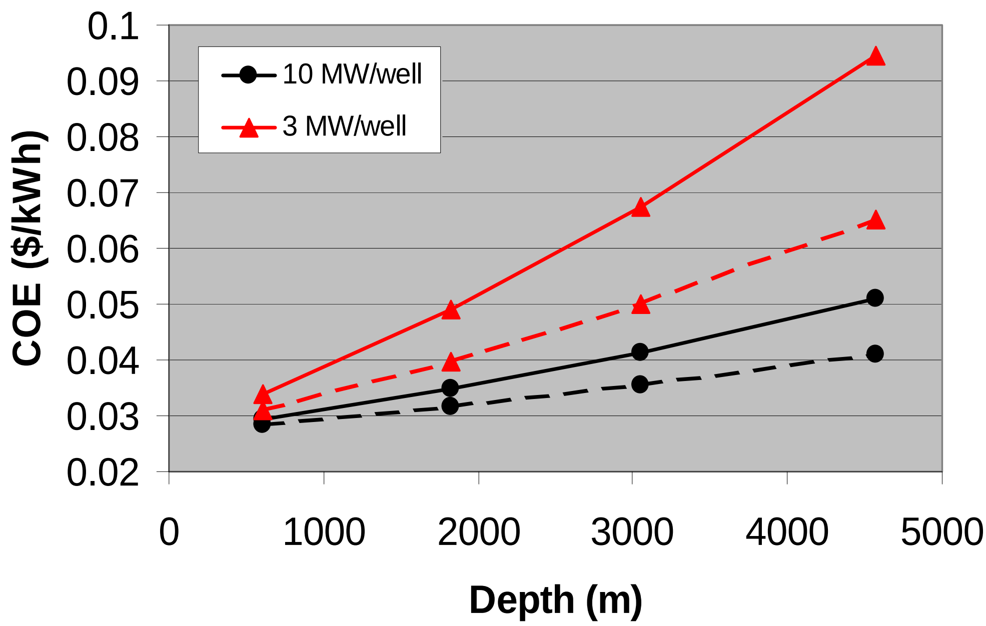


Figure 5.1 Decrease in cost of electricity versus well depth for a 50 MWe plant considering technology improvements

5.5 Subtasks

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

5.2.1 Subtask A- Compile Geothermal Well Drilling Cost and Performance Information (Subtask Leader: Previously Japan, now withdrawn from Annex VII. To be determined.)

This activity is a compilation of actual drilling cost and performance results associated with the development, construction and operation of geothermal wells. This information will be maintained in a single database, so that all participants can use it to identify key drilling operations that might be improved by new technology or by different drilling practices. It will include information on wells for both electricity and direct-use applications (including geothermal heat pumps), and will include information from 1990 to date.

The overall perception is that this Subtask suffers from a lack of cost and performance data. Another issue concerned the specification of how shared data will be used so as to allay company concerns about the release of proprietary information. Perhaps these situations could be alleviated through a better demonstration of the value that this information can provide to industrial donors – if shared and explained in a manner to accomplish mutual benefit. For example, we can compile individual well cost data to determine where the major costs drivers are (Figure 5.2) by reviewing cost breakdown and, for example, reviewing flat time events (Figure 5.3) to develop remedy and prevention scenarios

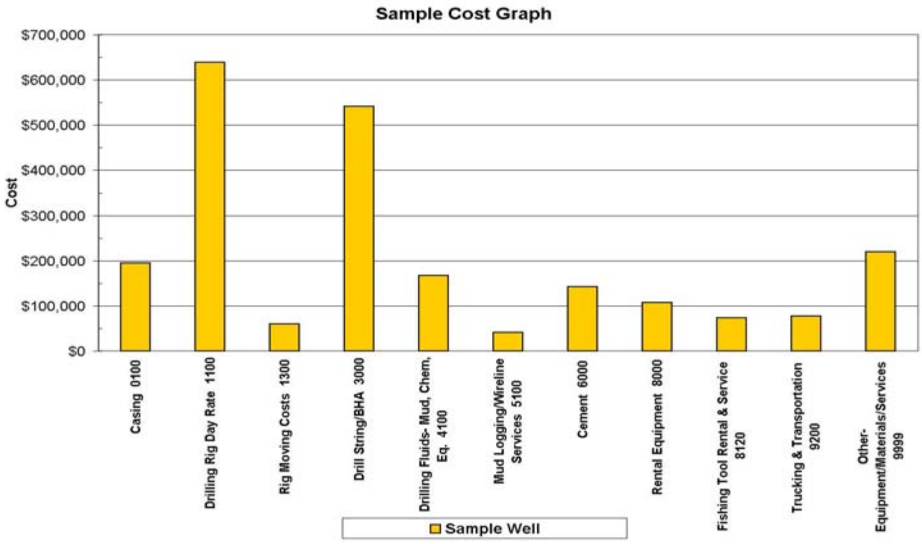
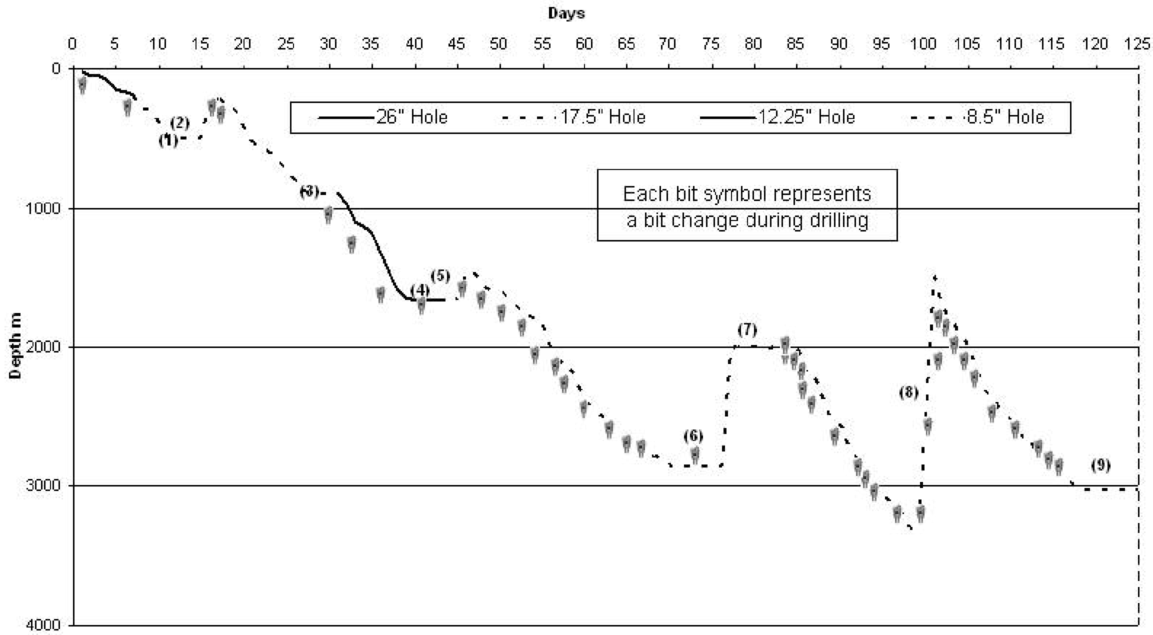


Figure 5.2 Cost breakdown in a sample well.

5.2.2 Subtask B- Geothermal Drilling Best Practices Handbook (Co-Subtask Leaders: High Temperature Drilling: Jaime Vaca, Comisión Federal de Electridad (CFE), Mexico; Low Temperature Drilling: Sverrir Thorhallsson, Orkustofnun (OS), Iceland)

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



1. 502 m - Stuck pipe/twist off at 271 m, 123 non-productive fishing hours.
2. 195 m - Pull out to shallower depth to drill around fish.
3. 896 m - Run and cement casing, treat wellhead, 88 hours.
4. 1655 m - Run and cement 12.25" casing, ream and test well, 143 hours.
5. 1460 m - Clean out cement, prepare BHA for directional drilling.
6. 2853 m - Twist off at 1820 m, retrieve part of fish, 155 non-productive hours.
7. 1993 m - Set cement plug, try to sidetrack around fish, 192 non-productive hours.
8. 1491 m - Pull out of hole to drill second leg.
9. 3016 m - Lost pressure, twisted off, fish and tear down rig, 79 non-productive hours.

Figure 5.3 Flat time "events" encountered in a well.

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.

The current status of the development of a "best practices" Handbook for geothermal drilling is as follows. Sverrir Thorhallsson (Orkustofnun, Iceland) has prepared a list of references that he uses for his drilling classes, as well as a draft *Table of Contents* for the Handbook. Mexico (CFE) has confirmed its intention to maintain its joint leadership role (with Iceland) for this Subtask.

5.2.3 Subtask C- Advanced Drilling Collaboration (Subtask Leader: Ed Hoover (to July 2004), Jack Wise (to early 2005); Steve Bauer (from early 2005), Sandia National Laboratories (SNL), USA)

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

The Advanced Drilling Collaboration is focusing on potential opportunities for collaborative field tests, particularly in Iceland and Mexico. Sverrir Thorhallsson has outlined upcoming work for the Iceland Deep Drilling Project (IDDP), whose first phase was scheduled to begin in December 2004. This work will involve completions to depths as great as 5 km. He expressed particular interest in collaborative efforts (e.g. with Sandia) to develop suitable logging tools to support this drilling program. Sverrir indicated that he planned to draft an "Offer Sheet" for circulation among Annex VII participants, which would describe detailed plans for upcoming wells. David Nieva agreed to have a CFE representative contact the Subtask C leader to discuss possibilities for technology demonstrations in conjunction with production geothermal drilling in Mexico.

Sandia Labs has agreed to supply a high temperature (300°C) down hole tool to support long-term pressure and temperature monitoring in a geothermal well in Australia.

5.3 Work Performed in 2004

The Annex VII working group met twice in 2004: on 17 March 2004 at IEA Headquarters in Paris, France, and on 12 October 2004 in Pisa, Italy.

All Subtasks were discussed at each of these meetings, with extensive input from participants. Although Subtask objectives are fairly clear and, in some cases, specific work assignments have been defined, a serious shortcoming in the work process is the funding mechanism under which the Annex operates. Because the Annex is structured in a task-sharing mode rather than cost-sharing, the labour-intensive activities such as data collection for Subtask A and writing/editing for Subtask B have very little support. This situation has been reported in some detail to the Executive Committee, and progress by the working group is somewhat dependent on the resolution.

Each attendee provided brief introductory remarks and indicated his organization’s interest in geothermal drilling in general and Annex VII in particular. The principal objectives were to update progress on the sub-tasks and to determine further actions needed to maintain progress.

A review of the discussions and decisions made at the two meetings is presented for each Subtask.

5.3.1 Subtask A- Compile geothermal Welling Drilling Cost and Performance Information

Meeting of 17 March 2004

Data on well cost are difficult to obtain. Thus far, the cost database only has information for 3 Japanese wells, 3 Mexican wells, and 1 US well. Information for 3 more Mexican wells was in preparation as of the last meeting in Reykjavik, but the current status of that data is unknown.

Well performance data, especially well depth versus drilling time, are much easier to obtain than cost data. The database contains performance information on 27 wells from Iceland. New Zealand may be able to offer data from six wells, and the European Commission can provide data from two wells at Soultz. Sandia has thus far been unsuccessful in obtaining data from US companies.

Satoshi Kubo left NEDO at the end of March, ending his active leadership of Subtask A. Apparently, NEDO intend to withdraw from the Annex. NEDO’s departure leaves the question of who will succeed as Subtask Leader. CFE may be interested, however, should they decline, inquiries are being made to see if Sandia could assume the leadership. All Participants will provide additional well data for the database from their available sources. Sources in the Philippines and Indonesia will be contacted for possible well data.

Meeting of 12 October 2004

Several issues were raised regarding Subtask A. First of all, Mexico (CFE) has not yet accepted the leadership role for this Subtask, which was formerly led by Japan (NEDO). A need was identified for an explicit description of responsibilities for the Subtask Leader. CFE will be contacted to ascertain their position on the issue of subtask leadership.

The overall perception was that this Subtask suffers from a lack of cost and performance data. Another issue concerned the specification of how shared data will be used so as to allay company concerns about the release of proprietary information. The participants agreed to compile (by 15 January 2005) individual lists of specific data that they would (1) find useful and (2) be willing to share.

It was pointed out that including information pertinent to the contractual basis under which a particular well was developed would enhance the database. Such information would clarify the distribution of risk. For example, it would be useful to know whether the well contract was based on either price per meter, day rate, fixed price plus price/meter, lump sum, or other combination of terms. Also, data pertaining to the type of rig (top drive or rotary table) and the type(s) of drilling fluid used on a given well would also be of value.

5.3.2 Subtask B- Geothermal Drilling Best Practices Handbook

Meeting of 17 March 2004

It was indicated that enough CFE material exists to move ahead with a Handbook of best practices, but the Subtask needs support in the form of funding for CFE researchers or an outside contractor.

The Handbook will document practices that have been found safe, efficient, and cost-effective in international geothermal drilling. It was pointed out that Iceland is drilling over 200 m per day and the Handbook would be quite useful in helping to reduce costs. A code of practice exists in New Zealand and the code might serve as a reference for the Handbook.

At the meeting in Reykjavik, two steps were proposed for this Subtask: attempt to identify existing literature references that are applicable to various sections of the Handbook, and post the Handbook outline on the GIA website and solicit comments. No progress was reported on these items.

Two options for completing the Subtask were discussed: (1) compile a set of references that would serve as a guide to the literature of best practices; (2) proceed with the Handbook as originally planned. Option (1) could be accomplished with nominal cost; option (2) would require the establishment of a common fund. No decision was made as to which option to pursue, but the participants felt that references could be obtained without difficulty. The status of posting the Handbook outline on the website will be investigated. All participants will provide a list of references to best drilling practices in their countries. A contact person at Sandia to whom the references should be sent will be identified.

Meeting of 12 October 2004

Focus was on defining the current status of the development of a "best practices" Handbook for geothermal drilling. Iceland had prepared a list of references used for drilling classes, as well as a draft *Table of Contents* for the Handbook. It was agreed this information would be forwarded for distribution to the other Annex VII members. Mexico (CFE) confirmed its intention to maintain its joint leadership role (with Iceland) for this Subtask.

5.3.3 Subtask C- Advanced Drilling Collaboration

Meeting of 17 March 2004

Activities in Iceland that may affect this Subtask were reported on. The Iceland Deep Drilling Project (IDDP) provides an excellent opportunity for collaboration in the testing of a variety of new tools. Specific interest in memory tools was expressed. Besides the IDDP, other wells in Iceland could be used for field testing. Iceland has experience with fracture stimulation and thermal stress cracking by pumping water over a wide range of flow rates, and improvements due to stress cracking in 5 of 6 wells were reported.

Interest in collaboration will depend on the facilities being offered to conduct the collaborative testing. A full description of those facilities would be helpful for a participant to decide on whether to collaborate. A description of facilities available in Iceland for future collaboration will be provided. Inquiries will be made as to what CFE may be able to offer for collaboration. A decision on whether Italy wishes to join the Annex will also be obtained.

Meeting of 12 October 2004

Discussions centred on potential opportunities for collaborative field tests, particularly in Iceland and Mexico. The upcoming work for the Iceland Deep Drilling Project (IDDP) was outlined, the first phase of which was scheduled to begin in December 2004. This work will involve completions to depths as great as 5 km. Iceland expressed particular interest in collaborative efforts (e.g. with Sandia) to develop suitable logging tools to support this drilling program. Iceland indicated that a an "Offer Sheet" would be drafted by 17 November 2004, for circulation among Annex VII participants, which would describe detailed plans for upcoming wells. It was agreed that a CFE representative would contact the Subtask C leader (Jack Wise) by 15 December 2004 to discuss possibilities for technology demonstrations in conjunction with production geothermal drilling in Mexico.

5.4 Highlights of Annex Programme Work for 2004

Two Annex VII posters were prepared for display at WGC 2005, one for IEA/GIA booth, the other for the technical poster session:

Wise, J. L., and J. T. Finger, "The IEA's Role in Advanced Geothermal Drilling," to be displayed during Technical Poster Session 1 at WGC 2005, Antalya, Turkey, April 24-29, 2005.

Wise, J. L., and J. T. Finger, "IEA/GIA Annex VII: Advanced Geothermal Drilling Technology," to be displayed in the IEA/GIA Booth at WGC 2005, Antalya, Turkey, April 24-29, 2005.

The following research papers and reports were also produced:

Fridleifsson, G.O., W.A. Elders, S. Thorhallsson, and A. Albertsson, "The Iceland Deep Drilling Project - A Search for Unconventional (Supercritical) Geothermal Resources," to be published in conjunction with WGC 2005, Antalya, Turkey, April 24-29, 2005.

Normann, Randy A., Recent Advancements in High-Temperature, High-Reliability Electronics Will Alter the Geothermal Industry, SAND2004-0902 A, World Geothermal Congress 2005 Antalya, Turkey, 04/24/2005.

Tyner, C. E., J. T. Finger, A. Jelacic, and E. R. Hoover, "The IEA's Role in Advanced Geothermal Drilling," to be published in conjunction with WGC 2005, Antalya, Turkey, April 24-29, 2005.

Wise, Jack L., Mansure, Arthur J., Blankenship, Douglas A., Hard-Rock Field Performance of Drag Bits and a Downhole Diagnostics-While-Drilling (DWD) Tool, SAND2004-2318 C, World Geothermal Congress 2005 (WGC 2005), Antalya, Turkey, 04/24/2005.

5.5 Work Planned for 2005

Plans to be developed at an Annex VII meeting to be held in conjunction with the 13th ExCo Meeting, in April 2005, in Antalya, Turkey,

5.6 Outputs

Bauer, Stephen J., Gronewald, Patrick J., Mansure, Arthur J. High-Temperature Plug Formation With Silicate Hydrates, SAND2004-2983 C International Symposium on Oilfield Chemistry, The Woodlands TX USA, 02/02/2005

Bauer, Stephen J. & Mansure, Arthur J., Comments on High Temperature Plugs: Progress Report on Polymers and Silicates SAND2004-4142 C 2004 Geothermal Research Council Conference, Indian Wells CA USA, 08/30/2004

Bauer, Stephen J., Gronewald, Patrick J., Mansure, Arthur J. High-Temperature Plug Formation with Silicates, SAND2004-6503 C, 2005 SPE International Symposium on Oilfield Chemistry, The Woodlands TX USA, 02/02/2005

Elders, W. A., and G. O. Fridleifsson, "The Iceland Deep Drilling Project - Scientific Opportunities," to be published in conjunction with WGC 2005, Antalya, Turkey, April 24-29, 2005.

Fridleifsson, G. O., W. A. Elders, S. Thorhallsson, and A. Albertsson, "The Iceland Deep Drilling Project - A Search for Unconventional (Supercritical) Geothermal Resources," to be published in conjunction with WGC 2005, Antalya, Turkey, April 24-29, 2005.

Finger, John Travis, Hoover, Eddie R. The IEA's Role in Advanced Geothermal Drilling Technology, SAND2004-0507 C, World Geothermal Congress 2005, Antalya, Turkey 04/24/2005

Normann, Randy A., Recent Advancements in High-Temperature, High-Reliability Electronics Will Alter the Geothermal Industry, SAND 2004-0902C World Geothermal Congress 2005 Antalya, Turkey, 04/24/2005

Tyner, C. E., J. T. Finger, A. Jelacic, and E. R. Hoover, "The IEA's Role in Advanced Geothermal Drilling," to be published in conjunction with WGC 2005, Antalya, Turkey, April 24-29, 2005.

Wise, Jack L., Mansure, Arthur J., Blankenship, Douglas A., Hard-Rock Field Performance of Drag Bits and a Downhole Diagnostics-While-Drilling (DWD) Tool, SAND2004-2318 C, World Geothermal Congress 2005 (WGC 2005), Antalya, Turkey 04/24/2005

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5.7 Websites Related to Annex VII Work

None yet, although the Annex VII working group has requested that an outline for the *Best Practices Drilling Handbook* be posted on the GIA website.

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CHAPTER 6

Annex VIII – Direct Use of Geothermal Energy

6.1 Introduction

The Direct Use of Geothermal Energy Annex is the most recent to be included in the GIA. It was initiated on 19 September 2003, when the agreement entered into force. Efforts during 2005 have concentrated on extending the membership of the Annex prior to the start of actual work. Work in the Annex is expected to begin in 2005, and continue to 2007.

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

The objectives of Annex VIII are to:

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

The Contracting Parties who officially agreed to participate in this Annex as by the end of 2004 were: The Federation of Icelandic Energy and Waterworks (Iceland) and Switzerland. In early 2005, Japan, New Zealand and USA confirmed their participation in the Annex, extending the total participation to five countries.

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

6.2 Subtasks

The objectives of this Annex will be achieved through work in four subtasks. The Subtask Leaders remain to be appointed.

6.2.1 Subtask A- Resource Characterization

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

6.2.2 Subtask B- Cost and Performance Database

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

6.2.3 Subtask C- Barrier and Opportunity Identification

Based on subtasks A and B, this Subtask 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.

6.2.4 Subtask D- Equipment Performance Validation

The work in this Subtask will 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. The testing can be at multiple sites or can be round robin.

6.3 Funding

The collaborative direct use technology research to be carried out under this Annex will involve both cost-sharing and task-sharing. A common fund will be established to cover the special duties of the Operating Agent, including the cost of publishing the reports and summary assessments and the cost of maintaining and distributing the cost database. The costs associated with collecting the information in the database shall be borne by the respective participants. In addition, each participant shall bear all costs it incurs in carrying out the Annex activities, including reporting and travel expenses.

The level of effort to perform the work specified in this Annex is estimated to be no more than one-person year per year for each participant.

6.4 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. Further, enhanced cooperation between the countries and increased exchange of technical and scientific information within the field of direct use of geothermal energy. 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.

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CHAPTER 7

Synopsis of National Activities

7.1 Introduction

This chapter, which is based on the national activities reports presented in Chapters 8-17, provides a brief summary of the geothermal state of affairs in the Member Countries and EC for 2004. It generally includes: national policy; current status of geothermal energy use (both for electricity generation and direct use); market development, stimulation and constraints; economics; research activities; education and international cooperation.

The status of geothermal installed capacity, electricity generated and direct use for 2004 are provided in Table 7.1 for the Member Countries.

7.2 The Context

Geothermal energy is used for the production of electricity and for direct heat applications such as district heating, agricultural drying, industrial processes, green house and aquaculture pond heating, bathing and swimming and snow melting. In 2004, electricity was being generated from geothermal sources in 24 countries, with a total installed capacity of 8,900 MW_e (Bertani, 2005). At the end of 2004, the installed thermal power was estimated to be about 27,830 MW_t, with 71 countries reporting the use of 261,420 TJ/yr (72,600 GWh/yr) (Lund, *et al*., 2005). There is considerable potential for a growth in geothermal electricity generation and it is possible that 5% of the global electricity could be supplied by 2020. The installed thermal power doubled between 1995 and 2000, and again between 2000 and 2005, and this significant growth is expected to continue, especially will the increasing interest in the use of geothermal heat pumps.

In 2004, the worldwide use of geothermal energy for electricity generation and direct uses saved the equivalent of about 28 million tonnes of oil (Mtoe) and reduced CO_2 emissions by about 92 million tonnes (Mongillo, 2005).

The use of geothermal energy provides many benefits: low emissions of pollutants such as particulates and greenhouse gases, especially CO_2; less dependence on imported fuels, hence reduced problems caused by their price fluctuations; increased security and more diversity in supply; independence from weather oscillations; effective distributed application in both on and off grid developments, especially useful in rural electrification schemes; and more employment and opportunity for industry and the local population through equipment supply and plant construction and servicing.

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

7.3 Review and Highlights of National Activities

7.3.1 Australia

At present, electricity is being generated by one 120 $kW_{e\,(net)}$ binary power station operating in western Queensland, and it produced about 1 GWh in 2004. There is also a small amount of direct use in the country, about 825 GWh was used, mainly for space heating and bathing.

However, Australia's fledgling geothermal industry is growing, with significant interest in the Geodynamics Limited EGS "proof of concept" project being conducted in the Cooper Basin. In 2004, Australia's second deep geothermal well was completed to 4,358 m and pressure communication was established with the first well, which was drilled in 2003. Temperatures in the drilled area of interest are as high as 250 ºC. Production testing will be conducted in 2005.

Interest in geothermal energy development is growing in Australia, with several new "geothermal" companies having formed (one having listed on the Australian Stock Exchange) and planning geothermal exploration programmes

Table 7.1 Installed capacity, power generated and direct use for GIA Member Countries in 2004 unless otherwise noted (§ = data from Bertani (2005) and Lund, *et al*. (2005)).

Country*	Installed Capacity (MW_e)	Power Generated (GWh)	Direct Use Energy Utilized (GWh)
Australia	0.120§	1§	825§
Germany	0.23§	1.5†§	808§
Iceland	202	1,433	6,600
Italy	862	5,127	2099§
Japan	535.25	3,486	1,428
Mexico	953	6,360	537
New Zealand	452	2,774	1,969
Switzerland	0	0	1,190
United States	2,400	16,000	8,678§
TOTAL	5,404.6	35,182.5	24,134

* Note that the European Community is not listed since it is not a country and generates none of its own energy.
† Estimated annual production.
§ Based on data from Chapters 8-17 of this annual report.

In 2004, the Government provided A$ 1.5 M to Geodynamics Limited for its Cooper Basin geothermal project; with industry providing about A$ 17 M for this R&D project.

Three states in Australia have geothermal exploration and development legislation in place and geothermal energy is included in the *Renewable Energy (Electricity) Act 2000,* which addresses greenhouse gas emission. A National Mandatory Renewable Energy Target (MRET) of 9,500 GWh/year of new renewable electricity by the year 2010 has been set, though it is currently under review.

7.3.2 European Community

The European Commission currently supports a major European EGS project at Soultz-sous-Forêts, France. This project involves France, Germany, Italy and Switzerland, in addition to groups from inside and outside Europe, including Japan and the USA. The project is coordinated by an industrial consortium, European Economic Interest Grouping (EEIG) Heat Mining. Most of the funding is provided equally by EC, France and Germany.

The aim of this project is to create an EGS at about 5,000 m depth, using one central injection well and two symmetrically located production wells to generate 6 MW_e of electricity. In 2004, the second production well was completed to about 5,000 m depth; and initial hydraulic stimulation was carried out.

The current plan is to bring a 1.5 MW_e power plant on line in late 2005, with completion of the 6 MW_e plant in 2006.

7.3.3 Germany

Germany inaugurated its first geothermal power plant (binary system) at Neustadt-Glewe, where a 250 kW_e plant was commissioned in late 2003.

There was a direct use installed capacity at the end of 2004 of about 500 MW_t, with about 800 GWh used. Direct heat is mainly used for thermal spas, space heating/cooling and greenhouse heating, with geothermal heat pumps making up the bulk of the use.

Germany worked on two deep EGS projects in 2004, the first its participation in the European Soultz-sous-Forêts programme; the other, at Bad Urach, where an EGS pilot plant demonstration venture was planned. At the latter, the second well experienced problems at 2,800 m, and drilling was halted. The Government has decided that continuation of the project will require financial participation by industry.

In addition, Government funded research continued at four sites located in northern Germany, to develop methods for utilizing shallower hot water/steam resources, in sedimentary structures having normal temperature gradients (30 °C/km). Techniques for dealing with high salinity fluids and new stimulation methods using water gel proppants are being investigated.

There were three R&D industry funded projects, with two known to be funded with "risk capital".

On 1 April 2000, the Law on Energy Supply (LES) became effective as a part of Germany's attempt to promote renewable energy use. It guarantees a minimum payment to companies that provide electricity from renewable resources, with geothermal getting 7.16-15 €-cents/kWh. This approach provides long-term planning and control protection. In addition, Germany signed the Kyoto Protocol in 2003, which will further encourage geothermal development as a part their aim to increase electricity production through the use of renewables to 20% by 2010.

7.3.4 Iceland

The renewables hydro and geothermal provide about 70 % of the primary energy supply in Iceland, with geothermal providing > 50%. In 2004, Iceland had an installed capacity of 202 MW_e and produced 1,433 GWh, or 17% of Iceland's electricity.

In Iceland, geothermal is mainly employed in direct use, with about 6,600 GWh utilized in 2004. Principally used for space heating, geothermal supplies about 87% of the total. Direct use of geothermal energy is also employed for heating swimming pools, snow melting (sidewalks, parking spaces, streets), greenhouses (air and soil heating), fish farming (~ 50 farms, mainly salmon) and industrial uses (production of diatomite for filters, drying seaweed, salt, liquid CO_2, wood and fish drying, *etc*.).

The use of geothermal energy in Iceland provided a savings of about 0.7 Mtoe and reduced or avoided the emission of about 2.23 Mt of CO_2.

Expansion in energy intensive industry has resulted in a rapid increase in electricity demand and stimulated large-scale geothermal power development, with 200 MW_e now under construction.

The United Nations University Geothermal Training Programme has been operating a 6-month annual course for professionals from developing countries since 1979. It offers specialized training in various geothermal disciplines, and provides the opportunity to continue on towards a MSc degree at the University of Iceland.

7.3.5 Italy

Geothermal energy In Italy is mainly used to produce electricity, and at the end of 2004 the installed capacity was 862 MW_e. The net generation exceeded 5.1 billion kWh, and provided 1.9% of Italy's total domestic generation and 24% of that used in Tuscany. Geothermal resources are also used in direct applications, with about 975 GWh utilized in 2003 for providing heat to spas, space and district heating, fish farming, greenhouses and industrial processes; and saved about 213 ktoe (thousand tons of oil equivalent). In addition, 36,000 tonnes of CO_2 was produced from a "dead" well for the food industry. The proprietary AMIS technology for H_2S and Hg emission abatement is being retrofitted on 15 existing plants and two new ones.

The use of geothermal energy for electricity generation and direct use saves approximately 1.4 Mtoe and avoids the emission of about 4 Mt of CO_2.

From 2002, all electricity operators had to generate, or purchase, at least 2% (> 3.5 billion kWh) from "new renewable plants". This encouraged the renewables market and gave rise to the "Green Certificate" market. Each Green Certificate in 2004 proves 50 MWh of electricity is being generated by renewables and in 2004 was worth 9.739 €-cent/kWh. The value of renewable generated electricity is the sum of the base price plus that of the Green Certificate.

As a signatory to the Kyoto Protocol, Italy has been charged with reducing greenhouse gas emission by 6.5% of 1990 level within the 2008-2012 commitment period (note the EU's total reduction is 8%). Subsequently, a 2002 economic planning decree stipulated that the Italian electricity industry must reduce their CO_2 emission by 26 million tons/year, or 50% of Italy's required total. One consequence has been the setting of a target of 500-1,200 MW_e increase in installed capacity from renewable power plants, resulting in a CO_2 reduction of 1.5-3.1 million tons/year.

Italian research activities continued to focus on the development of geophysical models that will improve on the ability to discover resources, hence reduce risk. New methods for interpreting seismic reflection data have been quite successful in locating fractured zones at depths > 3,000 m.

7.3.6 Japan

Japan's total geothermal output capacity has remained almost constant at 535 MW_e for the past few years and the only new developments expected are small binary units. As of March 2004, geothermal resources generated about 0.3% of the total electricity generated, or 3,486 GWh of a total of 1,094 TWh. This is equivalent to a savings of 0.92 Mtoe with an avoided

CO_2 emission of 2.8 Mt. Total direct use of geothermal water as of March 2002 was about 1,430 GWh (5,139 TJ), excluding bathing, and is equivalent to a savings of 0.12 Mtoe.

The government has taken a leading role in the development of geothermal resources by providing compensation for interest on bank credits to support developers undertaking well drilling (requires large investment at early stage); and construction of production and reinjection wells, ground facilities and binary power generation facilities. In addition, NEDO continues its programme to support geothermal development by funding surveys in prospective areas where investigations are of high risk; and NEF assists with the business of developing new energy sources.

The Japanese government implemented the Renewable Portfolio Standard system in 2003. It requires electricity utilities to procure a certain percentage of electricity from renewable resources, including geothermal. Electricity businesses can trade the excess or deficiency of renewable energies versus the target, in the form of securities.

Geothermal research in Japan during 2004 dealt mainly with the comprehensive evaluation of EGS power generation (AIST) and international cooperative investigations into the use of acidic geothermal fluids (NEDO).

Japan offers a doctoral geothermal programme at Kyushu University, which was initiated following the closure, in 2001, of the International Group Training Course on Geothermal Energy that operated for over 30 years and trained almost 400 specialists from 37 countries.

7.3.7 Mexico

Geothermal energy is mainly used for electricity generation in Mexico. In 2004, the installed capacity was 953 MW_e (third largest in the world) and 6,360 GWh was generated, about 3% of Mexico's total electricity production. Assuming the typical mix of fuel oil, natural gas and coal in electricity generation, geothermal electricity generation saved 36, 15.9 and 8.9 PJ, respectively. There is a small amount of direct use, 164 MW_t, mainly for balneology.

In Mexico, geothermal energy is considered a mature technology, thus it competes on an equal basis with fossil fuels, hydro and nuclear. Consequently, there are no incentives for its development. However, the Comisión Federal de Electricidad (CFE) is pursuing feasibility studies for increasing installed capacity and replacing some of the older power plants.

Most research continues to be focused on the development and exploitation of geothermal resources for power generation, hence, is mainly aimed at improving knowledge of fields and predicting their behaviour during exploitation.

A geothermal training programme is offered at The University of the State of Baja California, however, most engineers and geologists are provided on-the-job training.

7.3.8 New Zealand

In New Zealand, geothermal energy continues to play an important role in both electric power production and direct use. As of October 2004, the geothermal installed capacity was 452 MW_e, with 2,774 GWh produced and contributing about 7% of the country's total generation. In 2004, the direct use installed capacity amounted to over 300 MW_t, with about 1,970 GWh (7,090 TJ) utilized in applications that included pulp and paper production (210 MW_t), timber drying, prawn breeding, glasshouse heating and tourism.

In 2004, new power developments were under construction at Mokai (40 MW_e) and Wairakei (15 MW_e).

Government policies encourage more renewable energy resource development, including geothermal. Interest in geothermal development is also increasing as a result of increasing fossil fuel prices, dwindling gas reserves and the growing importance of achieving the net CO_2 reductions specified under the Kyoto Protocol.

New Zealand government funded research continues to concentrate on four areas: deep high-temperature resources, use of low-enthalpy resources, better use of waste geothermal fluids and environmental effects.

The University of Auckland offers geothermal engineering and science MSc and PhD programmes, and the New Zealand Geothermal Association offers educational events such as seminars and workshops.

7.3.9 Switzerland

At present, there is no electricity generation from geothermal energy in Switzerland, though a major EGS project, Deep Heat Mining (DHM), is underway. In Basel, a well was recently drilled to 2.7 km and seismic equipment has been installed to record seismicity; and at Geneva, and well siting investigations are proceeding. In 2004, the local parliament secured major funding (20 M €) for the next phase of the Basel project, which includes drilling to 5 km and stimulation and circulation tests.

There is significant geothermal direct use in Switzerland, mainly for heating and at spas. In 2004, the total installed capacity was about 585 MW_t, with a total 1,190 GWh energy used. Of the latter, geothermal heat pumps provided 781 GWh, almost 70% of the total geothermal heat production. The total geothermal use is equivalent to savings of about 150,000 toe and a reduction in CO_2 emission of 450,000 tonnes.

The use of geothermal heat pumps continues to grow in Switzerland, and its worldwide rank in their use is very impressive (see Table 16.4). There is also an emerging demand for using them for both heating and cooling.

The SwissEnergy programme, mainly devoted to the more efficient use of energy (including reduction of CO_2 emissions and increasing the contribution of renewable energies), supports and promotes the use of indigenous renewable energy. Its basic strategy is to use voluntary measures as far as possible, though other control measures such as CO_2 tax and incentives are available if necessary.

Geothermal research in Switzerland includes involvement in the EC EGS project at Soultz.

Significant effort is going into geothermal education and information dissemination in Switzerland, including regular university lectures. In addition, in 2004, special post-graduate courses and workshops were offered and education was provided on the international level with presentation of short courses in Poland.

7.3.10 United States of America

In 2004, the installed geothermal power capacity in the USA was about 2,400 MW_e, with about 2,020 MW_e operating to generate 16,000 GWh (about 0.4% of total US generation), at a capacity factor of 90 %. Use of geothermal for generating electricity in the US reduced the emission of CO_2 by about 12-16 million tonnes, compared to the use of oil or coal plants, respectively.

The total installed thermal capacity for direct heat use in 2004 was about 7,820 MW_t, utilizing about 31,240 TJ (8,678 GWh), with direct use amounting to about 620 MW_t, using 9,025 TJ, and heat pumps 7,200 MW_t using 22,200 TJ (Lund, 2005).

Several events and activities may be highlighted for the 2004 US geothermal programme, including: the passing of the production tax credit, which includes an expansion of the renewable energy production tax credit to geothermal electricity; the scaling-back of CalEnergy's zinc extraction from geothermal fluid operation.

The US DOE Geothermal Technologies Program seeks to make geothermal energy the Nation's preferred base-load energy alternative, with the mission to work with US industry to establish geothermal energy as an economically competitive contributor to the US energy supply. The Program has three strategic goals: to decrease the levelized price of geothermal generated electricity to less than 5 US cents/kWh by 2010; increase the economically viable geothermal resource to 40,000 MWe (hydrothermal and EGS) by 2040; and decrease the levelized cost of EGS to less than 5 US cents/kWh by 2040. Top priority has been given to technology development of EGS.

The US DOE Geothermal Technologies Program has set a goal of reducing the cost of geothermal electricity to competitive levels through improvements in technology and expansion of the geothermal resource base by 2010. The Production Tax Credit will contribute to bringing additional geothermal resources on line.

The US DOE works in partnership with US industry to conduct geothermal research, development and deployment in: EGS, exploration, well field construction, power systems and energy conversion, and institutional barriers.

There are a large number of geothermal education activities in the US, including: education at the graduate level, through a university research programme, and for the public, teachers and students nationwide through the Geothermal Education Office (GEO). The Geothermal Resources Council and the Geo-Heat Center at the Oregon Institute of Technology also provide additional education services; and several universities have geothermal research centres.

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CHAPTER 8

Australia

8.1 Introduction

Geothermal energy becomes better known in the Australian community because of publicity associated with the hot fractured rock project operated by Geodynamics Limited in the Cooper Basin.

Geodynamics completed its second well, Habanero-2, a production well 500 m south west of its injection well, Habanero-1 (see Figure 8.1 showing steam production). The well was completed at a depth of 4,358 m. Pressure communication between the two wells was established during the drilling phase. The 35 Mpa overpressures encountered will be tested in 2005 for natural geothermal production and for energy extraction by circulation between the two wells.

Geodynamics is also actively seeking projects to develop Kalina Cycle electricity generation based on its exclusive Australasian license of the patented process.

Several other companies are making attempts to commercialize geothermal energy, particularly in South Australia.

8.2 National Policy

8.2.1 Strategy

Geothermal energy is included in the National Mandatory Renewable Energy Target (MRET) of 9,500 GW of new renewable electricity by the year 2010.

8.2.2 Legislation and Regulation

Three states, South Australia, New South Wales and Queensland have legislation in place to control geothermal exploration and development. The regulations governing the Queensland legislation are still not completed.

8.2.3 Progress Towards National Targets

The review of the MRET target was completed with a result that it would not change. The Government has placed a new emphasis on carbon capture and sequestration.

8.2.4 Government Expenditure on R&D

This year the Government provided $1.5 million to Geodynamics Limited.

8.2.5 Industry Expenditure on R&D

All Geodynamics Cooper Basin field expenditure is classed as R&D, and is estimated at $17 million for the 2004 calendar year.

8.3 Current Status of Geothermal Energy Use

8.3.1 Electricity Generation

Geothermal energy is presently produced at one small binary power station at Birdsville, in western Queensland. The fluid is 98 °C and derives from the Great Artesian Basin. The gross capacity of the plant is 150 kW, with a net output of 120 kW. The total electricity generated in 2004 was approximately 1 GWh.

There were no new developments in 2004.

The Cooper Basin project is edging closer to success. The "Proof of Concept" circulation test between two deep geothermal wells has been delayed because of difficult drilling conditions and is now likely in 2005.

One new well was drilled in 2004.

The contribution of geothermal electricity to the national grid was nil in 2005.

8.3.2 Direct Use

Geothermal energy is used for space heating and bathing, notably at Portland in Victoria and Moree in NSW. Ground source heat pumps have been installed on some commercial buildings and private dwellings, but the industry is in its infancy in Australia. However, the total installed thermal capacity and energy used are unknown.

There were no new developments during 2004; with the rates and trends in development very slow and no wells were drilled.

8.3.3 Energy Savings

Currently diesel fuel is saved at a 120 kW_e output binary plant from a water bore in western Queensland.

8.4 Market Development and Stimulation

8.4.1 Support Initiatives and Market Stimulation Incentives

The Australian Government is supporting Geodynamics Limited through its research and development scheme known as START with a further A$1.5 million dollars beyond the initial A$5 million. The funds are being used for Geodynamics' deep geothermal well program beneath the Cooper Basin.

8.4.2 Development Cost Trends

The one geothermal well drilled in 2004 by Geodynamics was more expensive than originally budgeted. The higher costs were the result of difficult drilling conditions in overpressured fracture granite and equipment failures. The well, Habanero #2, needed sidetracking of a stuck bottom hole assembly. This was achieved by milling 7-inch casing at a depth of 3,872 m where the temperature was approximately 230 degrees Celsius.

8.5 Development Constraints

Interest in geothermal energy development is growing in Australia, and particularly in South Australia where geothermal "prospecting" is the highest in the country. Several new companies have formed and new exploration programs are being formulated. One new geothermal company, Petratherm Limited, has listed on the Australian stock exchange. It aims to explore for radiogenic heat sources at depths of around 3-3.5 km in South Australia.

8.6 Economics

Funding from the general public for geothermal has continued to increase in 2004, with Geodynamics and Petratherm having raised more than A$15 million from public share subscription during the year.

Coal-fired electricity costs remain one of the lowest in the world so new renewable technologies find it difficult to compete. Renewable companies and green groups regard the renewable energy targets and incentives as pitiful

Figure 8.1 Steam production from well Habanero-2 at the Cooper Basin site, Australia.

8.7 Research Activities

The geothermal research focus in Australia is on EGS.

An additional A$1.5 million was provided to Geodynamics from the Federal Government to top up its original $5 million grant.

Industry (Geodynamics and Petratherm) also raised more than A$15 million from public share subscription during the year.

8.8 Geothermal Education

There are no formal geothermal education programs yet in Australian schools and universities.

8.9 International Cooperative Activities

Australia is a member of the IEA Geothermal Implementing Agreement. In addition, Geodynamics Limited and the Australian National University have formal agreements with Japanese researchers in geothermal energy.

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CHAPTER 9

European community

9.1 EGS Activities in the European Union 2003

The European Commission supports a major European EGS project at Soultz-sous-Forêts, France, involving France, Germany, Italy and Switzerland, as well as teams from other countries inside and outside Europe, including Japan and USA. The project is coordinated by an industrial consortium, European Economic Interest Grouping (EEIG) Heat Mining. The bulk of the funding is provided more or less equally by EC, France and Germany.

The aim of the new project period is to establish the world's largest and most efficient EGS at a depth of about 5,000 m. The system will consist of one central injection borehole and two symmetrically deviated production boreholes, each separated by about 500 m from the injection hole at depth. A total flow rate of 80 l/s is envisaged, equivalent to a total thermal power of 50 MW_t and an electric power of 6 MW_e.

At the beginning of 2003, there were two 5,000 m deep test wells at the site in Soultz. The well GPK-3, the centre future injection well, had just been finished in November 2002. The first production well, GPK-2, had already been stimulated in 2000, thus laying the foundation of the new deep underground exchanger.

Figure 9.1 Soultz drillrig. (Credit: European Economic Interest Group Heat Mining).

Drilling of the second production well, GPK-4, started in September 2003 and was completed in April 2004. The trajectory of GPK-4 was defined after the stimulation of GPK-3 using the microseismic data to target GPK-4. This was the most difficult trajectory to hold as the well was 5,000 m deep with the bottom being 1,200 m to the south of the wellhead. Basic parameters of the in-situ rock mass were investigated by injection tests in GPK-3 and GPK-4.

After these tests, hydraulic stimulation of the well GPK-4 was carried out. A completely new hydraulic infrastructure required for the stimulation of GPK-4 had to be designed, manufactured and installed. This included high-pressure injection and low-pressure production pipelines. The pipelines were configured in such a way to allow either the injection or the production from any of the three wells. This was done to facilitate the manipulation of the pressure in the reservoir if the necessity arose to either inflate or deflate the reservoir rapidly to control seismic activity. The stimulation was halted by an incident in the wellhead. All the three deep wells were killed and pack-off assemblies and risers were modified to alleviate the casing wellhead problems. Stimulation of GPK-4 will be restarted in early 2005.

The aim is to bring a 1.5 MW_e power plant on line by the second half of 2005, and to increase this to some 6 MW_e in 2006.

9.2 Website for Further Information

Soultz project: www.soultz.net

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CHAPTER 10

Germany

10.1 Introduction

The German Government will continue to development renewable energy resources. The government aims to increase the production of electricity using renewable energies to 20% by 2010.

Due to a lack of natural steam reservoirs, geothermal energy cannot be used to generate electric power at competitive prices in Germany at present. And the new EGS technology for converting the heat of hot dry rock at depth is only currently being developed. However, direct use of geothermal heat takes place in a small number of large-scale centralized installations as well as in many decentralized units.

10.2 National Strategy

At present the Federal Environment Ministry alone is responsible for funding of renewable energies. Research and Development (R&D) is conducted under the 4th Programme on Energy Research and Energy Technology. The Project Management Organization PTJ Jülich manages important parts of this Programme, namely the development of techniques for an efficient use of energy and renewable energies.

The Future Investment Programme FIP finished in 2004. In addition, the funding for geothermal projects in 2004 decreased as shown in Table 10.1.

Table 10.1 Geothermal funding for 2002-2004.

Year	**Funding** (Euros, millions)
2002	9
2003	11
2004	5

The Law on Energy Supply (LES) that became effective on 1 April 2000 is one attempt of the German government to promote the use of renewable energies. Operating companies, which supply regenerative electricity in the public net, get a guaranteed minimum payment.

In that way renewable energy operating companies have a long-term security as regards planning and calculation. The cost-effectiveness and competitiveness of alternative energy production plants will therefore increase.

Table 10.2 The minimum payment for geothermal power plants based on the new law on energy supply, July2004.

Plant Size (MW)	**Minimum Payment** (€-Ct/kWh*)
Up to 5	15
Up to 10	14
Up to 20	8.95
Up to 30	7.16

* €-Ct = Euro cent

10.3 Current Status of Geothermal Energy Use

10.3.1 Electricity Generation

The first geothermal power plant in Germany was installed in Neustadt-Glewe in November 2003. It utilizes an organic-Rankine cycle plant with an installed capacity of 250 kW_e and will produce an estimated 1,400 MW/year

The geothermal-projects in Unterhaching, Bruchsal, Speyer, Groß Schönebeck, Hannover and Soultz-sous-Forêts are continuing.

10.3.2 Direct Use

At present, 27 installations with direct use of geothermal heat are operating in Germany. Each of these has an installed capacity in excess of 100 kW_t. These plants comprise centralized heating units, thermal swimming pools sometimes combined with space heating, greenhouses and clusters of ground heat exchangers used for space heating and cooling.

The total thermal power installed is 55 MW_t. The temperature of the geothermal fluid used in all of the direct use developments is less than 100 ^oC

Table 10.3 Examples of geothermal direct use in Germany.

Location	**Installed Power (MW_t)**	**Use**	**Temperature (^oC)**	**Method**
Neustadt-Glewe	11	heat	95	Doublet
Erding	9	heat	66	Heat Pump
Straubing	5	heat	36	Doublet
Waren (Müritz)	5	heat	60	Doublet
Wiesbaden	2	heat	70	-

One new well was drilled at the geothermal project at Aachen Aachen for heating/cooling of a university building. In addition, wells were in the process of being drilled at Unterhaching and Speyer. A third well was also completed at Soultz.

10.3.3 Geothermal Markets and Constraints

At present, there is no real market for geothermal energy in Germany.

The constraints for development include the high risk and costs associated with drilling. In addition, the geothermal fluids have a very high salinity. The costs for heating and electricity production using oil, gas and coal (hard and brown) are very low.

10.4 Research Activities

10.4.1 Soultz-sous-Forêts (Alsace, France)

The task is the installation of a scientific geothermal pilot plant (first phase). The project is a European project on EGS. It is funded by the funding agencies of the EC, France and Germany and in a smaller part by industry. The working plan on the German side is distributed to 5 partners (federal agency, university and companies).

In the first phase, 3 boreholes (GPK-1, 2, 3) are drilled, with two up to 5,000 m deep. Stimulation tests were done with very much success. It was possible to generate two heat exchangers at two horizons. The upper reservoir is located at 3,000 m to 3,600 m depth, and delivers temperatures of 165 °C. The lower reservoir at depths of 5,000 m and deeper has a temperature of about 200 ^{o}C. The new reservoir at 5,000 m shows closer boundaries compared to the upper reservoir. No leak-off to the upper reservoir has been detected.

Well GPK-4 was completed in April 2004 to a depth of 5,200 m.

The cost for this project for Germany in 2004 was 6.4 M €. The total cost of the investigation for all parties will amount to 30 M €.

Phase II of the Soultz project began in 2004.

10.4.2 Government Funded R&D Projects

10.4.2.1 Neustadt-Glewe

This study involves the evaluation of operational parameters for the geothermal heat plant at Neustadt-Glewe for the production of both heat and electricity generation using turbines working on ORC basis. The work is spread over two projects.

The Neustadt-Glewe plant is the first working geothermal plant in Germany. It has been successfully providing heat to industry, commercial customers and about 2,000 private homes since 1995. In addition, the first geothermal power plant to produce electricity in Germany went online here in November 2003, with the installation of a 250 kW_e organic-Rankine cycle plant.

Total project costs were 1.3 M €, with 0.6 M € funding.

10.4.2.2 Groß Schönebeck

The aim is to prepare hot water rock storage in the sedimentary north German Basin for the production of geothermal heat. This task is performed through a network of 6 “stand alone” projects.

The focus of this project lies on new stimulation techniques for sediments. An old oil and gas exploration well is used. Experiments were conducted in the sandstone and vulcanite layers.

Stimulation tests injected water and gel proppants. Fracture growth was observed by seismic events. The flow rate increased to 75 m^3/h.

The total project costs amounted to 5.5 M €, with 5.3 M € funding.

10.4.2.3 Hannover

The task is to study the one-probe-two-layer-method. Two institutions are working on this project.

The aim is to examine the method for extraction of geothermal heat from sedimentary rocks in the north German Basin.

During hydraulic tests temperature and pressure logs are run as well as seismic monitoring. The results are interpreted using analytical and numerical models to get information on the thermal capacity and the physical and economic life of the one-probe-two-layer-system.

The total costs are 2.0 M €, with 2.0 M € funded.

10.4.2.4 Bruchsal

The objective was to investigate the use of high salinity, high temperature deep geothermal water at the Bruchsal geothermal field for heat and electricity production.

Two wells were drilled in 1980. After obtaining new government aid it was possible to conduct circulation tests. Due to the high salinity and extreme temperature and pressure changes during the circulation tests the fibreglass heating pipeline broke up. It is planned to fund a new heating pipeline to get the project running again. Steel will be used for the new pipeline. It will receive an inner wall scaling made of the natural aragonite or calcite precipitation. The scaling will be applied under controlled (temperature, pressure, inhibition of oxygen entry) conditions. Under constant conditions, even during the test phases, and later in operation, the scaling should prohibit corrosion.

The total cost for this project amounts to 3.1 M €, with 1.5 M € funding.

10.4.2.5 Bad Urach

The task of this project is development, verification and demonstration of location independent EGS concepts for the production of electricity and heat from hot deep rocks considering geological, hydraulic, technical and economic parameters of methods and plants (data set for a EGS pilot plant).

Hydraulic stimulations in the first borehole were a success. The production rate increased from 30 l/sec to 50 l/sec. It is assumed that an artificial heat exchanger was created. Seismic clouds were evaluated with a special processing method, which showed that the heat exchanger is placed between 3,300 m and 4,200 m depth. The temperature is approximately 170°C.

A second borehole (planned depth of 4,500 m) was drilled from January to April 2004. However, the project was halted at a drilled depth of 2,800m, because funding was much overspent.

The Ministry has decided that the project may only continue with financial participation of industrial partners.

The total cost for this project is 6.7 M €; with 6.5 M € funded.

10.4.3 Industry Funded R&D

10.4.3.1 Neustadt-Glewe

There is a long-term project in which BEWAG-Berlin is investigating the reservoir parameters (depth of 2,250 m) using the geothermal plant. The costs for this are unknown.

10.4.3.2 Unterhaching

A project to investigate the production of heat and electricity using two boreholes is being conducted at Unterhaching. The first well has been drilled to a depth of 3,446 m and has reached a temperature of 122 ºC with production of 150 l/sec. The second well is expected to begin in the spring of 2005.

This is funded by “risk capital” amounting to 30 M €.

10.4.3.3 Speyer

The aim of this investigation is to produce heat and electricity utilizing 5 wells.

The first well was drilled to 2,700 m in 2004, and it is planned to drill the second one in the spring of 2005.

Costs for this project, provided by “risk capital”, are unknown.

10.5 Geothermal Education

Geothermal education is provided at several universities in Germany, e.g. Uni Bochum, RWTH Aachen, TU Berlin.

10.6 International Cooperative Activities

Participation in the IEA GIA is funded by the German Ministry of Environment.

Focus is on the project in Soultz-sous-Forêts. Further activities from the German funded participants.

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CHAPTER 11

Iceland

11.1 Introduction

Geothermal energy provides over half of the primary energy supply in Iceland. The principal use of geothermal energy is for space heating, and about 87% of all energy used for house heating comes from geothermal resources. Of the total electricity generation, about 17% comes from geothermal energy. See Figure 11.1 for locations of geothermal areas in Iceland and Figure 11.2 for the distribution of geothermal energy utilization.

11.2 Highlights for 2004

Because of the location of Iceland on the Mid-Atlantic Ridge the geothermal resources are abundant. Over half of the primary energy supply in the country comes from geothermal energy. The main use of geothermal energy is for space heating and about 87% of all houses are heated by this energy source. Other sectors of direct use are swimming pools, snow melting, industry, greenhouses and fish farming. An expansion in the energy intensive industry has led to a rapid increase in electricity demand in the country. This has stimulated the development of geothermal power production and resulted in the construction of new plants. Two of the largest energy companies in Iceland, Reykjavik Energy and Hitaveita Suðurnesja, both have a new power plant for electricity production under construction. The total capacity of these two plants, plus an expansion being made at Nesjavellir power plant, is approximately 200 MW_e. This will double the existing capacity in the country.

11.3 National Policy

The national strategy is aimed at harnessing geothermal resources whenever possible, respecting the natural and human environment. IN addition, foreign investment in power intensive industry is encouraged and watch is being kept on developments in the hydrogen fuel field.

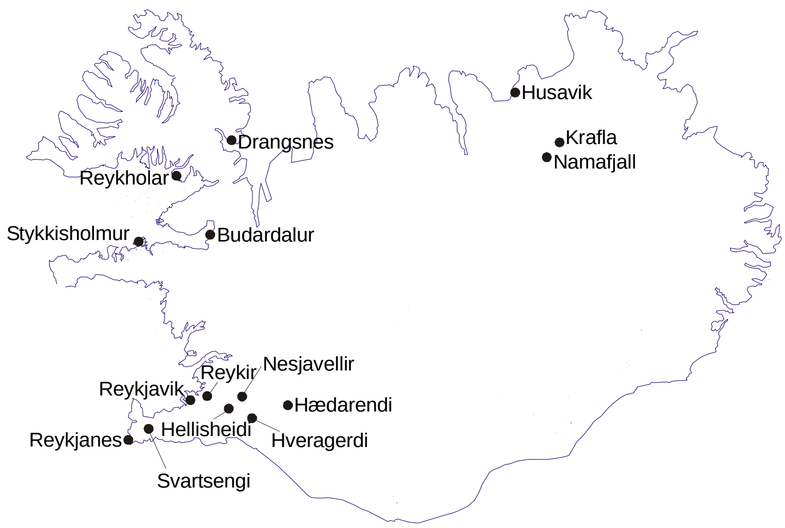

Figure 11.1 Location of Iceland's geothermal utilization sites.

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

Government expenditure on geothermal R&D was about 1M Euros in 2004. Industry expenditure amounted to 6-7 M Euros.

11.4 Current Status of Geothermal Energy Use in 2004

11.4.1 Electricity Generation

As a result of a rapid expansion in the energy intensive industry in Iceland the demand for electricity has increased considerably. This has partly been met by increased geothermal electricity production. Two new geothermal power projects are now under construction.

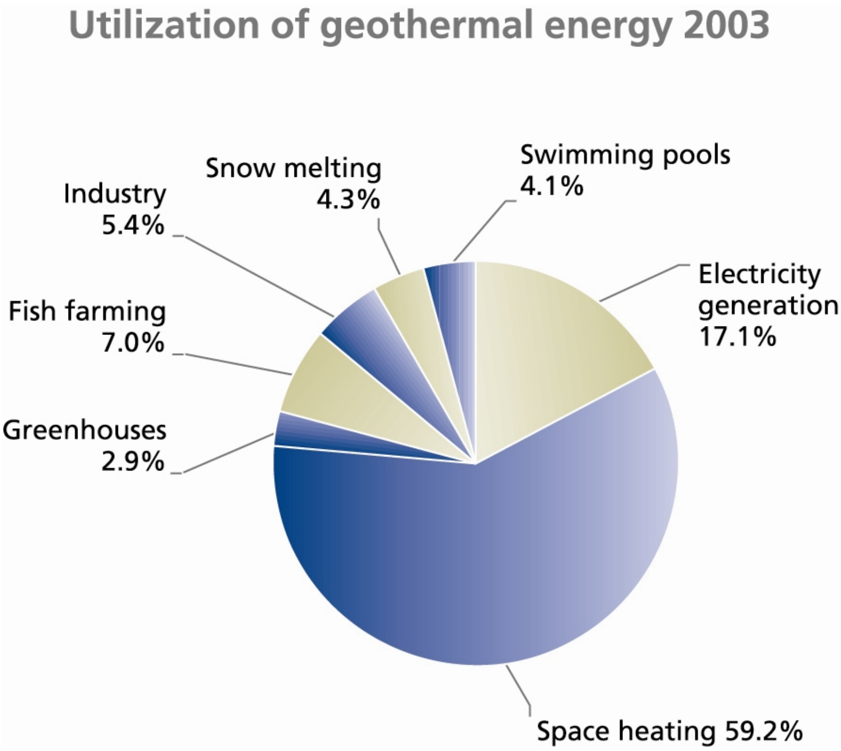

Figure 11.2 Utilization of geothermal energy in Iceland for 2003.

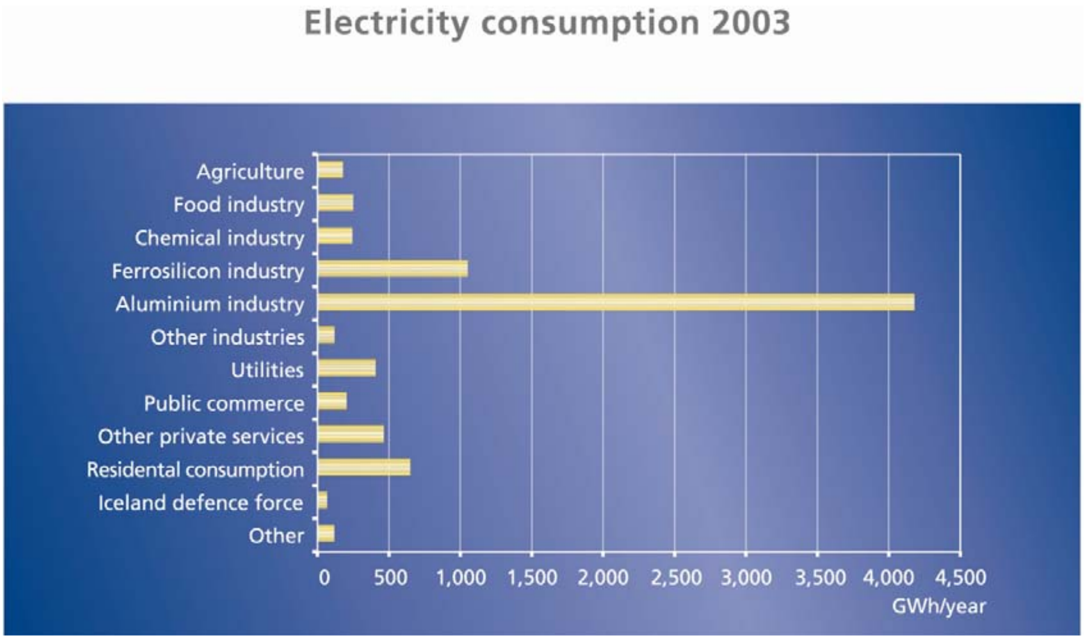

Figure 11.3 Iceland's electricity consumption for 2003.

In 2004, Iceland's geothermal installed capacity was 202 MW_e, with 1,433 GWh/y generated. There were no new developments during the year.

To meet the increasing demand for high temperature geothermal wells, the drilling company Jarðboranir invested in a new drill rig that started operation in the summer of 2004. The new rig, named Geysir, can drill up to 4,000 m deep wells. It is the biggest and most advanced drill rig in operation in Iceland.

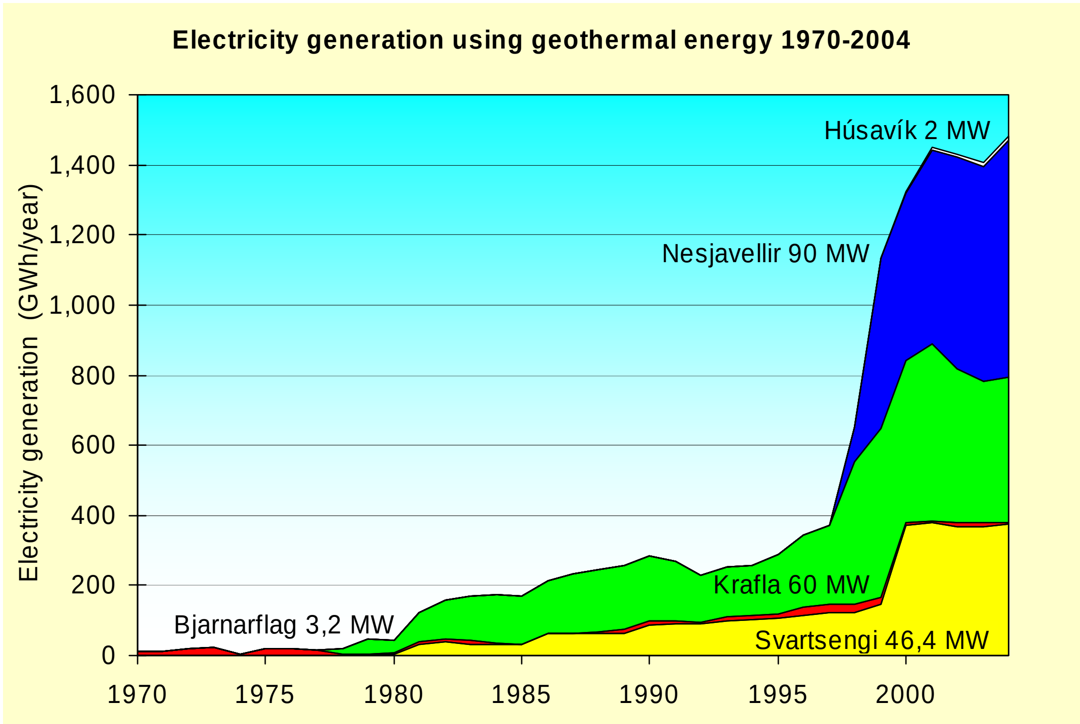

Figure 11.4 Electricity generation using geothermal energy in Iceland 1970-2004.

11.4.2 Direct Use

The total direct use installed capacity in 2004 was 1,459 MWt, with 18,718 TJ/y used. The capacity factor was 0.41.

Geothermal is very widely used in Iceland for space heating, bathing and swimming, greenhouses and soil heating, fish farming, snow melting and in industry.

The new developments consisted of small-scale space heating installations. With almost 90%of homes heated by geothermal energy, further developments are small.

Ten production wells and two reinjection wells were drilled. In addition, 99 temperature gradient wells were drilled for surveying purposes to locate geothermal areas.

11.4.3 Energy Savings

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

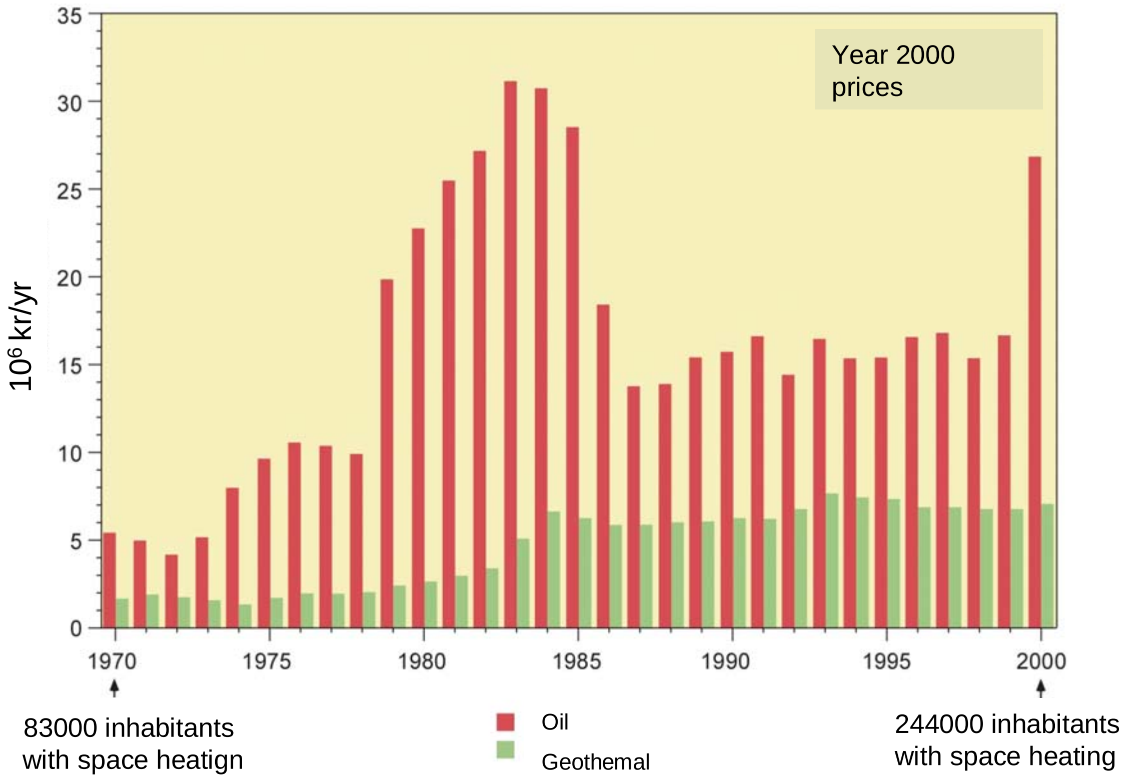

Figure 11.5 Comparison of oil and geothermal prices for 1970-2000.

11.5 Market Development and Stimulation

The government gives grants to small projects in the field of energy. However, for the last few years emphasis has been on finding usable geothermal water for space heating in areas where resources were previously unknown.

The high demand for electricity for intensive industry resulting from the favourable prices of electricity has resulted in large-scale geothermal power development.

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

11.6 Development Constraints

Development constraints are mostly due to environmental issues, though geothermal energy was looked upon more positively than hydropower in a recent national review. Local issues do place constrains on drilling sites and access to them.

11.7 Economics

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

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

The cost of energy has been stable.

11.8 Research Activities

11.8.1 Focus Areas

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

A consortium of Icelandic energy companies is preparing to drill a 4-5 km deep drill hole into one of the high-temperature hydrothermal systems to reach 400-600 °C hot supercritical hydrous fluid at a rifted plate margin on a mid-ocean ridge. The main purpose of the project is to find out if it is economically feasible to extract energy and chemicals out of hydrothermal systems at supercritical conditions. The first candidate well was drilled to 3,000 m depth at Reykjanes and further drilling is planned for 2006.

11.8.2 Government Funded Research

During the past six years the Ministry of Industry has been running a program to encourage geothermal exploration for domestic heating in areas where geothermal resources have not been identified, so-called “cold areas”. A total of US$1.9 has been granted for this purpose and used mainly for drilling 50-100 m deep thermal gradient exploration wells. This method has proven to be a successful exploration technique in Iceland.

11.8.3 Industry Funded Research

In the past years, Reykjavik Energy has been drilling several exploration and production wells on Hellisheidi, where they have started the construction of a new 80 MW power plant for both electricity and hot water production. Also at Nesjavellir, new wells have been drilled in preparation for expansion of the existing power plant.

At Reykjanes, Hitaveita Suðurnesja has been carrying out exploration and production drilling in connection with the decision to utilize this high-temperature field for power production. They plan to build, as a first stage, a power plant of 90 MW_e.

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

11.9 Geothermal Education

The Geothermal Training Programme of the United Nations University (UNU) has operated in Iceland since 1979 with six-month annual courses for professionals from developing countries. Specialized training is offered in different geothermal disciplines. The aim of the programme is to assist developing countries with significant geothermal potential to build up groups of specialists that cover most aspects of geothermal exploration and development. Most of the candidates receive scholarships financed by the Government of Iceland and the UNU. It is also possible to continue on in this programme towards an MSc degree at the University of Iceland.

The Natural Resources Faculty, University of Akureyri offers BSc and MSc degrees in sustainable energy utilization of the renewable energy sources with emphasis on hydro and geothermal energy. The students attend several courses covering the harnessing of geothermal energy and are trained in different geothermal disciplines.

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

11.10 International Cooperative Activities

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

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

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CHAPTER 12

Italy

12.1 Introduction

This chapter outlines the development of the geothermal activities in Italy in the year 2004.

Geothermal resources in Italy are mainly used to produce electricity. The first industrial power plant dates back to 1913. Since then, geothermal installed capacity has increased, reaching 862 MW_e at the end of the year 2004.

In 2004 geothermal net generation exceeded 5.1 billion kWh. Though this represents only 1.9% of the total domestic generation, it meets about 24% of the electricity demand in Tuscany, the Italian region where almost all the plants are located.

In addition to the electricity generation, geothermal fluids are used as heat sources, mainly for spas, space and district heating and greenhouses. Thermal energy supplied in 2003 was about 213 ktoe (thousand tonnes of oil equivalent).

At present, Enel Green Power carries out all the activities related to the exploration, development and exploitation of geothermal resources in Italy for electricity generation. The company is fully owned by ENEL Group and was established in October 1999 with the name of Erga; the name was changed to Enel Green Power in January 2002. The mission of Enel Green Power is to develop electricity generation from renewable energy sources (geothermal, small-hydro, wind, solar and biomass) both in Italy and abroad, in order to achieve the reduction of CO_2 emission, according to Kyoto Protocol.

Enel Green Power received the 2002 Global Energy Award as best operator in the renewable energy field.

12.2 National Policy

According to the European Directive 96/82/EC aimed at creating a single market for electricity in the EU, the Italian government issued a decree on 19 February 1999, known as “Bersani Decree”, which established the basic rules for the electric power industry. According to the decree, as from 1 January 2003, no individual operator is allowed to generate or import more than 50% of the domestic overall consumption of electricity. In order to comply with this requirement, ENEL has been obliged to sell 15,000 MW of its generating capacity to domestic and foreign operators.

In addition, as from the year 2002, all operators (importers and producers of electricity from non-renewable sources) must generate or buy a fixed share of electricity from “new renewable plants” (generating plants using renewable energy sources, commissioned or repowered after 2 April 1999. For repowered plants, only the additional capacity is taken into account).

For each operator, the share was initially set at 2% of the total energy exceeding 100 GWh produced or imported in the year. Cogeneration, plant auxiliary consumption and exports are excluded from this requirement. Applied to the Italian scenario, the 2% share presently corresponds to about 3.5 billion kWh, an amount large enough to spur the market effectively. A recent decree, issued on 31 January 2004, increased this share starting from the year 2005. The conceived mechanism provides a great deal of flexibility: operators are allowed to meet their obligations by generating directly or by purchasing some or all of the “green” energy required or merely emission rights (called “green certificates”).

In the year 2002, Italy signed the Kyoto Protocol to the United Nations Framework Conference on Climate Change, together with all the other countries of the European Union (EU). According to the Protocol, the EU must reduce total greenhouse gases emissions by 8% compared to the 1990 level, within the commitment period (from 2008 to 2012). Inside the EU, each country has a different obligation; for Italy, the reduction has been fixed at 6.5%.

According to the decree of the Interdepartmental Committee for Economic Planning (CIPE) of 19 December 2002 (Revision of the Guidelines for the strategy and national measures for greenhouse gases emission reduction), the electricity industry must reduce CO_2 emission by 26 million tons per year by the commitment period. This figure represents more than 50% of the total reduction required.

One of the selected measures to pursue this target, is a 500-1,200 MW_e increase in the installed capacity of renewable based power plants, with a reduction of CO_2 emission in the range 1.5-3.1 million tons per year.

The ENEL Group, by far the major national utility, is partly owned by the Ministry of Treasury (at present, about 30% of the shares). The new Company strategy is focused on the core business for increasing ENEL Group activities in the energy market (electricity and gas), especially abroad. One of the most important targets is to reduce the cost of the electricity generated, increasing coal and natural gas use (the latter in combined cycle plants) and reducing fuel oil consumption. Another important target is the development of renewable energy sources (geothermal, small-hydro, wind, solar and biomass) both in Italy and abroad.

The development program for geothermal generation forecasts the drilling of new wells, construction of new power plants, revamping of old plants and installation of hydrogen sulphide and mercury emission abatement systems, based on a proprietary process (AMIS). The target is a yearly generation of 5.4 billion kWh by 2009 and a substantial environmental improvement of the generation park, with a total investment of about 170 million € for the period 2005-2009.

In 2004, ENEL spent 275,000 € to improve efficiency and environmental impacts of the geothermal plants. There was no expenditure by the Italian Government.

12.3 Current Status of Geothermal Energy Use

12.3.1 Electricity Generation

As of 31 December 2004, 218 production wells were in operation, feeding many steam line networks for a total length of about 158 km. In addition, 26 reinjection wells were in operation to reinject the condensed steam into the reservoirs.

There were 33 power plants in operation, with a total installed capacity of 862 MW_e and a maximum electrical capacity of 699 MW_e.

In 2004, 5.127 billion kWh were delivered to the electric grid. This figure represents 1.9 % of the domestic electricity demand.

In 2004, drilling activities consisted of:

- Drilling and commercial operation of five new production wells: four deep wells with depths ranging from 3,500 m to 4,900 m (drilling of two of these wells began in 2003).
- Completion of the drilling of GPK-4 to 5,260 m, at Soultz, France, in the framework of HDR Project).

- Start of the drilling of two deep wells (3,400 m and 4,050 m depths) which will be completed in 2005. One of these wells is the first of 11 wells to be drilled by 2007 as part of the framework of the exploratory programme launched in 2003 and focused on enlarging the exploited productive horizons and areas.

- Deepening of two existing wells.

A total of 18,000 m was drilled. As a result, the additional steam recovered was 88t/h, corresponding to an increase in generating capacity of about 12.5 MW_e. This figure does not include the steam from one deep well whose testing is to be completed.

Other 2004 activities included:

The design and construction of two power plants and of 17 AMIS abatement plants has continued.

- The power plants include a 1x40 MW retrofitting and a 1x20 MW rehabilitation of an old unit decommissioned several years previously.

- The abatement plants will remove H_2S and Hg from plant emissions using a proprietary AMIS technology developed by ENEL and successfully demonstrated at two commercial plants. Fifteen AMIS plants will be retrofitted on existing plants and two will equip new power plants.

  The abatement of H_2S and Hg emission will allow a substantial improvement of the environmental impact of the generation park. It will eliminate the bad smell of H_2S present in the geothermal areas, and which represents a real nuisance for the people living near the plants. In addition, Hg removal will prevent possible effects of mercury build up in soils, water and food chain in the long-term operation of the plants.

Figure 12.1 The ENEL proprietary AMIS hydrogen sulphide and mercury emission abatement system installed at the 20 MW_e Bagnore 3 geothermal power station, Tuscany, Italy. (Photo by Aldo Baldacci, ENEL).

Forecasts of the development program for 2005:

Production wells:

- Drilling of four new production wells
- Testing of one deep well drilled in 2004
- Completion of drilling and testing of one production well, whose drilling started in 2004

Exploration wells:

- Drilling of four exploration wells (two wells to be completed in 2005 and two in 2006)
- Completion of drilling and testing of the first well of the exploration programme whose drilling started in 2004 (see above)

Power plants:

- Commissioning of two power plants: 1x40 MW (retrofitting) and 1x40 MW (rehabilitation)

Abatement plants:

- Commissioning of 11 AMIS plants (two for the two abovementioned power plants and 9 as retrofits of existing units)

12.3.2 Direct Use

In addition to the electricity generation, geothermal fluids are also used in Italy as thermal sources. In 2003 the total heat supply was equivalent to about 213 ktoe.

Most of the applications (60% of the supply) are for bathing (temperatures less than 40 °C), which has a long tradition in Italy, dating back to Etruscan and Roman times. There are also several other uses including space and district heating, fish farming, greenhouses and industrial process heat.

Enel Green Power is the most important domestic operator in the field of direct use, supplying the equivalent of about 26 ktoe of geothermal heat: 47% for both greenhouses and district heating, 5% for industrial processes and the balance for fish farming.

In addition, Enel Green Power is selling about 36,000 t/y of nearly pure CO_2, produced from a deep dead well and mainly used, after purification, in the food industry.

12.3.3 Energy Saving

The use of the geothermal fluids for electricity generation and direct use provides a saving of about 1.4 Mtoe (million tons of oil equivalent), avoiding, at the same time, emission to the atmosphere of about 4 Mt of CO_2.

It should be noted that the exploitation of steam-dominated fields reduces the amount of CO_2 naturally emitted from the soils in the geothermal areas, so that the total CO_2 emission (natural plus power plant emission) remains unchanged.

CO_2 emission has not been included by APAT (the National Agency for the protection of the environment and the territory) in the GHG inventory.

12.4 Market Development and Stimulation

In Italy, since 1 January 2003, the Bersani Decree requires producers or importers of electricity from non-renewable sources to deliver to the grid a share of electricity generated from renewable sources. This provision gave rise to the "Green Certificate" market.

The Green Certificate proves that a certain amount of energy is produced by renewable resources with each certificate representing 50 MWh of electricity (The original provision of 100 MWh for each green certificate, the Decree of the Minister of the Industry of 11 November 1999, has been recently reduced to 50 MWh by the Law nr. 239/2004, known as "Marzano Law"). It does not matter what the source of renewable energy is, but it is necessary that this energy be produced by new plants or by plants re-powered, rebuilt or re-activated, which begin operation after 2 April 1999. Green certificates apply for the first eight years of plant operation.

For the first year (2002), a share of 2% was established. According to Decree n° 387/2003, issued on 31 January 2004, which enforces in Italy the European Directive 2001/77/EC on the promotion of the electricity from renewable sources in the internal market, this share is increased to 2.35% in 2005. In addition, an annual increase of 0.35% is established for the two following years (2.7% in 2006 and 3.05% in 2007). The Decree also states that the Minister of Industry will fix the shares for the years 2008-2010 by 31 December 2004 and the shares for the years 2011-2013 by 31 December 2007.

Green Certificates will be exchanged between producers and importers in an open market. In order to carry out this exchange, the Electric Market Authority will promote the negotiation of the certificates.

As a consequence, the value of the kWh generated from renewables is the sum of the base price of the energy and of the market value of the Green Certificates (the latter is limited to the first eight years of plant operation). For 2004, the value of the Green Certificates was 9.739 €-cent/kWh.

Producers and importers can also comply with the decree by importing electricity generated from renewable energy plants of foreign countries adopting similar policies for renewable energy promotion.

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

- Incentive to the end users of 10.33 €/MW_t on a permanent basis plus 15.49 €/ MW_t to be confirmed every fiscal year. The latter has been recently confirmed for 2005 by the budget Law (Law nr. 311/2004)

- Incentive to the developers for new supplies or for the increase of the existing ones is 20.66 €/ MW_t

12.5 Development Constraints

As a consequence of the lower cost of fossil fuel generation, geothermal generation needs incentives, e.g. Green Certificates. Therefore, geothermal development is limited, on the one hand, by the amount of electricity that can benefit from Green Certificates and, on the other, from the competition with other renewables. This competition favours the renewable sources with the lower generation cost.

At present, and for the next few years, this will not be a problem because the demand for Green Certificates will largely exceed the production. In the year 2003, the demand was about 3.5 TWh compared with a production of 1.5 TWh. It is likely the difference will increase in the next years as a consequence of the increase of the share of generation from renewables required by the law, even though new renewable plants will go on stream.

Environmental issues could also limit geothermal development in areas characterised by natural beauty, tourism-based economy, vicinity to spas or major ground waters, *etc*. The bad smell of hydrogen sulphide, build-up of boron and mercury in soils and rivers, depletion of groundwater or spas and landscape degradation are the most common arguments for the local opposition to geothermal development.

It should be noted that, by law, ENEL must pay a royalty to the municipalities and to the District where the plants are located for each kWh generated using geothermal resources. A District law has recently doubled the royalty to the municipalities of Tuscany. Starting from January, 1, 2003 , ENEL must pay:

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

12.6 Economics

Capital cost of the geothermal plants largely depends (50% or more) on the total cost of the production wells feeding the power plant. The latter varies from field to field, as a consequence of the stratigraphy, well depth, well productivity, fluid enthalpy, non-condensable gas content, *etc*. Capital cost must also take into account the costs of field development (feasibility studies, surface exploration, drilling of exploration wells, *etc*.), which require a large investment at an early stage. Typical capital costs range from 2.0 to 3.0 million € /MW_e installed.

Generation costs largely depend on the capital costs (about 80%), with O&M costs making up the balance. Typical costs range from 5 to 8.5 €-cent/kWh.

12.7 Research Activities

Research activities are mainly focused on the implementation of geophysical models able to improve the ability to discover geothermal resources, reducing mining risk. Advanced methodologies for understanding the results of reflection seismic prospecting have been applied with good results in locating the fracture zones inside the geothermal reservoirs at depths higher than 3,000 m.

This research is totally funded by ENEL.

12.8 International Cooperative Activities

ENEL (by means of the fully owned Enel Green Power) is a partner of La Geo (former Geotermica Salvadorena or Gesal), the El Salvador geothermal company, which currently operates with an installed capacity of 161 MW_e.

Enel Green Power received 8.5 % of La Geo's shares in exchange for drilling six wells and for evaluating the geothermal resources in Southeast Berlìn and in the area of the Ahuachapan field. If the resources will support a capacity increase, Enel Green Power will build new power plants in exchange for an increase in its share in La Geo.
In 2004 four wells were drilled with positive results (the drilling of two of these began in 2003).

Development plan has forecasted the drilling of new wells, both in the Berlìn and Ahuachapan fields, and the construction of a 40 MW power plant at Berlìn.

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CHAPTER 13

Japan

13.1 Introduction

Japan's first geothermal electricity generation of 1.12kW took place in Beppu, Oita Prefecture, Kyushu, in 1925. The practical use of geothermal energy commenced in 1966, with the introduction of the first full scale geothermal power plant, the Matsukawa Geothermal Power Plant of 9.5 MW_e (23.5 MW_e at present), Iwate Prefecture, in the Tohoku District of northern Honshu.

Japan, as a volcanic country, has favourable conditions for geothermal development. However, the construction of geothermal power plants has been restricted due to factors such as the restrictions on the use of National Parks and low and stable oil prices. Therefore, as shown by Table 13.1, at the end of the 1980s only nine plants were operating, with a total capacity of about 215 MW_e.

Table 13.1 Geothermal power plants in operation as of 31 March 2004.

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.	Donan Geothermal Energy Co., Ltd.	50.0	155,333	Nov. 1982
Sumikawa	Tohoku Electric Power Co., Inc.	Mitsubishi Materials Corporation	50.0	424,403	Mar. 1995
Onuma	Mitsubishi Materials Corporation	same as on the left	9.5	63,000	June 1974
Matsukawa	Japan Metals & Chemicals Co., Ltd.	same as on the left	23.5	157,276	Oct. 1966
Kakkonda 1	Tohoku Electric Power Co., Inc.	Japan Metals & Chemicals Co., Ltd.	50.0	229,387	May 1978
Kakkonda 2	Tohoku Electric Power Co., Inc.	Tohoku Geothermal Energy Co., Ltd.	30.0	221,439	Mar. 1996
Uenotai	Tohoku Electric Power Co., Inc.	Akita Geothermal Energy Co., Ltd.	28.8	199,543	Mar. 1994
Onikobe	Electric Power Development Co.	same as on the left	12.5	104,434	Mar. 1975
Yanaizu - Nishiyama	Tohoku Electric Power Co., Inc.	Okuaizu Geothermal Ltd. Co.,	65.0	388,211	May 1995
Hachijojima	Tokyo Electric Power Company	same as on the left	3.3	16,239	Mar. 1999
Suginoi	Suginoi Hotel	same as on the left	3.0	9,782	Mar. 1981
Kuju	Kuju Kankou Hotel	same as on the left	2.0	7,477	Dec. 2000
Takigami	Kyushu Electric Power Co., Inc.,	Idemitsu Oita Geothermal Co., Ltd.	25.0	201,613	Nov. 1996
Otake	Kyushu Electric Power Co., Inc.	same as on the left	12.5	89,384	Aug. 1967
Hatchobaru 1	Kyushu Electric Power Co., Inc.	same as on the left	55.0	386,591	June 1977
Hatchobaru 2	Kyushu Electric Power Co., Inc.	same as on the left	55.0	437,968	June 1990
Takenoyu	Hirose Trading Co., Ltd.	same as on the left	0.05	0	Oct. 1991
Ogiri	Kyushu Electric Power Co., Inc.	Nittetsu Kagoshima Geothermal Co., Ltd.	30.0	245,365	Mar. 1996
Kirishima Kokusai Hotel	Daiwabo Kanko Co., Ltd.	same as on the left	0.1	13	Feb. 1984
Yamagawa	Kyushu Electric Power Co., Inc.	Japex Geothermal Kyushu Co., Ltd.	30.0	149,007	Mar. 1995
Total			**535.25**	**3,486,465**	

Note: 1. "Annual Energy Production" covers energy production for one year from 1 April 2003 to 31 March 2004.

The risks involved in initial investment also hinder geothermal development. Thus, the government has been promoting research and development of exploration techniques in several areas of geothermal activities. As a result, geothermal development in several areas in the Tohoku and Kyushu Districts reached the construction stage in the early 1990s.

The operational status of Japan's geothermal power plants as of 31 March 2004 is indicated in Table 13.1. No geothermal generation plants were begun in fiscal year 2003 (April 2003-March 2004). The total authorized output of the geothermal power generation in Japan is 535.25 MW_e. Geothermal direct use in Japan is shown in Table 13.2, as a database developed by the New Energy Foundation (NEF). It must be noted that data for bathing and geothermal heat pumps are not included in this table by their policy. The total installed capacity of geothermal heat pump systems in Japan is probably less than 3,000 kW.

Table 13.2 Direct Use of Geothermal Energy in Japan as of March 2004.

	Utilization Capacity (MWt)	Annual Mean Utilization (TJ/y)
Greenhouse heating	41.49	404.11
Aquaculture	16.91	212.34
Stockbreeding (Space heating)	0.14	1.48
Agriculture (Paddy warming, Washing crops)	2.12	30.07
Industry	1.52	40.86
Food processing	0.16	3.60
Accommodation (Space heating, Hot water)	49.43	715.16
Tourism (Cooking, Pool)	13.79	125.15
Housing (Space heating, Hot water)	27.50	564.33
Medical treatment (Space heating, Hot water)	10.59	128.05
Welfare (Space heating, Hot water, Pool)	17.25	250.22
Public service (Space heating, Hot water)	39.53	672.64
Snow melting	133.26	448.60
Other (Hot water supply)	55.70	1,542.11
Total	**409.38**	**5,138.71**

Source: Results of the survey conducted by Geothermal Energy Development Center, New Energy Foundation Geothermal Energy Vol.27, No.4

*: It must be noted that data for "Accommodation" in this table includes only swimming pool and not bathing.

*: It must be noted that geothermal heat pump data is not included in this table.

13.2 National Policy

13.2.1 Strategy

In June 2002, the Japanese government concluded a law to introduce the Renewable Portfolio Standard (RPS) system. Under this law, each electric utility business must procure a certain percentage of its electricity sales by target energy categories. Target energy categories are wind, photovoltaic, geothermal (target unit is binary system), hydroelectric (target unit size under 1 MW_e) and biomass. Electricity businesses can trade the excess or deficiency of renewable energies versus the target, in the form of securities. The system was implemented in Financial Year (FY) 2003. The government will determine the target and the procedures for the security dealing as an administration ministerial ordinance.

13.2.2 Legislation and Regulation

There is no separate “geothermal legislation” that defines geothermal resources and governs their use and development in Japan.

13.3 Current Status of Geothermal Energy Use

13.3.1 Electricity Generation

13.3.1.1 Installed Capacity

The total installed generation capacity of geothermal energy at the end of March 2004 was 535.25 MW_e, including industry-owed power plants (Figure 13.1 and Table 13.1). The total installed generation capacity for the country at the end March 2004 was 268,287 MW_e, of

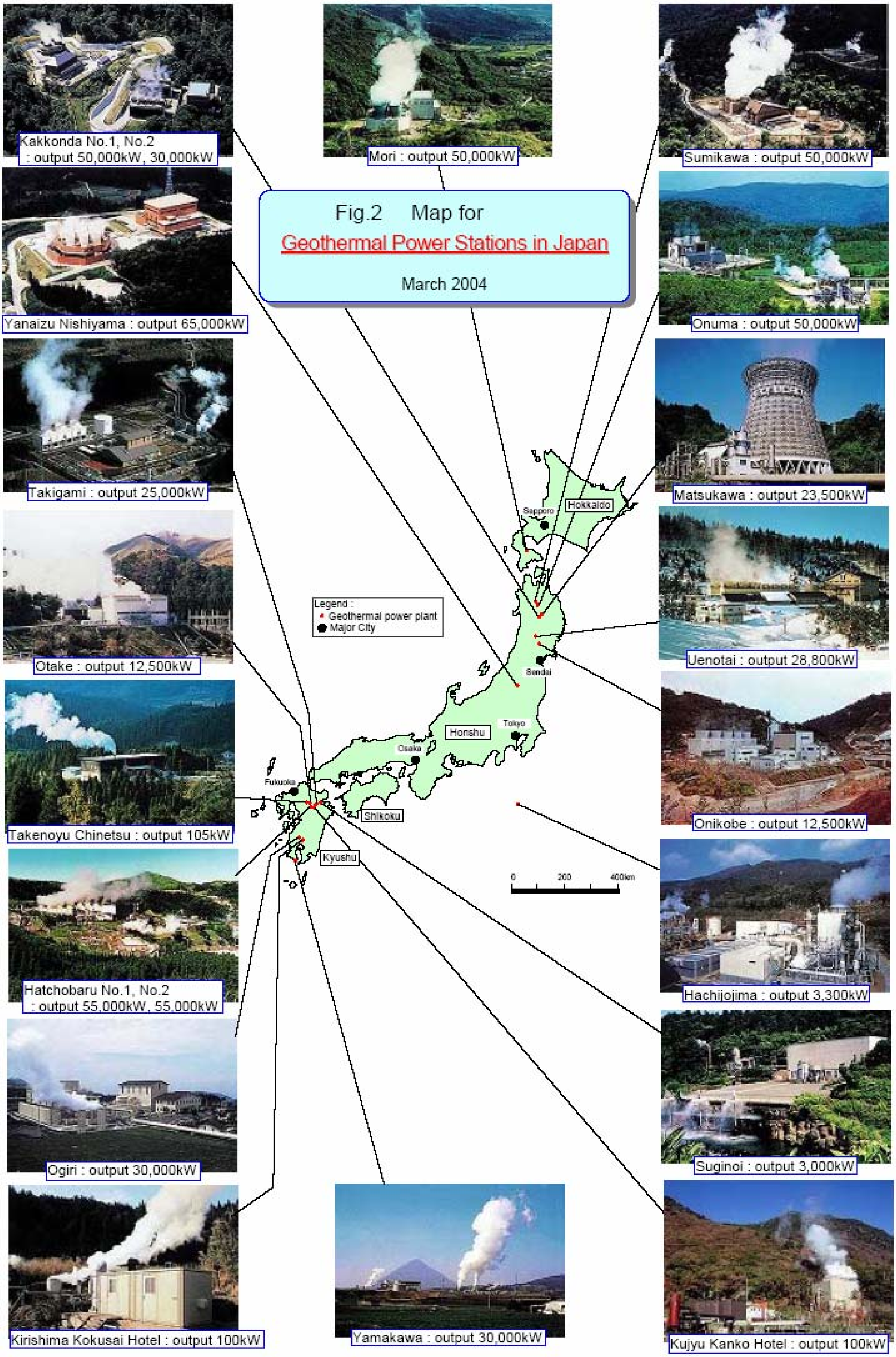

Figure 13.1 Geothermal power stations in Japan as at March 2004.

which thermal power accounted for 65.1%, hydroelectric power 17.4%, nuclear power 17.0%, and geothermal 0.2% (Figure 13.3).

13.3.1.2 Total Electricity Generation

The total electricity generation for geothermal energy of FY 2003 was 3,486 GWh. (Figure 13.2 and Table 13.1).

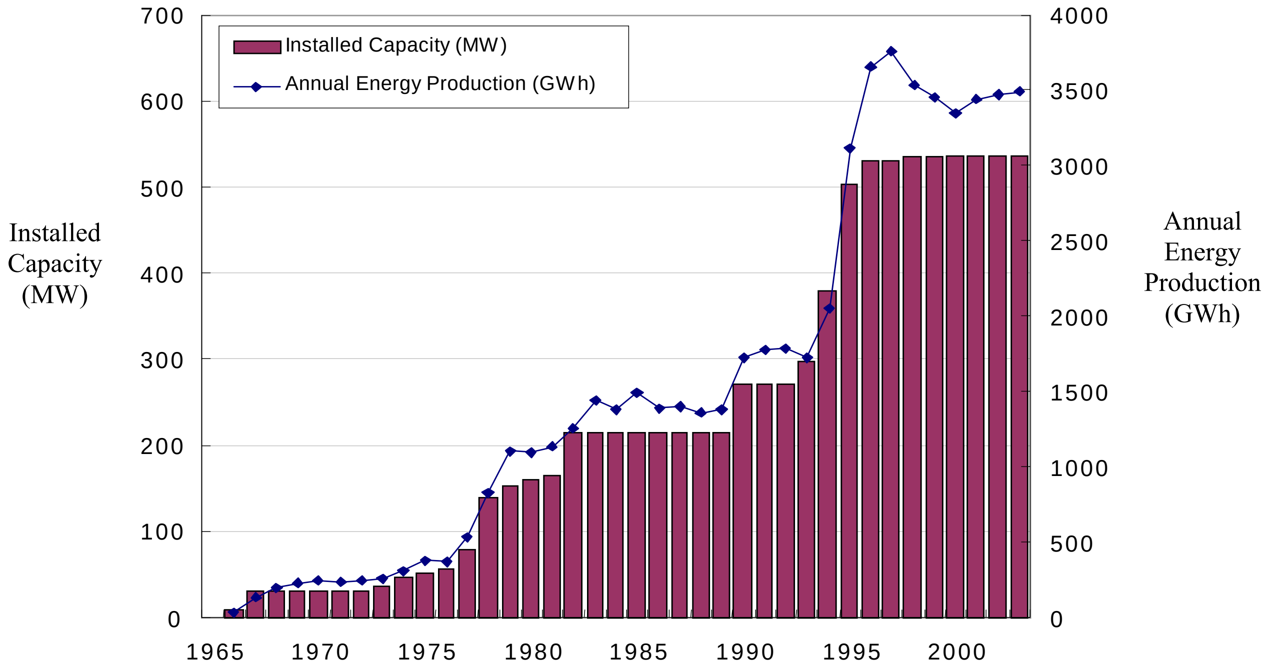

Figure 13.2 Installed capacity and annual energy production of the geothermal power plants in Japan (the fiscal year in Japan is from 1 April to 31 March).

13.3.1.3 New Developments During 2004

At present, promising geothermal areas to be developed in the future are very few.

13.3.1.4 Rates and Trends in Development

The output capacity for geothermal energy has remained almost constant in the past few years, and there is no plan to develop new power plants in the near future, without some small binary generation unit.

13.3.1.5 Number of Wells Drilled for Power Plants

Production wells were drilled at: Kakkonda, 1 well; Yanaizu-Nishiyama, 1well; and Hatchobaru, 1well.

Reinjection wells were drilled at: Sumikawa, 1 well; Kakkonda, 1 well; Hatchobaru, 1well; Takigami, 1well and Ogiri, 1 well.

Survey wells were drilled at: Kirishimaeboshi-dake field, 2 wells Minase field, 1 well and Ten'ei field, 1 well.

13.3.1.6 Contribution to National Demand

The total electricity generation in Japan for FY 2003 was 1,094 TWh (Figure 13.3), with geothermal providing about 0.3%.

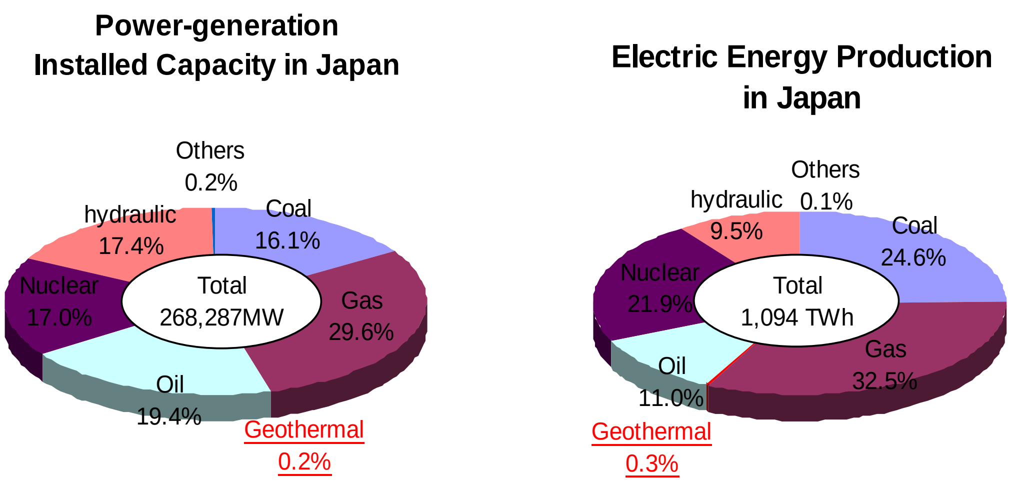

Figure 13.3 Condition of Power-generation in Japan at FY2003.

13.3.2 Direct Use

Direct use of geothermal water in Japan amounts to 5,139 TJ per year, excluding bathing, data compiled in March 2002 (Table 13.2). Geothermal heat pump capacity was 3.6 MW_t in 2000.

13.3.3 Energy Saving

The total geothermal electricity produced in Japan is equivalent to saving 0.92 Mtoe (million tonnes of oil equivalent) per year. The total direct use and geothermal heat pump energy use in Japan is equivalent to savings of 0.12 Mtoe per year.

Geothermal electricity generation in 2004 saved the production of about 2.8 Mt of CO_2 compared to fossil fuel use (not considering CO_2 emission in geothermal steam).

13.4 Market Development and Stimulation

13.4.1 Support Initiatives and Market Stimulation Incentives

13.4.1.1 NEDO

The New Energy and Industrial Technology Development Organization (NEDO) initiates "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 was started in 1980. The survey programme is composed of Surveys A, B and C, varying the scale and the content depending upon the regional potential and existing data. Surveys have been completed in

Table 3.2 Direct Use of Geothermal Energy in Japan as of March 2002.

	Utilization Capacity (MWt)	Annual Mean Utilization (TJ/y)
Greenhouse heating	41.49	404.11
Aquaculture	16.91	212.34
Stockbreeding (Space heating)	0.14	1.48
Agriculture (Paddy warming, Washing crops)	2.12	30.07
Industry	1.52	40.86
Food processing	0.16	3.60
Accommodation (Space heating, Hot water)	49.43	715.16
Tourism (Cooking, Pool)	13.79	125.15
Housing (Space heating, Hot water)	27.50	564.33
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Snow melting	133.26	448.60
Other (Hot water supply)	55.70	1,542.11
Total	**409.38**	**5,138.71**

Source: Results of the survey conducted by Geothermal Energy Development Center, New Energy Foundation Geothermal Energy Vol.27, No.4

*: It must be noted that data for "Accommodation" in this table includes only swimming pool and not bathing.

*: It must be noted that geothermal heat pump data is not included

55 areas as at the end of 2004. Since 1999, NEDO has been carrying out Survey C intensively, aiming at a further reduction of survey risks and development lead-time for private sector companies to construct geothermal power plants based on those preliminary results. Therefore, geothermal reservoir evaluation using large-bore production wells for long-term production tests is included.. For this purpose, one area; Kirishimaeboshi-dake was to be surveyed in FY2004 as Program C-1 (Figure 13.4). On the other hand, three areas; Obama, Ten'ei and Minase were surveyed as Program C-2 based on a new concept of "local energy for local area". (Figure 13.4, Figure 13.5 and Figure 13.6).

13.4.1.2 Subsidy System

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 provides compensation for interest on bank credits to support developers undertaking well drilling, a process that requires a large investment at an early stage. There are two types of subsidies for companies developing power plants, one aimed at the drilling of exploration wells, with a subsidy ratio of 50%; and the other for the construction of production and reinjection wells, and facilities on the ground, with a subsidy ratio of 20%. These systems started in 1983. Beginning in 2002, binary facilities in geothermal power generation systems are rewarded with a subsidy ratio of 30%.

Actual subsidy record for FY 2004:

- Exploration well: nothing.
- Production wells : Kakkonda 1 well; Yanaizu-Nishiyama 1well and Hatchobaru 1 well.
- Reinjection well: Sumikawa 1 well, Kakkonda 1 well; Hatchobaru 1well; Takigami 1well and Ogiri 1 well.
- Facilities (including new pipe laying, *etc*.): Sumikawa, Kakkonda, Yanaizu-Nishiyama.
- Binary Facilities: nothing.

Figure 13.4 Production test for exploration well in Kirishimaeboshi-dake (South side of Kyushu) geothermal field, research activities under Survey Program C-1 conducted by NEDO, started from FY2001 to FY2004. Flow rate: Steam 40t/h, water 120t/h (Nov. 2004).

Figure 13.5 Drilling for exploration well in Minase (North side of Honshu) geothermal field, research activities under Survey Program C-2 started FY2004. (Nov. 2004)

13.4.2 Organizations for Promoting the Development of Geothermal Energy

13.4.2.1 NEDO

NEDO was established in 1980. This organization is devoted to the promotion of technological development, aiming in particular at reducing the Japanese economy's dependence on oil. Furthermore, as part of its activities, it grants subsidies for the development of geothermal resources.
To support geothermal development, NEDO conducts "Geothermal Development Promotion Surveys C" and provides a compensation system for geothermal developers.

Figure 13.6 Drilling for exploration well in Ten'ei (Middle of Honshu) geothermal field, research activities under Survey Program C-2 started FY2004 (Nov 2004).

13.4.2.2 New Energy Foundation (NEF)

Established in 1980, this foundation handles business related to the development of new energy sources. It is active in such fields as surveying, research, feasibility testing, and the distribution of information concerning the development and utilization of small and medium sized hydraulic, geothermal and other local energy sources.

13.4.2.3 Geothermal Research Society of Japan (GRSJ)

GRSJ was established in 1978 to promote research and development in scientific and technical fields related to the exploration, development, and multipurpose utilization (including power generation) of geothermal energy. This society holds its general meeting in autumn of each year, welcoming participation by numerous foreign specialists. The association consists of approximately 90 corporate and 667 individual members. The society also is also open to foreign members. In December 2001, the Technical Division of Underground Thermal Utilization came under GRSJ with a strong collaboration with GeoHPAJ.

13.4.2.4 Geo-Heat Promotion Association of Japan (GeoHPAJ)

GeoHPAJ was established in April 2001. Its base were the members of former Geothermal Heat Pump Association, which was formed in 2000 by interested people from universities and private companies. Currently GeoHPAJ consists of 76 company members (including geo-technical consultants; electric power companies; drilling, construction and civil engineering companies; heat-pump manufactures; facility owners; *etc*.) and several individual members from research institutes and universities. Four working groups: public information, planning, drilling technology and regulation and strategy, perform activities on a voluntary basis. Besides regular information exchange, services for the members and public information are emphasized.

13.4.2.5 Heat Pump & Thermal Storage Technology Center of Japan (HPTCJ)

HPTCJ is an affiliate of the Ministry of Economy, Trade and Industry (METI). It was begun as a study group for the utilization of geothermal heat pumps in July 2002 for information exchange and technical improvement. HPTCJ is the Japanese agency for International Energy Agency (IEA) tasks on heat pump systems and thermal storage (Annex 17 and Annex 14).

13.4.2.6 Geothermal Journals and Booklet

The following two journals play a leading role among Japanese journals in the field of geothermal science and technology:

- ***Chinetsu Energy*** (***Geothermal Energy***) -New Energy Foundation
- ***Nihon Chinetsu Gakkaishi*** **-** Journal of Geothermal Research Society of Japan

The Thermal and Nuclear Power Engineering Society publishes the booklet: Trends of Geothermal Power Generation in Japan (*Wagakuni no chinetsu hatsuden no doko*) written in Japanese, which gives detailed information on geothermal energy in Japan and the world.

13.5 Development Constraints

To date, geothermal energy in Japan has been developed as a substitute for oil energy since the oil crisis. No adequate study has been done to evaluate the potential of geothermal energy as a renewable energy consistent with the earth's environment. Internationally, geothermal energy is recognized and categorized as a new and/or renewable energy together with solar, wind, hydro and biomass energy. However, in Japan, only solar and wind are classified as "new energies" that enjoy protection under the law concerning Promotion of the Use of New Energy enacted in 1997. Geothermal is not included. Moreover, in 2001, biomass was added to the list of renewable energies to be promoted by the New and Renewable Energy Subcommittee of the Advisory Committee for Natural Resources and Energy, but geothermal was not. According to the Energy Supply and Demand Outlook presented by the Japanese 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. This decision was purely political.

13.6 Research Activities

Research and Development activities are conducted under the leadership of NEDO and National Institute of Advanced Industrial Science and Technology (AIST).

In April 2001, the Geological survey of Japan (GSJ), the Agency of Industrial Science and Technology (AIST) and the National Institute for Resources and Environment (NIRE) were consolidated into AIST as a single organization. In 2004, the only investigation being pursued was a comprehensive evaluation for the development project of Hot Dry Rock Power Generation System.

NEDO is conducting some international cooperative projects, one of which is a "study of methods for utilizing acidic geothermal fluids". In this study, which operates from December 2002 to March 2004, a neutralization method is being investigated. The use of acidic geothermal fluids is usually avoided because it causes corrosion problems. In Costa Rica, acidic fluids have been used after neutralization for power generation since 2000, but scaling problems were occurring in the production wells and surface equipment. The optimal conditions for neutralization will be determined from the results of this study, based on data collected for scaling rates, corrosion rates and other monitoring results under certain conditions.

13.7 Geothermal Education

Japan has made a great contribution to extend technical assistance in the field of geothermal energy to developing countries through the group-training course at Kyushu University and the geothermal projects in developing countries provided by the Japan International Cooperation Agency. An International Group Training Course on Geothermal Energy was started in the Earth Resources Engineering Department of Kyushu University for development of alternative energy resources at the request from United Nations (UNESCO) and JICA (OTCA) in 1970. From 1970 to 2001 when the course ended, a total of 393 specialists from 37 countries have participated to the group training courses on geothermal energy and environmental sciences held in Kyushu University.

A new geothermal course was initiated at Kyushu University on October 2002 following the end of the JICA course. It is a doctoral programme in the Graduate School of Engineering entitled: "International Special Course on Environmental Systems Engineering" (http://www.c-shop.net/kyushu/). Twenty students are admitted per year into the Graduate school of Engineering, ten of which are awarded with a MEXT (Ministry of Education, Culture, Sports, Science and Technology) Scholarship. Participants in this new course study under five advanced departments of Kyushu University 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, the language used for all education and other activities is English.

13.8 International Cooperative Activities

The Japan International Cooperation Agency (JICA) has been in charge of the geothermal development activities for developing counties since 1973. From 2001 to 2005, one of the development projects being conducted is at the Yangbajain field located in Tibet, China.

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CHAPTER 14

Mexico

4.1 Introduction

Geothermal energy is, by far, the most important non-conventional renewable energy source utilized in Mexico. Although there is some tradition for direct uses of geothermal energy, mainly related to balneology, the most important use is for electricity generation.

Geothermal development for electricity generation started in Mexico in 1959, with the commissioning of the first commercial plant in the Pathé field (central Mexico). By December 2004 the geothermal-based installed capacity for electricity generation reached 953 MW_e, placing Mexico in third place worldwide.

14.2 National Policy

About 86% of the installed capacity for electricity generation belongs to the two government-owned utilities, namely the Comisión Federal de Electricidad (CFE) and Luz y Fuerza del Centro (LyFC). CFE is responsible for all electricity generated with geothermal steam. This primary energy source has been utilized for decades for power generation; the technology is considered mature, and it is set to compete under the same bases as fossil fuel, conventional hydro and nuclear technologies.

CFE is currently doing feasibility studies to increase the installed capacity and replace some of the older power plants. The aim is to replace 75 MW_e with 100 MW_e, using the same amount of steam. CFE is also considering increasing 25 to 50 MW_e in Los Humeros and is taking steps to install 75 MW_e in the partially developed Cerritos Colorados field. Undeveloped areas with geothermal potential are also being studied (see below).

14.3 Current Status of Geothermal Energy Use

14.3.1 Electricity Generation

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

The total electricity generated with geothermal steam during 2004 was 6,360 GWh.

There were no new developments during 2004.

During the year 2004, CFE drilled a total of 12 new geothermal wells, 5 in the Cerro Prieto field (9 producers and 3 injectors).

Electricity generation from geothermal sources represented about 3.0 % of total production. The geothermal contribution to electricity generation is more than 1.5 times higher than its contribution to the installed capacity, reflecting the very high capacity factor.

14.3.2 Direct Use

The installed thermal power was estimated to be about 164 MW_t, used for balneology in 160 sites distributed in 19 states.

14.3.3 Energy Savings

The electricity generated from geothermal steam in 2004 amounted to the avoided consumption of 36, 15.9 and 8.9 PJ of primary energy from fuel oil, natural gas and coal, respectively, considering the typical mix of fossil fuels utilized in Mexico.

14.4 Market Development and Stimulation

14.4.1 Support Initiatives and Market Stimulation Incentives

At present there are no incentives for geothermal development in Mexico. The Comisión Federal de Electricidad, the larger of two national utilities, increased its installed capacity for power generation with geothermal sources from 853 to 953 MW_e in the year 2003, and this is the only substantial increase expected throughout 2006. However, studies for possible new developments and expansion in developed fields are underway (see below).

14.5 Development Constraints

As mentioned above, power generation with geothermal energy is considered conventional in Mexico, and thus it is set to compete under the same bases as fossil fuel, conventional hydro and nuclear technologies. Therefore, it is fair to say that the main constraint for further geothermal development in this country is its economic disadvantage against modern fossil fuel generation technologies, particularly combined-cycle generation. At least in one case, namely that of the La Primavera geothermal field, which is a fully proven resource, development has come to a full stop because of concerns from the local (State) government about possible environmental impacts.

Figure 14.1 Unit 14, project II, los Azufres, Mexico.

14.6 Economics

14.6.1 Trends in Geothermal Investment Foreseen

As mentioned above, although the target for geothermal development in the present federal administration has been met, studies are underway in CFE for future developments on the order of 50 MW_e in Los Humeros, 100 MW_e in Cerro Prieto and 75 MW_e in Cerritos Colorados (La Primavera), as well as the development of new fields in Acoculco, San Pedro, La Soledad and Tacaná.

14.6.2 Trends in the Cost of Energy

The increase of the average price for electricity has accelerated in the last few years (*ca* 5.4% from 2000 to 2001 and 14% from 2001 to 2002), reflecting, in part, the trend in fossil fuel prices and also the reduction of subsidies for certain consumer sectors.

14.7 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 the exploration of new areas with geothermal potential. The federal government funds practically all geothermal research.

14.8 Geothermal Education

The University of the State of Baja California (UABC) offers a Geothermal Training Program (10-months long) which, in addition to the program offered by Iceland and the one previously offered by New Zealand, has been utilized by CFE to train some of their young engineers. During the last three years CFE has sent young engineers for training to Japan, under an agreement between JICA and the Mexican government. 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.

14.9 International Cooperative Activities

CFE signed a cooperative agreement with the Japan Bank for International Cooperation (JBIC) to do a feasibility study of the Cerritos Colorados project (75 MW_e). The study is being conducted by West Japan Engineering Consultants.

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 now participating in Annex VII (Advanced Geothermal Drilling Technologies) of the Geothermal Implementing Agreement.

In 2004, IIE continued a project for the evaluation of low and intermediate enthalpy geothermal resources in Mexico and Central America, with the aim of promoting direct uses of this energy source. This project is partially supported by the International Atomic Energy Agency.

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CHAPTER 15

New Zealand

15.1 Introduction

Geothermal energy continues to play an important role in both electric power generation and direct use in New Zealand. The contribution to total electricity production remains steady at about 7%, mostly base load power. This helps balance the weather dependency of some of New Zealand's other renewable energy resources, such as hydro (60%) and wind (0.25%). Interest in geothermal energy use is increasing because of the growing importance of achieving net reductions in CO_2 emissions under the Kyoto Protocol, (signed by New Zealand in 2003), rising fossil fuel prices, and dwindling gas reserves. Evidence of this is the commitment by several major developers to staged expansion and geothermal exploration expenditure, despite a tougher regulatory environment.

15.2 Highlights for 2004

- Mokai- 40 MW_e expansion under construction, with wells MK10-14 completed and tested and new greenhouses constructed (using MK2).

- Wairakei- Consent application for the next 25 years heard and approved in mid-October 2004; and a 15 MW_e binary plant (130-90 ^oC) is under construction.

- Rotokawa- 5 MW_e expansion operational, 3 production wells drilled, 30 MW_e expansion application lodged, and new exploration for future expansion.

- Kawerau- 3 exploration wells drilled in the east (Putauaki), and new greenhouses planned.

- Tauhara- testing of well TH2 for direct steam use for Fletcher Wood Panel wood processing plant.

- Ngawha- application heard for 10 MW_e expansion (but declined on local environmental grounds).

- Exploration activities conducted at Atiamuri, Horohoro, Ngatamariki and Tikitere.

- Waikato Regional geothermal environmental policy and planning hearings completed (appeals still pending).

15.3 New Zealand National Policy

15.3.1 Strategy

The energy supply strategy for New Zealand is anticipating a doubling of geothermal energy use over the next 8 to 10 years to replace gas. By 2025 even more geothermal energy will be required to avoid a large increase in coal use, which would compromise Kyoto Protocol commitments.

Government policies have been put in place to encourage more development of renewable resources, including geothermal. These initiatives include:

- **The National Energy Efficiency and Conservation Strategy (NEECS)**

This strategy aims to improve energy efficiency by 20%, and increase use of renewables.

- **The National Climate Change Policy Package (CCPP)**

This is designed to reduce CO_2 emissions by reducing dependence on fossil fuels and placing more emphasis on renewable sources.

- **Sustainable Development Programme of Action for Energy**

One of the outcomes of this programme is to ensure that renewable sources of energy are developed and maximised.

- **Resource Management (Energy and Climate Change) Amendment Bill**

This bill seeks to align national and regional energy and environmental objectives.

- **Development of Geothermal Assets Owned by the Crown**

Better utilization of government owned geothermal assets.

- **Energy Outlook to 2025**

This document, published by the Ministry of Economic Development, has signalled an expected increase in use of geothermal energy for electricity generation to at least 600 MW_e by 2025.

Regional Councils (Waikato, Bay of Plenty and Northland,) have established geothermal policies and plans with which to administer the provisions of the Resource Management Act. Public hearings into the Waikato policies and plans have attracted a large number of submissions, and decisions have been appealed. Environmental groups want stronger protection provisions, but developers want more flexible rules to balance the need for more renewable energy use versus the local environmental issues.

15.3.2 Progress Towards National Targets

Growth in geothermal power generation has been slow but steady. Renewed expenditure in exploration and drilling suggests that progress towards national targets will increase over the next 5 years.

15.4 Current Status of Geothermal Energy Use

15.4.1 Electricity Generation

As of October 2004, the total installed geothermal generating capacity was 452 MW_e, with the total electricity generated amounting to 2,774 GWh/year.

In 2004, new developments were under construction at Mokai (40 MW_e) and Wairakei (15 MW_e).

In 2004, four new production wells and one reinjection well were drilled in Mokai and Rotokawa, adding to the four drilled in 2003. Three exploration wells were also drilled at Putauaki, Kawerau.

Geothermal energy contributed about 7% towards the national total demand, with hydro providing 60%, wind and biomass 1.5%, cogeneration 1.5% and coal and gas 30%.

15.4.2 Rates and Trends in Development

Development has been steady with a small growth in capacity, driven partly by current prices and partly by industry positioning for future fossil fuel price increases, the Kyoto agreement on CO_2 emission reductions, and vulnerability to hydro shortfall in dry years.

Table 15.1 Utilization of geothermal energy for electricity power generation in New Zealand in 2004.

1)	OP = operating	OPr =operating at <60%	UC = under construction
2)	HP= high pressure	B = Binary (Rankine Cycle)	BP = back pressure steam
	IP = Intermediate pressure	H = Hybrid (BP steam & B)	C = Condensing Steam
	LP = Low pressure		

Locality	Power Plant Name	Year Com-missioned	No. of Units	Status[1)]	Type of Unit[2)]	Unit Rating (MWe)	Total Installed Capacity (MWe)	Annual Energy 2003/4 (GWh/yr)	Under Constr. or Planned (MWe)
Wairakei	Wairakei	1958-63	10	OP	2 IP - BP	2 x 11.2			
					1 LP - BP	1 x 5			
					4 LP - C	4 x 11.2			
					3 IP - C	3 x 30	162	1290	
			3	UC	B	3 x 5			15
Wairakei	Poihipi	1996	1	OPr	1 IP -C	1 x 55	55	215	
Wairakei	Tauhara								15
Ohaaki	Ohaaki	1989	4	OPr	2 HP BP	2 x 11.2			
					2 IP C	2 x 46	114	300	
Kawerau	Tasman P&P	1966	1	OP	1 BP	1 x 10	10	80	
Kawerau	Kawerau Binary	1990	3	OP	B	3 X 2	6	50	
Rotokawa	Rotokawa	1997	1	OP	H	1 x 12			
		1997	3	OP	B	3 x 4.5			
		2003	1	OP	B	1 x 4.5	31	290	
Northland	Ngawha	1998	2	OP	B	2 x 4.5	9	79	
Mokai	Mokai	1999	7	OP	H	1 x 25			
					B	6 x 5	55	470	
				UC	H,B				40
Total							**452**	**2774**	**70**

15.4.3 Direct Use

Direct use at existing plants in Kawerau (Tasman Pulp and Paper Mill), Ohaaki (timber drying), Wairakei (Prawn Farm), and at existing tourist and bathing facilities has remained steady. A new 5-hectare glasshouse project has been constructed at Mokai, and an estimated 20 new direct use wells have been drilled.

15.5 Research Activities

The primary focus of NZ government funded geothermal research, which amounts to about NZ$ 2 M/yr) is currently targeted as follows: deep high temperature resources, use of low-enthalpy resources, better use of waste geothermal fluids and environmental effects.

New research initiatives include: arsenic removal from waste water using bacteria, improved subsidence modelling and prediction, monitoring changes in natural CO_2 gas and steam emission from thermal areas.

15.6 Geothermal Education

Due to the withdrawal of New Zealand Government funding for the Geothermal Institute in 2002, there were no students enrolled in the Geothermal Institute diploma course. However, several graduate students were supervised in the MSc and PhD programmes in engineering and geology at the University of Auckland.

Other geothermal educational events included the 26th annual NZ Geothermal Workshop, which was successfully held at Taupo in December 2003, in conjunction with the annual NZ geological and geophysical society conferences (GEO^3). A one-day seminar run by the New Zealand Geothermal Association was also appended to the conference. These events attracted a large number of local and overseas participants.

15.7 International Cooperative Activities

New Zealand has collaborative research relationships and links with many international agencies including: USGS (USA), KIGAM (South Korea), GSJ (Japan), AEA (Switzerland), University of Utah, Energy and Geoscience Institute (USA), University of Alberta (Canada) and Tohoku University (Japan).

15.8 References

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Manville V. (2004) Geo3 Programme and Abstracts incorporating 26th Annual Geothermal Workshop. Geological Society of NZ Miscellaneous Publication 117A ISBN 0-908678-98-3

White, B.R. (2003) Some recent and current government initiatives related to geothermal energy. *Proceedings of the 25th New Zealand Geothermal Workshop 2003*: 1-8.

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CHAPTER 16

Switzerland

16.1 Introduction

The previous (2003) Country Report of Switzerland is Chapter 17 in the GIA Annual Report 2003, which can be found in the Publications area on the IEA GIA website at: http://www.iea-gia.org

The numbers presented in the 2003 Country Report were based on estimates by extrapolation. In 2004 a new statistical survey was carried out (Signorelli *et al*., 2004); the 2004 Country Report is based on these new numbers for installed capacities, energy produced, fossil fuel and CO_2 emission savings, *etc.* They are also reported in the Swiss Country Update Report prepared for WGC2005 (Rybach and Gorhan, 2005).

The main setback in the year 2004 was the end of funding for geothermal pilot and demonstration projects by the Federal Government. The highlight was the funding provided by local Cantonal government and private industry and start of the next phase of the Deep Heat Mining Project in Basel (including drilling to 5 km, stimulation, circulation tests). Some details are provided below.

The key achievement of Switzerland is in the use of shallow geothermal resources by ground-coupled heat pumps. An evaluation of available worldwide data reveals that Switzerland occupies a prominent rank in installing and running geothermal heat pump systems.

16.2 National Policy

The *SwissEnergy* program, mainly devoted to a more efficient use of energy (with specific tasks such as energy saving, reduction of CO_2 emissions, a definitive increase in the contribution of renewable energies) and its goals and measures have been described in the 2002 Country Report (also accessible through the IEA GIA homepage).

16.2.1 Strategy

In addition to the description given in the 2002 Country Report (which is still valid for 2004) further information can be found in Vuataz, *et al.* (2003).

16.2.2 Legislation and Regulations

The legal situation concerning geothermal energy utilization in Switzerland has been described in detail in the 2003 Country Report. No significant changes happened in 2004. A comparison with geothermal legislation in other European countries reveals great differences in existing legislations (Rybach, 2004a). Serious efforts are needed to harmonize legislation and to simplify procedures particularly within the EU.

16.2.3 Progress Towards National Targets

The progress in reaching both the overall goals of the *SwissEnergy* Program as well as of the Geothermal Program are satisfactory to date, although the cutback of funding geothermal pilot and demonstration projects is painful.

16.2. Government Expenditure on Geothermal R&D

In 2004 the Swiss Government, through the Federal Office of Energy, has supported various geothermal R&D projects with a total sum of about 1 M €.

16.3 Current Status of Geothermal Energy Use

16.3.1 Electricity Generation

So far there is no electricity generation from geothermal sources in Switzerland. However there is a substantial project underway (DHM: Deep Heat Mining) with the aim to establish EGS-type co-generation plants based on the EGS principle at sites in Basle and Geneva, within the next 10 years. At the Basel site a recently drilled 2.7 km deep exploration well has been equipped with seismic instrumentation to record natural and artificial seismicity. At the Geneva site detailed investigations are conducted to place the first exploratory drilling. So far the DHM project has been co-funded by federal and local governments. In 2004, significant funding for the next DHM project phase in Basel (including drilling to 5 km, stimulation, circulation tests) has been secured by the local parliament (20 M €). Commercial companies are also contributing.

16.3.2 Direct Use

There is now new statistic material, covering the years 2002 and 2003 (Signorelli, *et al.* 2004). The numbers for 2004 have been estimated from these data by extrapolation. Tables 16.1 and 16.2 show the results.

The most common technology for direct use applies borehole heat exchanger (BHE)-heat pump coupled systems. Their share is by far the highest among the other categories (see Tables 16.1 and 16.2).

Table 16.1 Installed capacity for direct use in Switzerland in 2004.

Energy Source/Use	Capacity (MW_t)	Percent of Total (%)
GHP with borehole heat exchangers (including shallow horizontal coils)	450.0	77
GHP with groundwater	75.4	12.9
Thermal springs/boreholes (balneology)	40.8	7.0
Deep aquifers	6.1	1.0
Tunnel waters	5.2	0.9
Deep borehole heat exchangers	0.2	0.03
Geostructures ("energy piles")	7.0*	1.2
Total	**584.7**	**100.0**

* Heating: 4.8 MW_t, cooling: 2.2 MW_t

Recent trends indicate that BHEs are more and more placed directly beneath the buildings being erected (Figure 16.1). A further development emphasizes the use of such systems not only for space heating and domestic hot water supply but also for cooling. This secures optimum property use.

16.3.2.1 Installed Thermal Power

Table 16.1 shows the installed capacity of the various utilization technologies in 2004 (the numbers are based on the statistical survey of Signorelli, *et al*., 2004). The statistical survey reveals that in 2004, geothermal heat pumps (GHP), with 525 MW, formed the largest part of installed capacity in Switzerland (90 % of installed geothermal capacity, Table 16.1).

Although the contribution of the category *geostructures* (mostly "energy piles", which are foundation piles equipped with heat exchanger pipes) did not expand significantly in 2004, their recognition is increasing. Their prominent example, the Midfield Terminal C at Zurich International Airport "Unique", is now in service, and the new terminal is heated and cooled by an energy piles/heat pump system.

The total installed capacity for direct use was 585 MW_t. Switzerland still occupies a prominent rank in geothermal heat pump applications (see below).

16.3.2.2 Thermal Energy Used

The numbers for the energy produced by the different categories have also been taken from Signorelli, *et al*. (2004). Table 16.2 shows the numbers for heat production in 2004. The average capacity (load) factor, due to the climatic conditions, is around 20 % but varies with application: thermal springs and wells for balneology and wellness are utilized all year around. The low capacity factor for geothermal heat pump systems is not necessarily disadvantageous; in well-insulated buildings the heat pump runtimes can be kept low.

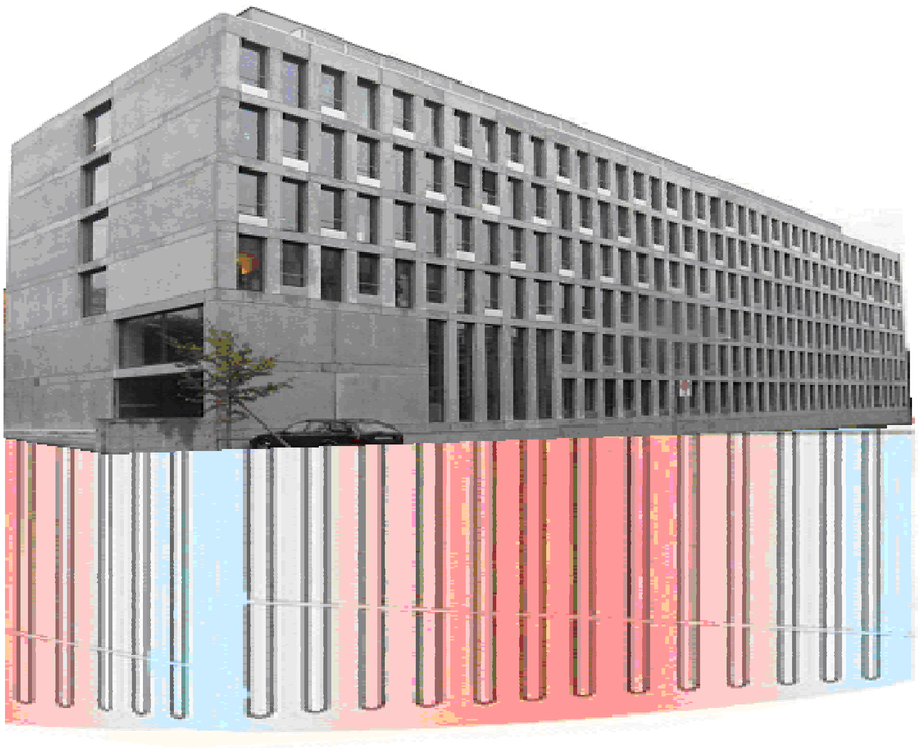

Figure 16.1 Borehole heat exchangers placed directly beneath the building to be heated/cooled (Office building, Amstein & Walthert AG, Zurich).

The statistical survey reveals that GHPs contributed 781 GWh in 2004, over 66 % of the total geothermal heat production (Table 16.2). Total energy produced was 1,190 GWh.

Table 16.2 The heat production in 2004 from direct use in Switzerland.

Energy Source/Use	**Heat Produced in 2003 (GWh)**	**Percent of Total (%)**
GHP with borehole heat exchangers (incl. shallow horizontal coils)	666.3	56.0
GHP with groundwater	114.4	9.6
Thermal springs/boreholes (balneology)	341.5	28.7
Deep aquifers	37.2	3.1
Tunnel waters	13.7	1.2
Deep borehole heat exchangers	0.9	0.1
Geostructures	15.2*	1.3
Total	**1,189.2**	**100.0**

* Heating: 12.2 GWh, cooling: 3.0 GWh

16.3.2.3 Category Use

The various categories of use are listed in Tables 16.1 and 16.2. No significant new categories have emerged in 2004.

16.3.2.4 New Developments During 2004

Increasing demand is now emerging for combined heating and cooling. For this, geothermal heat pumps are well suited. Often "free cooling" circulating the heat carrier in the BHEs without running the heat pump is sufficient to create a comfortable indoor environment. It can be expected that in coming years the geothermal option for space cooling will significantly penetrate the market.

16.3.2.5 Rates and Trends in Development

The installation of GHP systems in Switzerland has proceeded rapidly since their introduction in the late 1970s. Figures 16.2 and 16.3 show the impressive growth. The rapid spreading of GHPs calls for quality control. The elaboration of a quality label for the entire GHP system (heat source like borehole heat exchanger, heat pump (HP), circulation hydraulics, heating circuit) is still in progress.

16.3.2.6 Drilling Activities

In 2004, a large number of wells (several thousand) were drilled to install double U-tube borehole heat exchangers (BHE) in the ground. The average BHE drilling depth is now around 150-200 m, though depths > 300 m are becoming more common. Average BHE cost (frilling, U-tube installation including backfill) is now about 40 around 40 € per meter. Figure 16.4 shows the increasing trend; in 2003 over 550 km (!) of drillholes were deepened for BHEs. Since 2003, drilling for the category of BHE arrays (i.e. sites with > 10 BHEs and > 1000 m drilling) is separately registered (Signorelli, *et al.*, 2004).

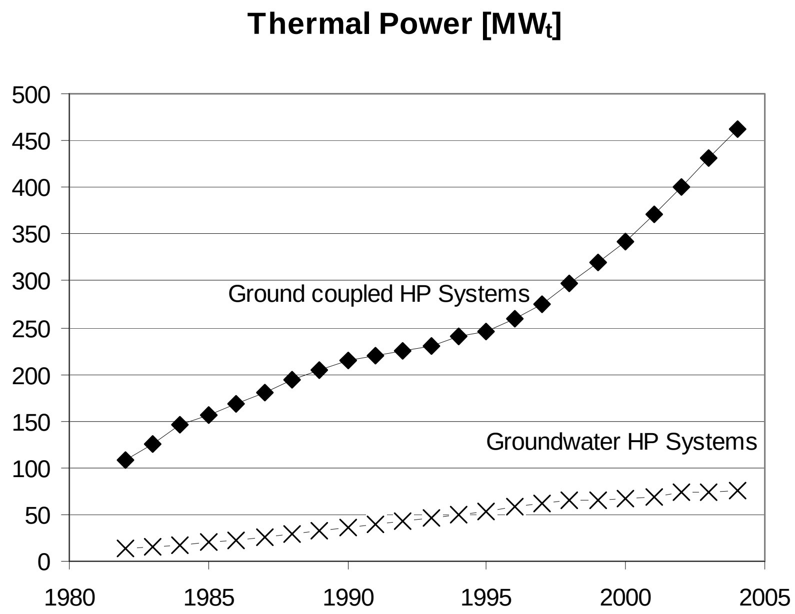

Figure 16.2 Development of installed capacities (MW_t) of ground-coupled and groundwater-based geothermal heat pumps in Switzerland during the years 1982 – 2003. (From Signorelli, *et al*., 2004).

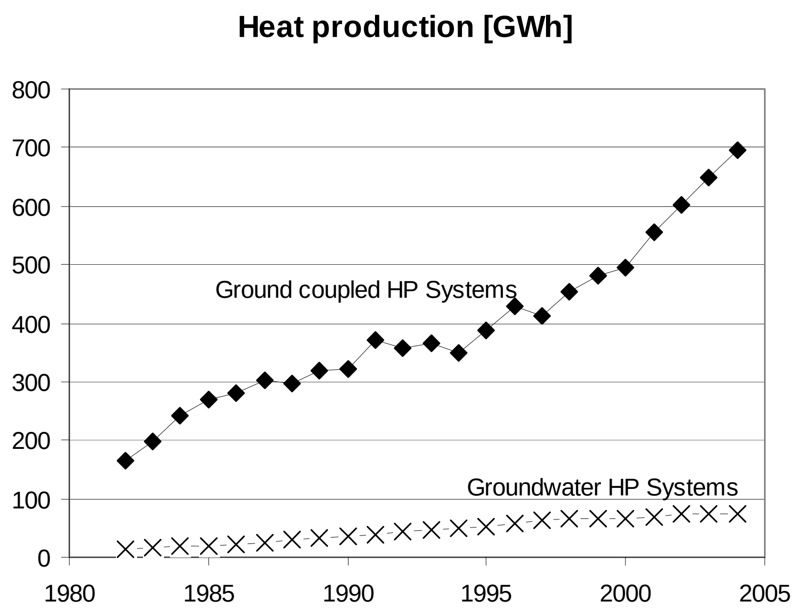

Figure 16.3 Development of heat production (GWh) by ground-coupled and groundwater-based geothermal heat pumps in Switzerland since 1982. (From Signorelli, *et al*., 2004).

16.3.2.7 Limitations of GHP Installations

The main aspect to be considered for new GHP installations is groundwater protection. Groundwater in Switzerland is not private property; cantonal authorities are responsible for regulation. These authorities also cover the aspects of groundwater protection. In groundwater protection zones, as delimited in special maps, absolutely no GHP types can be established; the systems with shallow horizontal coils are no exception. The basic concern of groundwater protection authorities is:

a) the risk of leakage of circulated fluid (usually with some antifreeze) from BHE or horizontal pipes

b) the risk of establishing vertical hydraulic connections between separate aquifer layers through improper backfill of drillings.

The first priority in groundwater use is for drinking water. Domestic hot water is also produced from this supply. Much of the household water in Switzerland comes from extended gravel aquifers, mainly located at valley bottoms. Incidentally, such gravel layers (now often mapped as groundwater protection zones) have low thermal conductivity, which makes the heat extraction from the ground for energetic use inefficient: e.g. the heat extraction rate for BHEs depends directly on the ground thermal conductivity (see e.g. Rybach and Eugster, 1998). Therefore, it is technically unfeasible to establish vertical (BHE) or horizontal pipes in such formations and so a conflict situation between energy source and groundwater protection aspects does not exist.

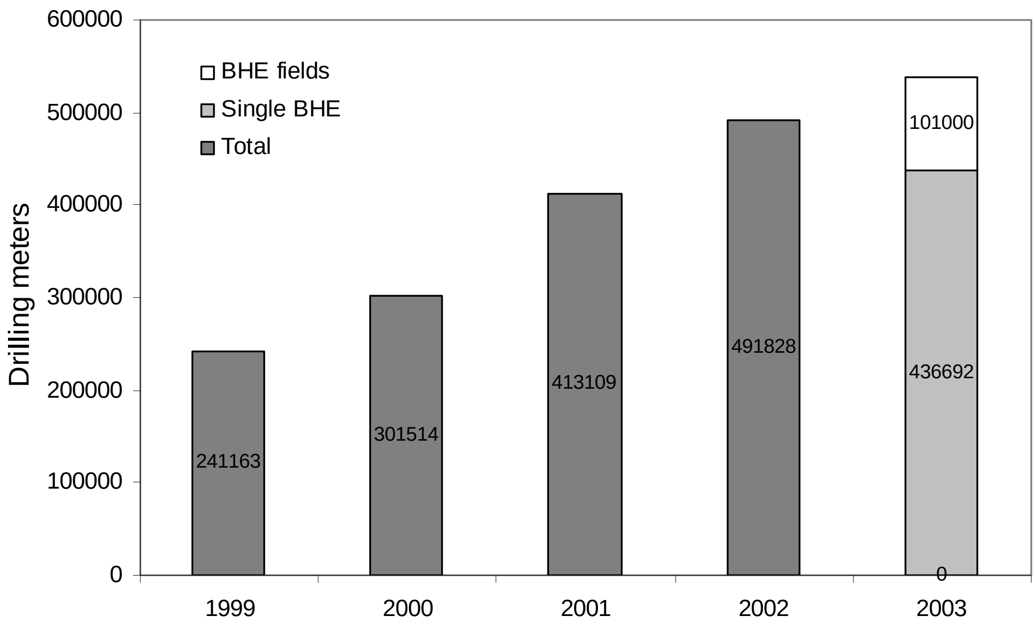

Figure 16.4 Development of drilling for borehole heat exchangers in Switzerland (total of drilled meters per year). (From Signorelli, *et al*., 2004).

Switzerland consists of 23 cantons and several cantonal water protection authorities have established maps for delimiting various zones. Some examples, which demonstrate that so far there is no uniformity in such maps, follow.

Canton Bern: A printed map on 1:100,000 scale was published in 1998 by the *Wasser- und Energiewirtschaftsamt des Kantons Bern*. It shows:

- groundwater protection zones where the installation of GHPs is prohibited
- zones where GHP with groundwater source can be installed
- zones where GHP with horizontal pipes and with BHE can be installed

- zones where GHP with horizontal pipes can be installed; BHE systems need special (mostly geologic) clarification
- zones where only GHP with horizontal pipes can be installed.

Canton Ticino: A synoptic geothermal map at 1:100,000 scale has been established in electronic format, as well as local maps at 1:25,000 which can be downloaded from the Internet (www.ist.supsi.ch). The map consists of different components:
- geologic map based on digital topography, lakes, rivers, roads, community borders
- terrestrial heat flow
- groundwater protection zones
- existing GHP installations.

Canton Zurich: A special map for GHP applications with BHE has been placed on the Internet at:
(www.wasserwirtschaft.zh.ch/erdwaermenutzung/). The scale can be enlarged by browsing, from 1:500,000 through 1:200,000, 1:100,000, 1:50,000 down to 1:25,000. Figure 16.5 shows a detailed map 1:25,000. The maps show
- topography, roads, rivers *etc*.
- groundwater protection zones, groundwater captures
- zones in which BHEs are permissible
- zones in which BHEs are permissible only with specific restrictions
- zones in which BHE installation needs further clarification
- zones in which BHEs are not permitted
- existing BHE installations, with/without geologic profile

Most maps are being continuously updated. The cantonal authorities distribute also the necessary application forms in order to get the necessary installation permits.

16.3.2.8 Worldwide Ranking in GHP Use

Nevertheless, GHP systems are increasingly used in Switzerland as well as abroad. According to the Country Update Reports prepared for the World Geothermal Congress 2005 (Lund, *et al*., 2005) 38 countries are using the GHP technology at present. From the Country Update Reports Lund extracted the relevant numbers for each country (J. Lund; written communication 2004): installed capacity (MW_t) and annual energy production (GWh/year). Using these numbers (Table 16.3), normalised figures (capacity or energy per country area or population) have been calculated, to take into account the country size and population (Table 16.4). The leaders based upon absolute numbers are the USA and Sweden, with Denmark and Switzerland also occupying high worldwide ranks.

In terms of the normalised figures (capacity or energy per country area or population), the leaders are clearly the Nordic/Scandinavian countries, with Denmark and Sweden being the champions.

The ranking results can be expressed by listing the medal winners:

- 1st rank (Gold): Sweden and Denmark 3x; USA 1x
- 2nd rank (Silver): Switzerland 2x, Denmark, Norway, Sweden, USA 1x
- 3rd rank (Bronze): Sweden and Switzerland 2x; China and Norway 1x

By all means Switzerland is a successful medallist and thus global player in GHP utilization.

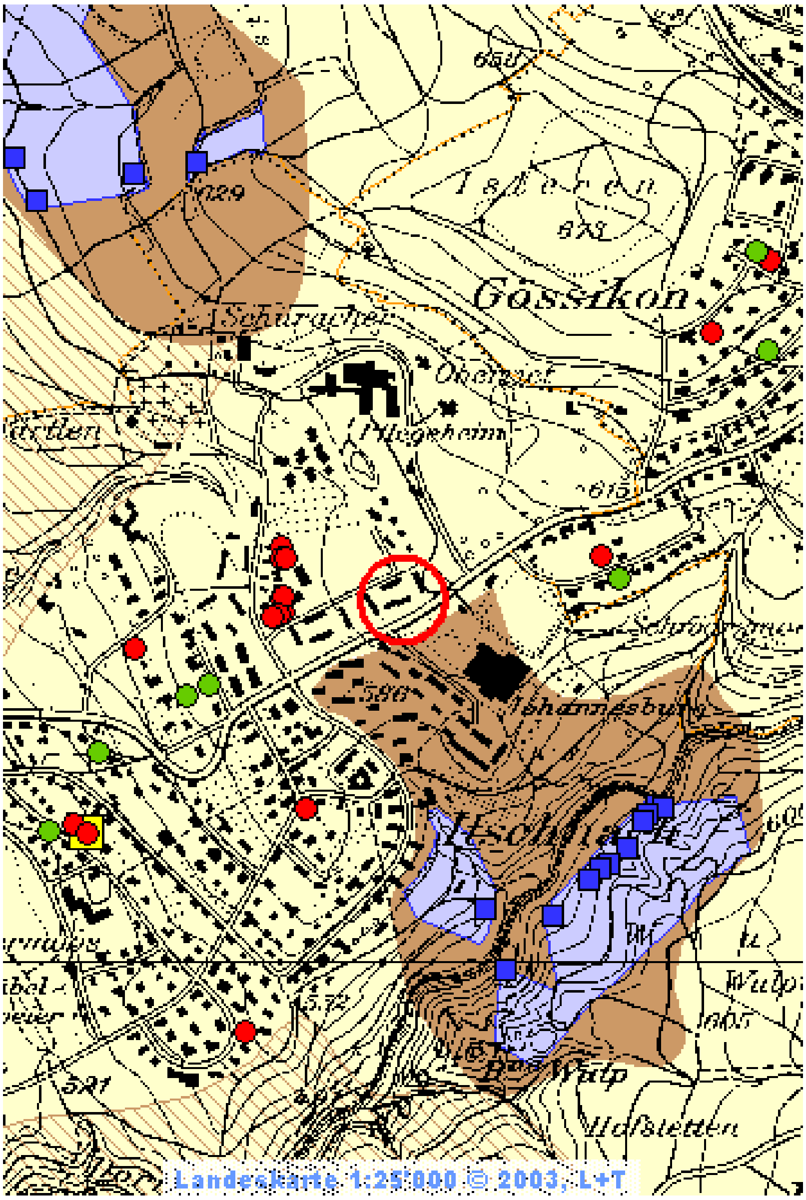

Figure 16.5 etail of the BHE map of Canton Zurich. Blue and brown: groundwater protection zones, blue squares: groundwater captures; existing BHEs with (green) and without (red) geologic profiles. Hachure: no special geologic considerations needed.

16.3.3 Energy and CO_2 Emission Savings

i. Fossil fuel savings/replacement (in tonnes equivalent [toe])

The heat production from geothermal sources (direct use) enables the savings of fossil fuels. The annual heat production in 2004, 1,190 GWh, corresponds to the saving of 150,000 toe (calculated for a conversion efficiency of 70 %).

ii. Reduced/avoided CO_2 emissions (in tonnes of CO_2)

The saving of 150,000 tons of oil per year avoids the emission of about 450,000 tons of CO_2 per year.

16.4 Market Development and Stimulation

The rapid development of geothermal heat pumps in Switzerland is striking (Figures 16.2 and 16.3). The various reasons, trends and costs are still the same as presented and discussed in detail in Rybach and Kohl (2003).

16.5 Development Constraints

The most serious competitor for geothermal space heating systems in Switzerland is natural gas. Besides strong marketing, there is also a financial advantage for gas-based systems: whereas geothermal solutions need two pipes (for delivery and return) gas only needs one pipe; the return pipe is the atmosphere.

The introduction of a CO_2 tax is still in parliamentary discussion.

16.6 Economics

Geothermal space heating and cooling, when based on geothermal heat pumps, can compete with conventional oil-fired systems, thanks to their lower running cost. A detailed comparison has been presented in the 2002 Country Report; the situation has not changed since then. Demand for energy contracting and subsidies by local utilities are increasing.

16.7 Research Activities

Whereas university research is rather stagnant, or even decreasing (a notable exception is the creation of the *Centre de recherche en géothermie* at the University of Neuchâtel), there is increasing activity in SM enterprises in this field. Applied research, funded by the Federal Government, is implemented more and more by specific teams. The Swiss Geothermal Association (SVG) is acting as a Competence Center for research funded by the Federal Office of Energy (BFE). Increasing commercial involvement, especially for the DHM project, must also be noted. Important research activities are embedded in international frameworks (see below).

The research projects supported by the BFE produce intermediate and final reports. These can be downloaded or ordered at:

http://www.energieforschung.ch/ENET/ENETHome.nsf/pgHomeEN?OpenPage

16.8 Geothermal Education

Significant efforts are undertaken for education and information dissemination. The SVG has a mandate from BFE for information and education. F.-D. Vuataz (CHYN Neuchâtel) is responsible for information. Various leaflets have been produced and several geothermal exhibitions have been organized in Switzerland in 2004. T. Kohl (GEOWATT AG, Zurich) is responsible for education. Besides regular university lectures, various special courses and workshops were organized for postgraduate training in 2004.

Education is also provided at the international level. L. Rybach presented, in September 2004, two lectures at the *International Geothermal Days POLAND 2004,* organized by the IGA International Summer School, in Zakopane:

- Geothermal legislation and regulatory aspects in selected European countries (Rybach, 2004a)
- Use and management of shallow geothermal resources in Switzerland (Rybach, 2004b).

Table 16.3 Worldwide geothermal heat pump statistics 2004 (compiled by L. Rybach from data in Lund *et al*, 2005, WGC 2005.)

Country	Installed MWt	Energy p.a. TJ/yr	Equivalent 12 kW units	Population 10^6 *)	Area 10^3 km^2	Capacity per area W/km^2	Rank	Capacity per capita W/capita	Rank	Energy per area GJ/yr per km^2	Rank	Energy per capita GJ/yr p.c.	Rank	Units** per km^2 area	Rank
Austria	300.0	1’450.0	25’000	8.05	84	3.6E-3	**5**	37.3		17.3	**4**	0.18		0.30	**5**
Canada	446.0	2’186.0	37’167	31.41	9’958	4.5E-5		14.2		0.22		0.07		0.004	
China	631.0	6’569.0	52’583	1’280	9’571	6.6E-5		0.49		0.67		0.005		0.005	
Czech Republic	200.0	1'130.0	16’667	10.21	79	2.5E-3		19.6		14.3		0.11		0.21	
Denmark	821.1	4’360	68’425	5.38	43	1.9E-2	**1**	152.6	**2**	101.4	**1**	0.81	**2**	1.59	**1**
Finland	260.0	1'950.0	21’667	5.20	338	7.7E-4		50.0	**5**	5.77		0.38	**5**	0.06	
Germany	400.0	2'200.0	33’333	82.48	357	1.1E-3		4.8		6.16		0.03		0.09	
Netherlands	253.5	685.0	21’125	16.15	42	6.0E-3	**4**	15.7		16.3	**5**	0.042		0.50	**4**
Norway	450.0	2'314.0	37’500	4.54	324	1.4E-3		99.1	**3**	7.14		0.51	**3**	0.12	
Sweden	3'840.0	36'000.0	320’000	8.93	450	8.5E-3	**3**	430.0	**1**	80.0	**2**	4.03	**1**	0.71	**3**
Switzerland	532.4	2'854.0	44’367	7.29	41	1.3E-2	**2**	73.0	**4**	69.6	**3**	0.39	**4**	1.08	**2**
USA	7'200.0	22'214.0	600’000	287.5	9’809	7.3E-4		25.0		2.26		0.08		0.06	

Table 16.4 Worldwide ranking results (in order) of geothermal heat pump utilization in 2004 (compiled and evaluated by L Rybach from data in Lund et al. (2005), WGC 2005)

Capacity installed (MWt)	Energy use (TJ/yr)	Capacity per area (Wt/km^2)	Capacity per capita (Wt/capita)	Energy per area (TJ/yr per km^2)	Energy per capita (GJ/yr per capita)	Units per area (12 kW equivalent units per km^2)
1. USA	1. Sweden	1. Denmark	1. Sweden	1. Denmark	1. Sweden	1. Denmark
2. Sweden	2. USA	2. Switzerland	2. Denmark	2. Sweden	2. Norway	2. Switzerland
3. Denmark	3. China	3. Sweden	3. Norway	3. Switzerland	3. Switzerland	3. Sweden
4. China	4. Denmark	4. Netherlands	4. Switzerland	4. Austria	4. Denmark	4. Netherlands
5. Switzerland	5. Switzerland	5. Austria	5. Finland	5. Netherlands	5. Netherlands	5. Austria

16.9 International Cooperative Activities

Switzerland participates in the IEA GIA, funded by the Swiss Federal Office of Energy. Here Annex III “Enhanced Geothermal Systems” must be especially mentioned (Subtask C leadership). In 2003 the experience of some of the major EGS research and development projects within the last 30 years worldwide was compiled into a first version of a Project Management Decision Assistant (PMDA). This handbook shall provide new project teams with the access to a synthesis of the available information to support a successful and frictionless project start. In principle, the EGS-PMDA indicates which items of data and information must be obtained during a project in progress ("Project Planning") and where to obtain those data and experiences already available ("Sources of Know-How"). Figure 16.6 gives an overview of the scope of this data-orientated management aid.

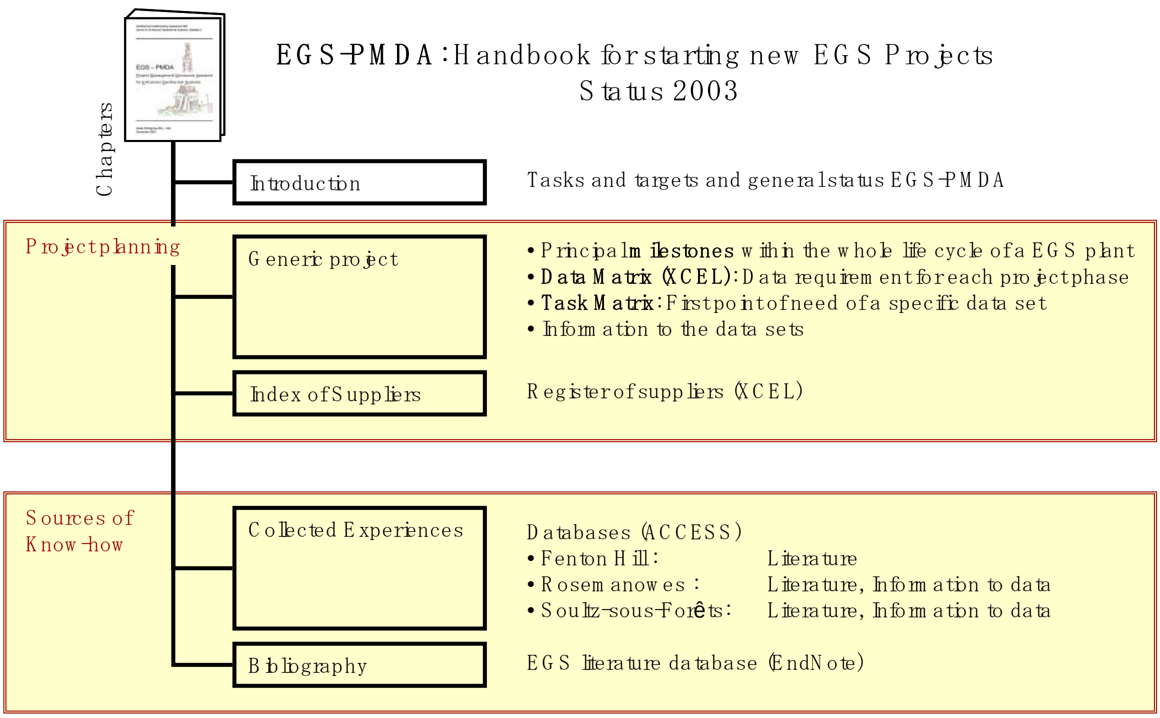

Figure 16.6 Overview to the content of the EGS-PMDA.

The first version of the EGS-PMDA contains more than 80 pages, divided into 5 main registers, and an attached CD-Rom with 6 data collections. In 2004 the first version of the EGS-PMDA classifier was disseminated to 8 participants of Annex III for a review. The EGS-PMDA has been presented at the Annex meetings during the 12th GIA ExCo Meeting in Pisa, Italy, in October 2004 and at the Annex III meeting at the AIST in Tsukuba, Japan, in November 2004.

There is also a strong interest for Switzerland to join the recently implemented Annex VIII-“Direct Use” of the IEA GIA.

The Swiss Federal Office of Education and Science and the Swiss Federal Office of Energy fund participation in the EU Project Soultz. The work of the Swiss EGS R&D Group involves the following tasks:

- Kinetic simulation of geochemical processes in the reservoir
- Integrated analysis of borehole logs, geologic, hydraulic and microseismic data to establish the mechanisms of permeability enhancement (stimulation)
- Analysis and simulation of hydro-mechanical processes in the borehole and the reservoir during a stimulation test

16.10 References

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16.11 Websites for Further Information

Further information can be found about:

The Swiss Geothermal Programme and Swiss Geothermal Association at: http://www.geothermal-energy.ch

The Deep Heat Mining project at: http://www.dhm.ch/dhm.html

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CHAPTER 17

United States of America

17.1 Introduction

By the early 1920s in the United States, the geothermal resource at The Geysers, in northern California, was being considered for electrical power generation. The first well was drilled in 1921 at a shallow depth and 'blew out like a volcano'. The second well, also called No. 1, was drilled in 1922. The first power plant was constructed at The Geysers in the early 1930s near Well No. 1. It was a 35 kilowatt power plant containing two reciprocating, steam-engine-driven turbine generators from General Electric. Ben McCabe of Magma Power drilled his first well, Magma No. 1, in 1955. In 1958, Pacific Gas and Electric Company (PG&E) signed a contract to purchase steam from the Magma-Thermal venture and built Unit 1 in 1960. By 1968, the capacity of the field had increased to 82 MW_e. By 1989, twenty-nine units had been constructed with an installed capacity of 2,098 MW. Today, Calpine Corporation and Northern California (9.1 percent of generation). Non-hydroelectric renewables account for 6.6 percent of projected additions to U.S. generating capacity from 2002 to 2025 and 6.8 percent of the projected increase in generation. Geothermal output is projected to increase from 13 billion kilowatt-hours in 2002 (0.3 percent of generation) to 47 billion in 2025 (0.8 percent).

The Annual Energy Outlook also includes a 'high renewables case' and a 'DOE goals case'. The AEO high renewables case assumes cost reductions of 10 percent on a site-specific basis. The DOE goals case assumes lower capital costs, higher capacity factors, and lower operating costs, based on the renewable energy goals of the U.S. Department of Energy. In the EIA 'high renewables case', additions of geothermal are substantially higher than projected in the reference case, with most of the incremental capacity added between 2010 and 2025. In the 'DOE goals' case, still more geothermal generating capacity is projected to be added. Geothermal electricity generation in 2025 is almost double the reference case projection, at 90 billion kilowatt-hours, or approximately 1.6 percent of total generation.

DOE has developed several scenarios for geothermal development, which could support rapid deployment of geothermal electricity generation after 2025 leading to as much as 98,000 MWe capacity by 2050.

17.3 Current Status of Geothermal Electricity Generation

17.3.1 Installed Capacity

Installed geothermal electric power capacity in the U.S. had grown from about 500 MWe in 1973 to almost 2300 MWe in 2004. Geothermal electric power plants are located in four States: California, Nevada, Hawaii, and Utah. A number of other western States, including Idaho, Wyoming, Oregon, Arizona, New Mexico, Colorado and Alaska, also have significant geothermal electric potential. At present, California has 44 plants with 1982 MWe on line, Hawaii has one plant with a capacity of 30 MWe, Nevada has 14 plants with a capacity of 244 MWe and Utah has 2a Power Agency (NCPA) operate the field with a gross capacity of 936 MW from 22 units. Recently, wastewater injection has brought back 77 MWe. An additional 100 MW_e increase is anticipated from the Santa Rosa project.

The total installed capacity in the U.S. is now about 2,400 MW_e (2,020 operating) generating about 16,000 GWh/yr at a capacity factor of 90%.('100 Years of Geothermal Power Production' by John W. Lund, Geo-Heat Center; GHC Bulletin, September 2004'). The United States geothermal industry experienced dramatic growth from 1981 to 1990. During this period, 1,786 MW_e of new geothermal generation came on-line, representing 70% of the current installed U.S. geothermal generation capacity. Several factors triggered the rapid development of the 1980s:

- The existence of known high and moderate temperature geothermal reservoirs, including The Geysers, the Salton Sea Geothermal Field, the Coso Geothermal Field, Steamboat Springs, Dixie Valley, Roosevelt Hot Springs and numerous small projects located primarily in Nevada.

- Passage of the Public Utility Regulatory Policy Act (PURPA) legislation in 1978, which required utilities to purchase power from independent power producers and certain renewable/cogeneration facilities at the utility's "avoided cost." Further, in 1977, Congress enacted the National Energy Act, which included tax credits for solar and wind development, and California enacted additional tax credits.

- In 1982, California regulators adopted key PURPA implementation policies and approved three standard contracts that Independent Power Producers could use to sell power at fixed and known prices for 20 to 30 year terms. Much of the new geothermal development came as the result of standard offer contracts developed in 1983, providing fixed payments for both energy and capacity over a period of time sufficient to allow the projects to obtain financing.

Since this decade of rapid growth, a number of States have enacted Renewable Portfolio Standards (RPS). Typically, RPS legislation requires local utilities to obtain a defined percentage of their electric supply portfolio from renewable sources. Some utilities in the western United States have issued Requests for Proposal from renewable generators for long-term power supply contracts from new projects. Often these stipulate that renewable energy cannot cost the utilities more than non-renewable energy. Additionally, utilities have been reluctant to finalize renewable energy contracts due to the higher cost of power contained in these bids when compared to more conventional power generation technology. Passage of the Federal Production Tax Credit (PTC) in October 2004 should help relieve some of this uncertainty for geothermal facilities already in the pipeline. Although geothermal exploration activities have been almost nonexistent for the last decade, approximately 2,500 MWe of additional capacity could be developed from known resources in the vicinity of producing fields at The Geysers, Imperial Valley, Coso, Steamboat Springs, Dixie Valley and numerous other locations. Identified new projects also exist at Glass Mountain and the Imperial Valley in California and in Idaho, Utah, New Mexico and Oregon. Development of this capacity would essentially double the amount of geothermal capacity currently on-line in the US (adapted from W.T. Box, Jr. and Charlene Wardlow; Power Engineering, June, 2004)

The Department of Energy's geothermal program traces its roots to 1971 with activities at the Atomic Energy Commission and the National Science Foundation. Geothermal research at the United States Geological Survey (USGS) goes back to 1945, but formal inception of the USGS Geothermal Research Program began in 1971. The 1978 USGS assessment of geothermal resources of the United States (USGS Circular 790) remains the definitive work in this area. The Geothermal Energy Research, Development and Demonstration Act was passed in 1974 and federal geothermal research activities have been the responsibility of the U.S. Department of Energy since its formation in 1976, and the Federal geothermal research and development program has worked closely with industry to make geothermal electricity a commercial success. Although the Federal program emphasizes electricity production, direct use geothermal systems have been installed throughout the United States. This report describes the status of geothermal energy development in 2004 in the United States.

17.1.1 Highlights for 2004

Events and activities selected for highlighting in this report are:

Production Tax Credit
The PTC was passed and signed by the President as part of the American Jobs Creation Act of 2004 in October 2004. The new law creates and extends a number of energy-related tax credits, including an expansion of the renewable energy production tax credit to geothermal electricity. The renewable tax credit indexed for inflation would be 1.8 cents/kilowatt hour and applies to facilities placed in service before the end of 2005.

Zinc Extraction Project
CalEnergy Operating Corporation, the largest geothermal energy company in the Imperial Valley scaled back its zinc extraction operation, a $400 million venture to produce zinc from the same geothermal liquid that produces energy. CalEnergy said the zinc operation never reached its commercial target of producing 70 metric tons per day. The goal of the zinc extraction operation was to find a new commercial use for the minerals in the geothermal liquid, the natural resource used to produce energy. CalEnergy is continuing the effort while trying to find a partner to make the zinc operation a commercial success.

17.2 National Policy

It is the national policy of the United States to improve energy security by fostering a diverse supply of reliable, affordable and environmentally sound energy. With regard to geothermal energy, this has four main thrusts:

- A Federal geothermal research and development (R&D) program
  The U. S. Department of Energy's Geothermal Technologies Program conducts research, development, and deployment activities in partnership with U.S. industry to establish geothermal energy as an economically competitive contributor to the U.S. energy supply.

- Energy leasing on Federal lands
  Renewable energy is a significant part of the National Energy Policy and the Administration has been working to improve the permitting process for geothermal projects. The Bureau of Land Management (BLM), pursuant to the Geothermal Steam Act of 1970, is responsible for leasing Federal lands for geothermal development and processing permit applications. This authority encompasses approximately 700 million acres of Federal minerals, including BLM lands, National Forest System lands, and other Federal lands, as well as private lands where the mineral rights have been retained by the Federal Government.
- Federal incentives such as the Production Tax Credit
  The PTC was passed and signed by President Bush in October 2004 as part of the "American Jobs Creation Act of 2004". This new law creates and extends a number of energy-related tax credits, including an expansion of the renewable energy production tax credit to geothermal electricity. The renewable tax credit indexed for inflation would be 1.8 cents/kWh and applies to facilities placed in service before the end of 2005.

- State initiatives to increase use of renewable energy
  Fifteen States have established requirements or goals to increase renewable energy use. They have enacted either (1) renewable portfolio standards that set increasing percentage shares of electricity generation or sales, (2) mandates that specify quantities of new generating capacity to be built, or (3) voluntary goals. Of the 15 States, 9 States have RPS, 4 States have mandates, and 4 States have voluntary programs. The type of program used most frequently by the States is an RPS requiring that some specified percentage of electricity supply be provided by qualifying renewable energy sources.

17.2.1 Strategy

The U.S. Department of Energy's Geothermal Technologies Program seeks to make geothermal energy the Nation's environmentally preferred base load energy alternative. The Program's mission is to work in partnership with U.S. industry to establish geothermal energy as an economically competitive contributor to the Nation's energy supply.

The Program has recently established three aggressive strategic goals that will drive its activities:

- Decrease the levelized cost of electricity from hydrothermal systems to less than 5 cents per kWh by 2010
- Increase the economically viable geothermal resource to 40,000 MWe (hydrothermal and EGS) by 2040
- Decrease the levelized cost of electricity from Enhanced Geothermal Systems to less than 5 cents per kWh by 2040

The strategies that the Program will use to achieve its goals include five categories of work: Enhanced Geothermal Systems, Exploration and Characterization, Drilling and Reservoir Management, Power Systems and Energy Conversion, and Institutional Barriers.

The Geothermal Technologies Program has placed top priority on technology development for Enhanced Geothermal Systems (EGS). EGS are geothermal reservoirs that have been engineered or enhanced to improve their productivity. EGS include the full spectrum of geothermal systems, from commercial hydrothermal reservoirs to non-hydrothermal hot rock systems. Fundamentally, an EGS is the circulation loop created by an injection-production well pair and the fractured rock connecting them. Over the next five years the program will demonstrate the viability of the technological tools needed to create an EGS. If successful, this work will create the potential for the entire nation to use geothermal power.

17.2.2 Progress Towards National Targets

The United States Department of Energy (DOE) has established strategic Program goals to guide its activities. Achieving these goals would provide the opportunity for geothermal electricity to be a contributor in the United States energy market. In order to achieve this, the cost of geothermal electricity has to decrease to competitive levels and the economic geothermal resource, both hydrothermal and EGS, has to increase significantly over current levels. Success will ultimately be measured by the amount of geothermal power on line.

The cost of geothermal power facilities has varied dramatically over time, but the trend has been toward reduced costs. Given available information, the estimated current cost of most commercial projects falls in the range of 4-6 cents per kWh, a substantial reduction from 10-12 cents per kWh in the 1980s. Pending a new national assessment, the total resource base in the identified hydrothermal systems in the United States is estimated to be on the order of 10,000 MWe.

In its Annual Energy Outlook (AEO2004) reference case, the United States Energy Information Administration (EIA) projected that grid-connected generators that use renewable fuels would increase from 343 billion kilowatt-hours of generation in 2002 (9.0 percent of total generation) to 525 billion kilowatt-hours in 2025 (9.1 percent of generation). Non-hydroelectric renewables account for 6.6 percent of projected additions to U.S. generating capacity from 2002 to 2025 and 6.8 percent of the projected increase in generation. Geothermal output is projected to increase from 13 billion kilowatt-hours in 2002 (0.3 percent of generation) to 47 billion in 2025 (0.8 percent).

The Annual Energy Outlook also includes a ‘high renewables case’ and a ‘DOE goals case’. The AEO high renewables case assumes cost reductions of 10 percent on a site-specific basis. The DOE goals case assumes lower capital costs, higher capacity factors, and lower operating costs, based on the renewable energy goals of the U.S. Department of Energy. In the EIA ‘high renewables case’, additions of geothermal are substantially higher than projected in the reference case, with most of the incremental capacity added between 2010 and 2025. In the ‘DOE goals’ case, still more geothermal generating capacity is projected to be added. Geothermal electricity generation in 2025 is almost double the reference case projection, at 90 billion kilowatt-hours, or approximately 1.6 percent of total generation.

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17.3.1.1 California

California has 25 known geothermal resource areas, 14 of which have temperatures of 300 degrees Fahrenheit or greater. The power plants have a dependable installed capacity of about 1,970 megawatts -- producing 5 percent of California's total electricity in 2003 (13,771 million kilowatt/hours). See Table 17.1.

Table 17.1 California power plant database.

CALIFORNIA POWER PLANT DATABASE				
PLANT NAME	**TECHNOLOGY**	**YR ONLINE**	**LOCATION**	**MWE ONLINE**
Salton Sea 1	Single Flash	1982	Imperial	10
CE Turbo LLC	Geothermal	2000	Imperial	11.5
Ormesa IE	Binary	1988	Imperial	14.4
Ormesa IH	Binary	1989	Imperial	14.4
GEM III	Double Flash	1989	Imperial	18.5
GEM II	Double Flash	1989	Imperial	18.5
Salton Sea 2	Single Flash	1990	Imperial	20
Ormesa Geothermal II	Binary Cycle	1987	Imperial	24
Ormes 1	Binary	1986	Imperial	31.2
JM Leathers	Double Flash	1989	Imperial	35.8
AW Hoch	Double Flash	1988	Imperial	35.8

CALIFORNIA POWER PLANT DATABASE (continued)				
PLANT NAME	**TECHNOLOGY**	**YR ONLINE**	**LOCATION**	**MWE ONLINE**
Vulcan	Double Flash	1985	Imperial	39.72
JJ Elmore	Double Flash	1990	Imperial	42
Second Imperial Geo.	Double Flash	1993	Imperial	48
Salton Sea 5	Geothermal	2000	Imperial	49.9
Salton Sea 4	Steam Turbine	1997	Imperial	51
Heber Geo. Co.	Double Flash	1985	Imperial	52
Salton Sea 3	Double Flash	1989	Imperial	53.97
Total - Imperial				**570.69**
Coso Unit 7-9	Double Flash	1989	Inyo	99.99
Coso Unit 4-6	Double Flash	1990	Inyo	99.99
Coso Unit 1-3	Double Flash	1987	Inyo	102.1
Total - Coso				**302.08**
Bear Canyon 2		1988	Lake	16.5
West Ford Flat 4		1988	Lake	27
Big Geyser 13		1980	Lake	27
Sonoma 3	Steam Turbine	1983	Lake	38
Quick Silver 16		1985	Lake	61
Calistoga 19	Steam Turbine	1984	Lake	65
Aidlin I	Steam Turbine	1989	Sonoma	15.5
Grant 20	Steam Turbine	1985	Sonoma	44
Cobb Creek 12	Steam Turbine	1979	Sonoma	50
Sulphur Springs	Steam Turbine	1980	Sonoma	56
Socrates 18	Steam Turbine	1983	Sonoma	57
Lakeview 17	Steam Turbine	1982	Sonoma	58
Eagle Rock 11	Steam Turbine	1975	Sonoma	60
Ridge Line 7&8	Steam Turbine	1972	Sonoma	63
McCabe 5& 6	Steam Turbine	1971	Sonoma	78
Geothermal 1		1983	Sonoma	110
Geothermal 2		1985	Sonoma	110
Coldwater Creek		1988	Sonoma	130
Total - Geysers				**1066**
Mammoth - Pacific 1	Binary	1984	Mono	10
PLES 1	Binary	1990	Mono	15
Mammoth – Pacific 2	Binary	1990	Mono	15
Total - Mono				**40**
Wineagle Developers 1	Binary	1985	Lassen	0.7
Amedee Geo. Venture 1	Binary	1988	Lassen	3
TOTAL				**1982.47**
Adapted from CEC Power Plant Database, July 1, 2004				

17.3.1.2 Nevada

Nevada has 244.3 megawatts of generating capacity from 14 geothermal power plants, at ten different physical locations. See Table 17.2.

Table 17.2 Nevada geothermal production in 2003.

NEVADA GEOTHERMAL PRODUCTION - 2003			
PLANT	**GROSS OUTPUT MWH**	**OUTPUT (SALES) MWH**	**NAMEPLATE RATING**
Beowawe	125,742	102,805	16.6
Brady	223,596	128,977	26.1
Dixie	493,532	441,767	62
Empire	26,717	17,190	4.8
Soda Lake			
Soda Lake 1	25,841	8,056	5.1
Soda Lake 2	79,771	65,382	21
Stillwater	96,267	59,717	21
Ormat			
SBI	45,391	29,570	8.4
SBIA	15,447	15,117	2.4
SBII	167,360	122,530	23.9
SBIII	162,753	120,454	23.9
Homestretch			
Unit I & II	9,195	5,850	2.2
Brady Power Partners Desert Peak	99,606	43,967	12.5
Yankee/Caithness	65,810	58,144	14.4
TOTALS	**1,637,028**	**1,219,526**	**244.3**
Source: State of Nevada			

17.3.1.3 Utah and Hawaii

The data for Utah and Hawaii are provided in Tables 17.3 and 17.4.

Note that power plant information is not consistent between States because the information is taken from different sources.

Table 17.3 Utah geothermal power plants.

UTAH GEOTHERMAL POWER PLANTS		
PLANT NAME	**OWNER/OPERATOR**	**CAPACITY (MWe)**
Blundell	PacifiCorp	26.1
Cove Fort	Utah Municipal Power Agency (UMPA)	13.2
Net Generation (2002): 214 GWh Source: State of Utah		

Table 17.4 Hawaii geothermal power plants.

HAWAII GEOTHERMAL POWER PLANTS			
PLANT NAME	**OWNER/OPERATOR**	**YR ON LINE**	**CAPACITY (MWE)**
PGV-1	Ormat Industries, Ltd	1993	30
Notes: Cycle: hybrid (single-flash, binary) 'Energy equivalent of 500,000 barrels of oil annually' Sources: press releases, HELCO			

17.3.2 Total Electricity Generated

In 2003, according to the EIA (AEO 2004), the United States generated 3,848 billion kilowatt-hours (kWh) of electricity, including 3,691 billion kWh from the electric power sector plus an additional 157 billion kWh coming from combined heat and power (CHP) facilities in the commercial and industrial sectors (Table 17.5). For the electric power sector, coal-fired plants accounted for 53% of generation, nuclear 21%, natural gas 15%, hydroelectricity 7%, oil 3%, geothermal and "other" 1%. Total geothermal generation in 2003 was 15.345 billion kWh.

Table 17.5 Total electricity generated in the USA.

GEOTHERMAL GENERATION 2003 BILLION KILOWATT-HOURS		
STATE	**MWe ON LINE**	**GENERATION**
California	1982.7	13.771
Nevada	244.3	1.22
Utah	39	0.214
Hawaii	30	0.14
Totals	**2296**	**15.345**
Notes: Geothermal generation as reported by the state for California, Nevada and Utah for 2003. Generation for Nevada based on 'sales'. Hawaii calculated based on 5 MWe to July 2004 and 27 MWe thereafter (HELCO) and assuming a capacity factor of 100%.		

17.3.3 Significant Developments in 2004

17.3.3.1 National

Production Tax Credit

The PTC was passed by the U.S. Congress and signed by the President, as part of the American Jobs Creation Act of 2004, in October 2004. The new law creates and extends a number of energy-related tax credits, including an expansion of the renewable energy production tax credit to geothermal electricity. The renewable tax credit indexed for inflation would be 1.8 cents/kilowatt hour and applies to facilities placed in service before the end of 2005, its current expiration date.

17.3.3.2 California

Zinc Extraction Project

CalEnergy Operating Corporation, the largest geothermal energy company in the Imperial Valley scaled back its zinc extraction operation, a $400 million venture to produce zinc from the same geothermal liquid that produces energy. CalEnergy said the zinc operation never reached its commercial target of producing 70 metric tons per day. The goal of the zinc extraction operation was to find a new commercial use for the minerals found within the geothermal liquid, the natural resource used to produce energy. The effort will continue and the company is talking with other companies that could form a partnership with CalEnergy to make the zinc operation a commercial success.

Salton Sea Power Agreement

IID Energy recently signed agreements to buy power from a proposed geothermal plant at the Salton Sea for as many as 30 years. The agreements extend IID's existing deals with CalEnergy. Under the deals, the utility, which serves about 120,000 customers in the Imperial and Coachella valleys, will buy up to 365 megawatts of power from the proposed geothermal plant by 2011. The new plant could be complete by 2007. CalEnergy already operates 10 geothermal plants around the southern end of the Salton Sea. The new plant is expected to be the largest of its kind in the nation and will contribute to IID's plan to derive 20 percent of its energy from renewable resources.

Fourmile Hill Geothermal Project

In March 2004, the Fourmile Hill geothermal project at Medicine Lake was given the go ahead by the United States District Court in Sacramento. The Calpine Corporation plans to build two 49 megawatt geothermal electrical generating plants near Medicine Lake. Medicine Lake is located 30 miles east of Mount Shasta and 10 miles south of Lava Beds National Monument. However, in May, Calpine announced it would cease major work at the Medicine Lake geothermal electrical generation facilities until 2005 in the face of continuing law suits.

Mammoth Pacific Award

In April 2004, Ormat Nevada announced that its Mammoth Pacific, LP geothermal facilities were selected to receive an award from the California Department of Conservation. This is the fourth consecutive year the facility has received this award for its outstanding record of environmental protection, resource management, and safety. Located in Mono County, California, Mammoth Pacific, LP generates up to 40 MWe of renewable, environmentally sound electricity sufficient for the needs of some 30 000 homes.

17.3.3.3 Idaho

Raft River Geothermal Project

U.S. Geothermal plans to build a binary-cycle power plant at Raft River, employing the same technology that was first demonstrated there by DOE over 20 years ago. The Raft River geothermal site is the former location of a DOE demonstration plant for binary-cycle power technology and includes four production wells that were drilled in the late 1970s. The company also leased a fifth production well on an adjacent property. Funded largely by DOE, flow tests to help determine the potential energy production from the geothermal wells were completed in October 2004. The company is negotiating a contract with Idaho Power Company to supply 10 megawatts of geothermal power for 20 years, and is working with the Bonneville Power Administration on the plant's connection to the power grid. Located in central Idaho about 16 kilometers north of the Utah border, the project could be the first commercial geothermal power plant in Idaho.

17.3.3.4 Nevada

New Ormat Geothermal Plant

A subsidiary of ORMAT Technologies, Inc. is planning to build a 20-megawatt geothermal power plant, the Galena Geothermal 1 plant, near Steamboat, Nevada, about 16 kilometers south of Reno. The Sierra Pacific Power Company announced in late June that it signed an agreement with ORNI 7 for 20 MW of geothermal power, starting in 2006. ORMAT Nevada has been busy in the state over the past year. ORMAT announced in July 2003 that it was acquiring the existing Steamboat Geothermal Complex, and announced in May that it was acquiring the sole remaining plant in the area, the Steamboat Yankee geothermal project.

Figure 17.1 Steamboat Yankee geothermal power plant, Nevada.

Blue Mountain Drilling

Nevada Geothermal Power Inc. (NGP) holds a 100% interest in 31 square-kilometers of geothermal leases just west of Winnemucca in north central Nevada. In 2002, a deep test well, 672 meters, confirmed the discovery of super-heated water that has the potential to develop an initial 30MWe electrical plant. The company has received grants from the U.S. Department of Energy for cost-share drilling. Recently NGP completed drilling a second deep well, Deep Blue No. 2, to delineate the resource and confirm the strength of the system. Drilled to a depth of 1,128 meters, the hole yielded a maximum temperature of 167°C at 585 meters confirming the presence of a high-temperature, shallow geothermal resource. Results from ongoing drilling combined with temperature gradient data and data from test wells Deep Blue No. 1 and 2 will be used to determine the optimum location for two production test wells. The company believes the site could eventually support 100 megawatts of geothermal power production

17.3.3.5 Alaska

Chena Hot Springs Resort

The Chena Hot Springs Resort plans to tap its geothermal resource for electric generation by the end of 2005, and will then evaluate whether the natural energy source can provide as much as 20 megawatts of electricity. Chena Hot Springs Resort is located about 97 kilometers northeast of Fairbanks and about 48 kilometers off of the local electric grid. The resort received approval for grant funding, announced in late August and early September, from both the Alaska Industrial Development and Export Authority and the DOE. The state grant will go toward the purchase and installation of a binary electric generation system that uses hot water at the resort to produce electricity. Estimated cost of that system, which will produce up to 400 kilowatts of electric power for the resort, is about $1.7 million. Currently the resort relies on diesel generators to produce 200 kilowatts . The second grant from the U.S. Department of Energy will allow further research of the area's geothermal potential and evaluate whether it can produce enough electricity to feed into the Fairbanks-area electric grid

17.3.4 Rates and Trends in Development

Growth in geothermal energy in the United States continues to be challenged by high capital costs, permitting delays, local opposition at some sites, and the limited number of undeveloped high quality sites. There has been consolidation in the industry with Calpine and CalEnergy emerging as the two largest producers. Recently, Ormat has been consolidating its position by purchasing a number of operating plants, including PGV-1 on Hawaii. Except for the Salton Sea area, development in California seems stalled out with local opposition at Medicine Lake threatening to halt planned development. No expansion is anticipated at The Geysers as the operators attempt to stave off further decline by injecting wastewater while trying to deal with increased seismicity in the area. (See section 1.6.3 for a discussion of seismic activity at The Geysers).

In Nevada, geothermal power producers enter into contracts with utility companies to sell electricity at a specific amount per kilowatt-hour. As in California, many of Nevada’s 14 operating geothermal power plants entered into multiple-year contracts that provided compensation on a per kilowatt-hour basis higher than avoided cost contracts. These contracts are expiring and plants are entering into avoided cost contracts at considerably lower rates. This market condition has held the expansion of Nevada’s geothermal industry flat. However, Nevada seems poised for major expansion with strong political support, an RPS driving procurement of renewable energy, a number of developable sites, and activities in the state by the Great Basin Center for Geothermal Research at the University of Nevada Reno.

17.3.5 Number of Wells Drilled

Determining accurately the number of geothermal wells drilled each year is difficult, because each state handles the issue differently and some not at all. Nevada provides information through its ‘Nevada Geothermal Update’ which can be accessed through the Internet.

17.3.5.1 Nevada

According to the ‘Nevada Geothermal Update’ of September 2004, there were two geothermal wells completed at existing geothermal power plants; a 1478 meters deep well at the Brady’s Power Plant and a 1675 meter well completed at the Desert Peak Power Plant. In addition, a set of eight geothermal gradient holes (each 150 meters deep) and a well (Deep Blue #2) at 1128 meters were completed in the Blue Mountain Geothermal Prospect Area.

17.3.5.2 California

The California Division of Oil, Gas and Geothermal Resources regulates all high-temperature geothermal wells on private and state lands. (The U.S. Bureau of Land Management regulates all high-temperature geothermal wells on Federal lands, except for wells on military bases, which are regulated by the Department of Defense.) The Division maintains a downloadable JAVA application, 'GeoSteam', on its website that allows to individual well records and technical data that geothermal companies have submitted to the Division since 1967. This is not a user-friendly site and does not provide summary information by year. There are about 470 producing steam wells and 230 high-temperature, hot-water wells in 10 high-temperature geothermal fields in California. In 2001, In addition, there were several hundred low-temperature geothermal wells in the state for which the Division has no records. There are also about 160 geothermal injection wells located in about a dozen geothermal fields in California.

(No information was found regarding geothermal well drilling in Utah, Idaho and Hawaii.)

17.3.6 Contribution to National Demand

In 2003, the United States generated 3,848 billion kilowatt-hours (kWh) of electricity, including 3,691 billion kWh from the electric power sector plus an additional 157 billion kWh coming from combined heat and power (CHP) facilities in the commercial and industrial sectors. For the electric power sector, coal-fired plants accounted for 53% of generation, nuclear 21%, natural gas 15%, hydroelectricity 7%, oil 3%, geothermal and "other" 1%. For 2004, electricity demand was expected to increase about 2% from 2003 levels (EIA 2004). Total geothermal generation in 2003 was 15.345 billion kilowatt-hours.

17.4 Current Status of Direct Use and Geothermal Heat Pumps

Logically, GHP are a subset of Direct Use geothermal; however, for the purposes of this report it is convenient to consider them separately. This is because there is more recent summary information on GHP as compared to Direct Use (excluding GHP). A summary paper on GHP was presented at the 2004 GRC Annual Meeting while the Direct Use statistics are primarily from a summary paper with data to 1999.

GHP Geothermal heat pumps are one of the fastest growing applications of renewable energy in the world. Most of this growth has occurred in the United States and Europe. In the USA, GHP accounted for 6,300 MWt, and the number installed is estimated at 600,000. In the United States, most units are sized for the peak cooling load and are oversized for heating, except in the northern states. Thus, they are estimated to average only 1,000 full-load heating hours per year. In the United States, GHP installations have steadily increased over the past 10 years with an annual growth rate of about 12%, mostly in the mid-western and eastern States from North Dakota to Florida. Today, approximately 80,000 units are installed annually, of which 46% are vertical closed loop systems, 38% horizontal closed loop systems, and 15% open loop systems. Over 600 schools have installed these units for heating and cooling, especially in Texas. One of the largest GHP installations in the United States is at the Galt House East Hotel in Louisville, Kentucky. Heat and air conditioning is provided by geothermal heat pumps for 600 hotel rooms, 100 apartments, and 89,000 square meters of office space for a total area of 161,650 square meters. A GHP was also installed on the Texas ranch of President Bush during the presidential election campaign of 2000. This vertical closed loop system cuts the heating and cooling cost by 40% ('Geothermal (Ground-Source) Heat Pumps: A World Overview' by J. Lund, B. Sanner, R. Curtis, and G. Hellstrom; GHC Bulletin, September 2004, condensed and paraphrased.)

Direct Use In 2000, Lund and Boyd estimated that geothermal energy supplied 20,478 TJ/yr of heat energy through direct heat applications in the United States. Of this, direct-use was 8,478 TJ/yr and geothermal heat pumps the remainder. Aquaculture had the largest annual energy growth rate of the direct-use categories, increasing in annual use by 16.9% compound per year over the past five years. From 1990 the growth rate for direct-use was 8.3% (Geothermal Direct-Use in the United States in 2000; Lund and Boyd, Geo-Heat Center). It was reported in November 2003 (EIA REA 2002) based on unpublished data from the Geo-Heat Center, that geothermal direct use was 9500 TJ in 2002. If the annual growth rate over the last two years has been 8% annually, then direct use geothermal (excluding geothermal heat pumps) will contribute about 11000 TJ in 2004.

17.4.1 Installed Thermal Power

In 2000, Lund and Boyd estimated that the installed capacity of heat applications in the United States was 5,373 MWt including geothermal heat pumps. The direct use portion was 573 MWt and geothermal heat pumps the remainder (4800 MWt). In 2004, Lund stated that 600,000 geothermal heat pumps were installed in the United States with an installed capacity of 6,300 MWt. (‘Geothermal (Ground-Source) Heat Pumps: A World Overview’ by J. Lund, B. Sanner, R. Curtis, and G. Hellstrom; GHC Bulletin, September 2004). No recent information is available on direct use capacity.

17.4.2 Thermal Energy Used

See Sections 17.4.1and 17.4.3.

17.4.3 Category Use

Apart from geothermal heat pumps, 35% of the annual energy use for direct-use is in the aquaculture industry, 28% is in bathing and swimming (resort and spa pool heating), 18% in space heating (including district heating), 14% in greenhouse heating, and 5% in industrial processing, including crop drying and snow melting (as of 1999). The EIA Survey of Geothermal Heat Pump Shipments showed that manufacturers shipped 36,439 geothermal heat pumps in 2003, which was a 2 percent decrease from 2002. Although GHP are being used in homes where the average application is probably less than 4 tons (50 MJ/hr); they are increasingly finding applications in Federal, State, and local government facilities (Utah State Prison, Alamagordo High School, Story County Administration Building, and the Oceana Naval Air Station) where long pay back times are acceptable and the energy savings are large.

17.4.4 New Developments During 2004

17.4.4.1 Utah State Prison

A geothermal resource at 85ºC is being used to supply heat and hot water to the Utah State Prison. When completed in 2005, geothermal water will heat four medium security buildings housing 576 inmates, a special service dorm, a furniture and sewing shop, and the Wasatch facility, which has 846 inmates.

Figure 17.2 Greenhouse in Boise, Idaho.

17.4.4.2 Frisco, Summit County

This project in Frisco, Colorado, is indicative of an increasing trend in the United States to consider direct use geothermal and geothermal heat pumps as approaches to dealing with high energy prices, particularly for new projects that can amortize the capital costs over a long period of time. In all, 56 holes, each 122 meters deep and approximately 15 cm in diameter will be drilled at the site. The system will heat or cool a fast food restaurant, convenience store and office space planned in the two-story, 835 square meter project. It will also cool the refrigeration systems, coolers and freezers, while heating water for the car wash and melting snow on the property.

17.4.4.3 Alamagordo High School

The Alamogordo, New Mexico project will provide a geothermal cooling and heating system to replace Alamogordo High School's existing HVAC, the main part of which was installed in 1969. The system uses water in a loop buried beneath the high school parking lot. The annual cost savings to the Alamogordo Public Schools will be almost $200,000 per year with a projected pay back of 10 years. The project has garnered a number of awards. The award from the Department of Energy recognizes Alamogordo Public Schools for participating in the GeoPowering the West program and for the schools' leadership.

17.4.4.4 Story County Administration Building

The county has previously installed GHP systems at the Human Service Center in Ames and at the Story County Justice Center in Nevada. At the county administration building, 110 wells, each being 75 meters in depth, were needed. Although the initial installation cost of a geothermal heating and cooling system is high, the 40 percent reduction in energy costs, the need for smaller buildings when no boiler or chiller room is needed and lower maintenance and insurance costs, make geothermal systems an exceptional investment with a payback time frame of around six years.

17.4.4.5 Northland College

The geothermal heating and cooling system at Northland College in Wisconsin began operation in summer 2004. The system decreases gas usage during the winter because it uses preheated air and decreases boiler usage, which will more than pay for the costs on the air conditioning side. The system has a well field of 60 wells, 84 meters deep, arranged 4.5 meters apart over three rows.

17.4.4.6 Oceana Naval Air Station

This Naval Air Station in Virginia is eliminating more than a dozen miles of steam pipes, which have been used to provide heat in buildings for four decades. (Oceana has 38 miles of steam pipes.) The $8.2 million project to install GHP on an individual building basis is expected to save the base $920,000 a year in maintenance and energy costs. The new approach, using geothermal heat pumps, will be more efficient as it is cheaper to have a small unit at each building than a single, large distribution system.

17.4.5 Rates and Trends in Development

For the period 1995-2000, Lund reported that most applications experienced some increase in use with agriculture having the largest annual energy growth rate, increasing by 16.9% compounded per year. Lund stated that the historical rates are expected to continue.

17.4.6 Number of Wells Drilled

Direct Use No summary statistics were found regarding wells drilled for direct use heat applications in 2004.

Geothermal Heat Pumps Geothermal heat pumps are ground-coupled, water-source heat pumps and use water-filled plastic pipe buried in the ground (vertical or horizontal). Since the objective in drilling is to install a specific length of heat exchanger, it is not necessarily important to reach a given depth at a particular site. Holes may be approximately 10-15 cm in diameter, 50-125 meters deep and drilled with air or bentonite mud. Horizontal spacing may be on the order of 4-6 meters. The wells are typically pressure grouted from the bottom with 20-25% bentonite. There are no accurate estimates of the number of such wells drilled each year in the United States, particularly since each site varies and larger sites may have hundred of wells. (Geyer, 2004).

17.4.7 Energy Savings

17.4.7.1 Direct Use (excluding GHP)

It was reported in November 2003 (EIA REA 2002), based on unpublished data from the Geo-Heat Center, that geothermal direct use was 9,500 TJ in 2002. If it is assumed that the annual growth rate over the last two years has been 8% annually, then direct use geothermal (excluding geothermal heat pumps) will contribute 11,000 TJ in 2004.

17.4.7.2 Heat Pumps

For 2003, Lund reported U.S. installed thermal capacity of geothermal heat pumps at 6300 MWt producing 6300 GWh/yr (assuming 1000 hours of operation per year in the heating mode). If the cooling mode is included (at same number of hours as heating) then GHP provided 12600 GWh/yr in 2003. [Lund et al., 2004].

17.5 Market Development and Stimulation

17.5.1 Support and Market Stimulation Initiatives

Most activity has been at the state level with significant market stimulation initiatives through RPS and power purchase agreements. In October 2004, a Federal Production Tax Credit was enacted which included geothermal energy. The DOE provides support to the geothermal industry through cost-shared exploration and to other stakeholders through GeoPowering the West, an education and outreach endeavor. Detailed information on Federal and State incentives for renewable energy is available on the Database of State Incentives for Renewable Energy (DSIRE) website.

17.5.1.1 Federal Incentives

Production Tax Credit

The American Jobs Creation Act of 2004 (HR. 4520) was enacted in October 2004. Within the act are a number of tax credits for renewable electric generation. The legislation shows a recognition by Congress of the importance of supporting the development of viable commercial renewable energy. The renewable tax credit for geothermal is 1.8 cents/kilowatt hour. However, the language of the bill will significantly limit the number of electric projects that will qualify by specifying only facilities that come on line between the enactment of the bill and January 1, 2006, can qualify for the 5-year tax credit term.

Modified Accelerated Cost Recovery System (MACRS)

Under the Modified Accelerated Cost Recovery System (MACRS), businesses can recover investments in solar, wind and geothermal property through depreciation deductions. The MACRS establishes a set of class lifetimes for various types of property, ranging from three to 50 years, over which the property may be depreciated. For solar, wind and geothermal property placed in service after 1986, the current MACRS property class is five years.

Solar and Geothermal Business Energy Tax Credit

The U.S. Federal government offers a 10% tax credit to businesses that invest in or purchase energy property in the United States. Energy property is defined as either solar or geothermal energy. Solar energy property includes equipment that uses solar energy to generate electricity, to heat or cool (or provide hot water for use in) a structure, or to provide solar process heat. Geothermal energy property includes equipment used to produce, distribute, or use energy derived from a geothermal deposit. For electricity produced by geothermal power, equipment qualifies only up to, but not including, electrical transmission.

Renewable Energy Systems and Energy Efficiency Improvements Program

The Renewable Energy Systems and Energy Efficiency Improvements Grant Program, a program of the USDA, has provided funding for Fiscal Years 2003 and 2004 for eligible agricultural producers and rural small businesses to purchase renewable energy systems and make energy improvements.

Green Power Purchasing Goal – Federal Government

Executive Order 13123, issued in 1999, requires Federal agencies to increase their use of renewable energy to a percentage determined by the Secretary of Energy. In 2000, Secretary of Energy Bill Richardson directed that Federal agencies obtain the equivalent of 2.5% of their electricity from renewable resources by 2005. Solar, wind, biomass and geothermal systems installed after 1990 qualify as renewable energy resources under this order.

Tribal Energy Grant Program

DOE's Office of Energy Efficiency and Renewable Energy's Tribal Energy Program provides financial and technical assistance to tribes for feasibility studies and shares the cost of implementing sustainable renewable energy installations on tribal lands. DOE released two solicitations in 2004 under this program. The first is 'Renewable Energy Development on Tribal Lands'. DOE is soliciting applications from Federally-recognized Tribes, Alaska Native villages and Alaskan Native Corporations to either conduct feasibility studies for the development of economically sustainable renewable energy installations; or for sustainable renewable energy development projects. The second solicitation is 'First Steps Toward Developing Renewable Energy and Energy Efficiency on Tribal Lands'. Under this announcement, DOE is soliciting applications for strategic planning, energy options analysis or resource planning, energy organization development, and human capacity building related to sustainable energy efficiency implementation or renewable energy development.

GeoPowering the West (GPW)

GPW is a DOE geothermal outreach program, which works with the U.S. industry, power companies, industrial and residential consumers, public interest groups, and Federal, state, and local officials to provide technical and institutional support and limited cost-shared funding for state-level activities. GPW provides information and assistance to States and local communities on how to explore and develop their own geothermal energy resources.

17.5.1.2 State Activities

Renewable Portfolio Standards

The approach used most frequently by the States is a Renewable Portfolio Standard (RPS) which typically requires that a specified percentage of electricity supply be provided by renewable energy sources. In most of the States with RPS programs, the years of required compliance begin after 2000, with New Mexico's 2006 initial compliance year being the latest. Because features of RPS programs and existing electricity supplies differ from State to State, the percentage of renewable energy specified in a given State's RPS does not necessarily reveal the actual amount of new renewable energy capacity required. Key differences among the States include definitions of qualifying renewables, alternatives to new renewable capacity, approaches to cost recovery, opt-out provisions, and enforcement mechanisms. To date, RPS requirements are being met for the most part by output from existing renewable capacity within States or from adjacent States. Some requirements are being met by purchasing credits or by expecting deficiencies to be made up in the future. (**'**State Renewable Energy Requirements and Goals: Status Through 2003'**;** Thomas Petersik, EIA)

California's renewables portfolio standard dates to 2002, when the Legislature and Governor Gray Davis required utilities and other retail sellers of electricity to use renewables to generate 20 percent of their load by 2017. Under that law, the only way for the sellers to meet those goals was to build plants or buy power that relied on renewable sources, including small hydroelectric, solar, wind, geothermal and biomass. Legislation enacting California's Renewable Portfolio Standard was signed on September 12, 2002. Under the RPS, vendors of electricity are required to increase their procurement of eligible renewable energy resources by at least 1 percent per year so that 20 percent of their retail sales are procured from eligible renewable energy resources by 2017.

Power companies in Nevada have until 2013 to provide 15 percent of their energy sales from renewable energy sources. The standard started at 5% new renewables in 2003, with 2% added every two years until it reaches 15%. The utilities estimate they will need 743 MWe in non-solar renewable generation and 155 MWe in solar by 2013 to comply with the law.

The Nevada PUC also took action in late April to encourage renewable energy development in the state by requiring the state's utilities to consider the economic impact and environmental benefits of renewable resources when preparing their long-term energy plans. The new regulations also allow the PUC to award financial incentives, such as enhanced financial returns, for some renewable energy projects.

New Mexico has approved a law requiring the state's major utilities (El Paso Electric, Xcel Energy, and the Public Service Company of New Mexico) to derive ten percent of the electricity they sell from renewable sources by 2011. The law reiterates a mandate passed down by the state's utility regulators in 2002 that requires utilities meet a five percent renewable power threshold by 2006.

Western Governors Initiative

A group of western governors agreed unanimously in June 2004 to explore opportunities to develop "a clean, secure and diversified energy system for the West and to capitalize on the region's immense energy resources. The energy resolution, adopted at the annual meeting of the Western Governors' Association (WGA), sets a preliminary goal of increasing the efficiency of energy use in the western United States by twenty percent by 2020, and also aims to develop 30,000 megawatts of clean energy by 2015. Clean energy includes renewable energy sources such as solar, wind, geothermal, and biomass energy, but also includes clean coal technologies and advanced natural gas technologies. The WGA will establish a Clean and Diversified Energy Working Group composed of regional stakeholders, with a steering committee comprised of representatives from governor's offices. The WGA represents the governors of 18 western States and American Samoa, Guam, and the Northern Mariana Islands

17.5.2 Development Cost Trends

The current cost of geothermal electricity in the United States probably falls in the range of 4-6 cents per kWh for the best hydrothermal resources. This is a substantial reduction from 10-12 cents per kWh in the 1980s. To sustain this trend in reduced costs and meet the DOE goals, additional geothermal resources of high quality will have to be found. Thus, in exploration technology development, the trend is toward using improved reconnaissance tools, which can be deployed quickly to characterize large geographical areas. Drilling costs will continue to decrease as a result of experience gained with improved technology. Cost-shared application and testing of EGS techniques at existing hydrothermal sites will continue.

17.6 Development Constraints

17.6.1 Cost and Price Constraints

The cost of producing electricity from geothermal resources compared to the cost of electricity from coal and natural gas is the primary constraint on geothermal development, at least in the near term. Geothermal costs have declined dramatically over the last two decades reaching parity with other energy sources at some hydrothermal locations. However, future cost reductions will become increasingly difficult as the industry develops lower quality resources. The DOE Geothermal Technologies Program has adopted a goal for 2010 that reduces the cost of geothermal electricity to competitive levels through improvements in technology and expansion of the geothermal resource base. The existence of a Production Tax Credit will also contribute to bringing additional geothermal resources on line.

17.6.2 Undiscovered Geothermal Resources

The most significant technical barrier to large scale development of geothermal energy is uncertainty regarding the size of the ultimately economical geothermal resource. This has two aspects, hydrothermal resources and EGS resources, even though in reality there is a gradation from hydrothermal to EGS.

17.6.2.1 Hydrothermal Resources

In 1978, the U.S. Geological Survey (USGS) estimated that already-identified geothermal systems hotter than 150 ºC had a potential generating capacity of about 23,000 megawatts electric (MWe) and could produce electricity for 30 years. Additionally, undiscovered geothermal systems were estimated at 72,000 – 127,000 MWe. Major resource areas that have been partially developed include the Basin and Range area of Nevada, Utah and parts of Idaho, Oregon and California; The Geysers in northern California; and the Imperial Valley area in southern California. However, based on exploration by the industry, some experts now believe that the amount of discovered hydrothermal geothermal resources in the United States is sufficient for an additional 2000-3000 MWe under current conditions.

GeothermEx, Inc. ('National Assessment of U.S. Geothermal Resources – A Perspective', Sanyal et al, GRC Transactions, Vol. 28, August 29-Sept. 1, 2004) has compared the results of assessment of resources in 37 geothermal fields with the resource base estimates for those same fields by the USGS in 1978. GeothermEx's re-assessment shows that the total resource base in these 37 fields is about 33% of the 1978 estimate. The 1978 assessment was found to be too optimistic primarily because of the use of too high a value for the heat recovery factor. GeothermEx also concludes, pending a new national assessment, that the total resource base in the identified hydrothermal systems in the United States is estimated to be on the order of 10,000 MWe.

17.6.2.2 EGS Resources

The American Association of Petroleum Geologist (AAPG) published the 2004 Geothermal Map of North America, which the Southern Methodist University Geothermal Lab produced over the last three years with numerous collaborators. The data used for production of the 2004 Geothermal Map of North America are important for geothermal resource evaluation and location and are particularly useful for EGS assessment. For example, temperatures at 4-6 km depth can be determined using surface temperatures, heat flow and the sediment thermal conductivity (Figure 17.3). ('The 2004 Geothermal Map of North America – Explanation of Resource and Applications', Blackwell and Richards; Southern Methodist University, GRC Transactions, Vol. 28, August 29-September 1, 2004).

GeothermEx stated that the resource base potentially available from EGS should be considered in any new assessment. ('National Assessment of U.S. Enhanced Geothermal Resources Base – A Perspective' by Sanyal and Butler, GeothermEx, Inc.; GRC Transactions, Vol. 28, August 29 – September 1, 2004). Such consideration is necessary, because, in the view of the authors, a new geothermal resource assessment effort is likely to reduce the previous USGS estimation of the nationwide resource base from identified hydrothermal systems by about two-thirds, reducing the total to about 10,000 MWe, while the resource base from EGS could potentially offer an order of magnitude higher level of strategic energy resource base not considered in Circular 790.

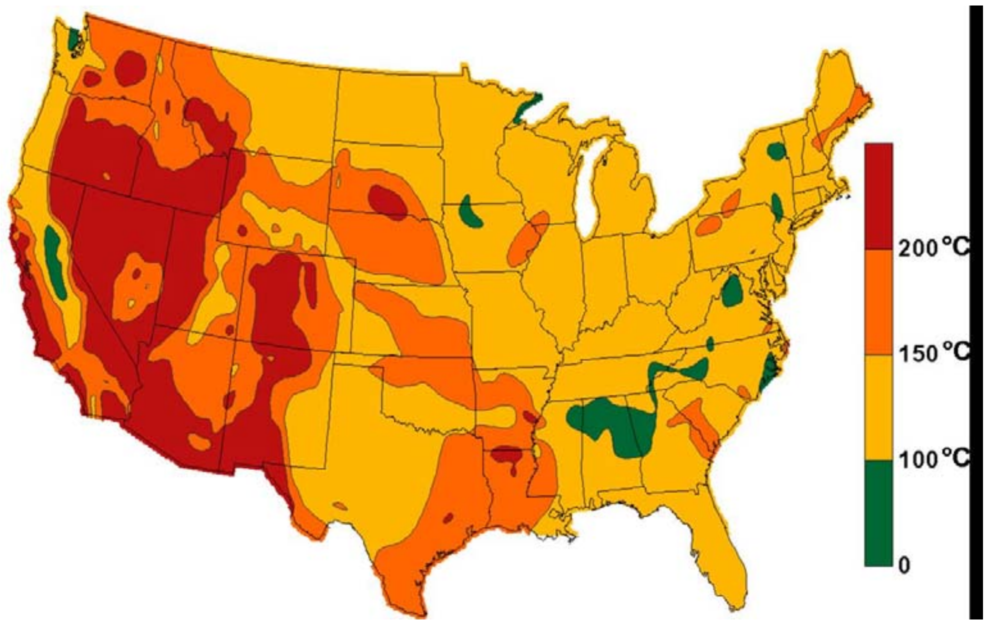

Figure 17.3 Geothermal resource at 6 km depth (Source: D. Blackwell, Southern Methodist University, 2004).

17.6.3 Environmental Concerns

In 2003, total energy consumption in the United States was 103.5E6 TJ.. This was 25% of world total energy consumption. Energy-related CO_2 emissions (2002) were 5,796 million metric tons of carbon (about 24% of world total carbon emissions. Fuel Share of Energy Consumption (2003E) was; oil (40%), coal (23%), natural gas (23%), nuclear (8%), hydroelectricity (3%), and other ("renewables" including geothermal) (3%). Renewable energy consumption in 2003 was 6.5E6 TJ (about 45% of which was conventional hydroelectric power). (EIA, April 2004))

Major environmental issues according to the EIA are:

- Air pollution resulting in acid rain in both the US and Canada;
- The US is the largest single emitter of carbon dioxide from the burning of fossil fuels;
- Water pollution from runoff of pesticides and fertilizers;
- Very limited natural fresh water resources in much of the western part of the country

Geothermal energy has the potential for addressing the first two; while the fourth could potentially be a limiting factor in geothermal development.

Environmental considerations are often cited as a rationale for the development of geothermal resources, because hydrothermal geothermal technology is relatively "clean," with minimal adverse impact on the environment when compared to combustion technologies. Atmospheric emissions are limited to the dissolved gases that are released during depressurization of the working fluid in open-cycle systems. Moreover, some recent plants, particularly those at Coso Hot Springs, California, reinject non-condensable gases into the reservoir, limiting emissions of greenhouse gases to well testing and unplanned outages. For projects that use lower temperature, binary-cycle technology, emissions from the closed cycle systems are negligible. Since it is likely that EGS will use the binary cycle, atmospheric emissions will not be a factor in development.

Environmental issues that could adversely affect the future development of geothermal resources include water requirements, air quality, waste disposal, subsidence, noise pollution, location and siting issues and, possibly, seismicity from production and injection.

Environmental considerations, specifically as they apply to the situation in the United States are discussed below. (Adapted from Lund, EIA and other sources).

17.6.3.1 Carbon Dioxide

The United States, with the world's largest economy, is also the world's largest single source of anthropogenic (human-caused) greenhouse gas emissions. Quantitatively, the most important anthropogenic greenhouse gas emission is carbon dioxide (CO_2), which is released into the atmosphere when fossil fuels (i.e., oil, coal, natural gas) are burned. Current projections indicate that US emissions of carbon dioxide will reach 5,985 million metric tons in 2005, an increase of 1,083 million metric tons from the 4,902 million metric tons emitted in 1990, and around one-fourth of total world energy-related carbon emissions.

Power Plants

Today's hydrothermal power plants with modern emissions controls have minimal impact on the environment and release little or no CO_2. On average, CO_2 is released in direct steam and flash systems at a typical rate of 55.5 metric tons per gigawatt hour, or at approximately 11 percent of the rate for gas-fired steam electric plants (EIA). (This is ignored in the calculation below). Total generation is estimated at 15.345 billion kilowatt hours in 2003. [Section 17.3.2]. Coal fired plants release approximately 1 metric ton of CO_2 per MWh for coal fired plants and .759 tonnes per MWhr for oil-fired plants. On this basis, geothermal power plants displace 15.3 million tonnes of CO_2 (coal plants) and 11.65 million tonnes (oil plants), respectively.

(To obtain an estimate of the million tonnes of oil equivalent (Mtoe) displaced by 15,345 billion kilowatt hours of annual geothermal electricity generation; assume a heat rate for oil of 10,000 Btu/kWhr and an energy content of 43 million Btu per tonne of oil. Then, heat rate times geothermal generation divided by energy content of oil per barrel yields 35.7 million tonnes of oil (MTOE).)

Direct Use

It was reported in November 2003 (EIA REA 2002), based on unpublished data from the Geo-Heat Center, that geothermal direct use was 9500 TJ in 2002. If it is assumed that the annual growth rate over the last two years has been 8% annually then direct use geothermal (excluding geothermal heat pumps) will contribute 11000 TJ in 2004. Based on the assumptions used by Lund (Geothermal Direct-Use in the United States in 2000**,** Lund and Boyd, GeoHeat Center); direct use of geothermal energy in 2004 is equivalent to saving 0.65 million tonnes of fuel oil per year. This produces a savings of 255,000 tonnes (natural gas) and 1,274,000 tonnes (coal) of carbon pollution. This assumes the replacement energy would have been provided by electricity.

GHP

Lund shows US installed thermal capacity of geothermal heat pumps at 6300 MWt producing 6300 GWh/yr (assumes 1000 hours of operation in the heating mode) in 2003. Lund also says the world total of 18,000 GWh saves 5.4 million TOE, which is a savings of about 16 million tonnes of CO2. Thus the respective numbers for the United States are 6300 GWh/18,000 GWh x 5.4 million tonnes of oil = 1.89 tonnes of oil and 5.6 million tonnes of CO_2. If cooling mode is included (at same number of hours as heating) then the numbers double to 3.78 million tonnes of oil and 11.2 million tonnes of CO_2. (Lund et al, GHC Bulletin, September 2004).

17.6.3.2 Potential Displacement of Oil

See preceding discussion in section 17.6.3.1 above. Only 5 percent of United States electricity generation is from oil. A better comparison is to coal-fired generation, which has been done for CO2 displacement. However, the GIA request for the annual report is to also report tones of oil displaced (Figure 17.6).

Table 17.6 Savings of oil and CO2 for geothermal replacement of oil.

Geothermal Category	Million Tonnes CO2	Million TOE
Power Plants[1]	15.3/11.65	35.7
Direct Use[2]	1.27	0.65
GHP[2]	11.2	3.78
TOTALS	27.77	40.13

Superscript notes:
1 CO2 displacement compared to coal-fired/oil fired
2 Lund, CO2 displacement compared to coal

17.6.3.3 Water Requirements

Geothermal power plants use large quantities of cooling water. For example, a 50-megawatt water-cooled binary- cycle plant requires more than 23 million liters of cooling water per day (455000 liters per megawatt per day). Since many geothermal resources are located in arid regions where water is a scarce and regulated commodity, long-term access to water could be an important constraint on their development. (Conversion systems for EGS will probably use air-cooled condensing in order to minimize water losses from the subsurface heat exchange loop.)

17.6.3.4 Air Quality

There are no air emissions where closed-loop binary technology is used. However, naturally occurring chemical compounds may be released into the atmosphere as a byproduct of the extraction of geothermal energy at sites using flash steam technology for energy conversion, including varying concentrations of hydrogen sulfide, hydrogen chloride, carbon dioxide, methane, ammonia, arsenic, boron, mercury, and radon. At The Geysers power plants in northern California, the geothermal fluid contains hydrogen sulfide. The sulfur (an average of 1.5 kg per MWh) is separated, dewatered, and recycled as feedstock for sulfuric acid production. Future technology will use microbial processes to extract metals contained in the sulfur, allowing further reuse. However, at most geothermal hot-water power plants, hydrogen sulfide is present in such low concentrations that it requires no special controls to comply with environmental regulations.

17.6.3.5 Solid Waste Disposal

To date, all waste streams from geothermal facilities in California have satisfied state standards through either treatment or emission control. At some sites, such as the Salton Sea field in California, geothermal fluids can contain large quantities of dissolved solids. The energy extraction process produces a low temperature liquid stream that must be disposed of in accordance with the appropriate regulations. Most often, the liquid is reinjected as part of the total reservoir management strategy. In the Imperial Valley, California, high-salinity brines are processed by flash crystallizers, which produce sludge containing potentially toxic heavy metals such as arsenic, boron, lead, mercury, and vanadium. For example, a 34-megawatt double-flash geothermal power plant tapping the high-temperature resource in the Imperial Valley could produce up to 50 tonnes of sludge every 24 hours. Valuable metals might be extracted from such sludge before its disposal, and this option has been explored at some Imperial Valley projects, but is not currently economically viable. Some hydrogen sulfide abatement systems produce elemental sulfur that is sold or hauled away by sulfur producers

17.6.3.6 Subsidence

Subsidence has not been a major issue at existing U.S. geothermal energy facilities. Most geothermal sites in the United States are not in areas that are prone to or affected by local subsidence. Subsidence in the Imperial Valley of California is dealt with as a part of the annual laser-leveling of the irrigated agricultural areas in the valley.

17.6.3.7 Site Related Issues

Many of the most promising geothermal resources are located in or near protected areas such as national parks, national monuments, and wilderness, recreation, and scenic areas. Although the average amount of surface area disturbed for the development of geothermal resources is slight in comparison with other forms of energy extraction, location in scenic areas and areas sacred to American Indians are sensitive issues. Noise is a siting issue. Noise from power generation equipment is routinely reduced by blanketing and insulating. Conflicts in multi-use areas with the sacred areas of Native Americans are also another area of concern.

17.6.3.8 Seismicity

In the 50-square-mile Geysers region about 90 miles north of San Francisco, there were 3,000 micro earthquakes in 2002, making it one of the most seismically active regions in the United States. Seismic activity increased when the plants began operating, but the number of small earthquakes has increased further, since Calpine began injecting millions of liters of wastewater. The vast majority of the quakes are small, usually magnitude 0 to 2, which can barely be felt. There have been nine earthquakes greater than magnitude 4.0 in the area over the last two decades, the largest being a 4.6. The injections of operating fluid and wastewater at The Geysers are necessary to maintain the production of steam. Small quakes related to injection have been recorded at the Coso field near Little Lake on the eastern side of the Sierra Nevada, and at the south end of the Salton Sea in the Imperial Valley of California. Studies have been initiated to evaluate this phenomenon, but it is too early to say whether this will be a significant factor in future geothermal development

17.7 Economics

17.7.1 Trends in Geothermal Investment

Because of the site-specific nature of geothermal resources, investment decisions are typically made on a project-by-project basis. The controlling factor is the projected economics of the project. The combination of a Production Tax Credit at the Federal level, if extended, and Renewable Portfolio Standards at the state level should be powerful incentives for the development of geothermal power by improving the economics and providing long-term market stability. Geothermal projects are capital-intensive in an area where investors prefer the lower capital costs and technical risks of natural gas power plants and coal-fired generation. Siting a geothermal facility is also expensive—requiring millions of dollars in up-front expenses for the plant and for permits and processes required for leasing, rights of way, etc. Geothermal developers have approached this most recently by developing previously discovered, but largely undeveloped fields. This also minimizes exploration risk and avoids the risks associated with drilling in unexplored areas.

Part of the dearth of new geothermal plants over the last decade was due, at least in part, to long delays in the leasing of Federal Land. A report released last year by the Departments of Energy and the Interior identified 35 top sites for near term development in six western States: California, New Mexico, Nevada, Oregon, Utah and Washington. By focusing on specific areas in each state, the Bureau of Land Management can prioritize funding toward the local leasing offices where geothermal power resources are high.

Renewable energy credits (REC) are being purchased to meet the renewable energy goals of government and multilateral agencies. Recent solicitations have been issued by the US Environmental Protection Agency, the US General Services Administration, and the World Bank Group. REC, also known as green certificates, green tags, or tradable renewable certificates, represent the environmental attributes of the power produced from renewable energy projects and are sold separately from commodity electricity.

17.7.2 Trends in the Cost of Energy

See sections 17.2.2, 17.5.2 and 17.6.1 for discussions of cost trends for geothermal direct use and electricity in the United States.

17.8 Research Activities

The U S Department of Energy's Office of Geothermal Technologies Program conducts research, development, and deployment activities in partnership with US industry to establish geothermal energy as an economically competitive contributor to the US energy supply. The strategies that the DOE geothermal program will use to achieve its goals include five focus areas: Enhanced Geothermal Systems; Exploration; Well Field Construction; Power Systems and Energy Conversion; and Institutional Barriers.

17.8.1 Enhanced Geothermal Systems

EGS technology is a top priority for the Program. EGS are geothermal reservoirs that have been engineered or enhanced to improve their productivity. EGS cover a spectrum of geothermal systems from modified hydrothermal reservoirs to non-hydrothermal hot rock systems. An EGS is the circulation loop created by an injection-production well pair and the fractured rock connecting them. Over the next five years the Program will demonstrate the technical feasibility of creating EGS. If successful, this work will create the potential for the entire nation to use geothermal power. High temperatures are available beneath the entire United States, if wells are drilled deep enough. The critical factors in demonstrating feasibility of producing power from this extensive resource are: exploration and assessment of the resource, creating the enhanced reservoir and managing the reservoir over the project lifetime.

The long-term goal of the Geothermal Technologies Program is to:

- ***Decrease the levelized cost of electricity from Enhanced Geothermal Systems to less than 5 cents per kWh by the year 2040.***

This target has been selected because 5 cents/kWh (in 2004 dollars) is projected to allow geothermal power to be competitive, and the target appears to be achievable within current R&D budgets.

Achievement of this goal is essential to attaining the Program's other long-term goal.

- ***Increase the economically viable geothermal resource to 40,000 megawatts by the year 2040.***

Modelling indicates that achieving economic viability of 40,000 MWe by 2040 is achievable with the current Program budget. However, because few new plants are currently being developed, and because industry does not currently have the ability to install new capacity rapidly, installed capacity is likely to lag the economically viable resource until after 2040. Because current industry analyses suggest that only about 10,000 MWe of economically viable unmodified hydrothermal resources exist, the remaining 30,000 MWe must come from EGS. A staged approach is required to first demonstrate the feasibility of developing EGS reservoirs, and then extend the program to reduce development costs. Therefore, the Program has adopted an interim goal for EGS:

- ***Prove the technical feasibility of EGS at multiple geothermal sites by 2010.***

The Program will perform R&D through both laboratory work and field projects. Systems analysis and technology assessment will identify the technology improvement possibilities with the greatest potential for improvement per dollar spent. Field projects will permit feasibility testing of R&D results, and field results will be integrated into R&D. Iterative feasibility testing will allow evaluation of technology improvements and measurement of progress toward meeting program objectives through 2010. A proof of concept field experiment, using either existing sites or a new EGS site, will be required to demonstrate that technical feasibility; i.e., achieving target performance values, has been achieved.

R&D will include analysis of previous geothermal studies that extend back to work on hot dry rock technology performed by Los Alamos National Laboratory from 1970 to 1995. Previous work also includes geothermal system enhancement projects in other countries (e.g. England, Japan, Switzerland, and France/Germany). EGS-related work in other fields, such as reservoir stimulation and improved oil recovery technologies in the petroleum industry, is also an important source of information that will allow the program to leverage its funding. R&D relies on technology improvements at universities and national laboratories supported by the program. Other R&D with potential application to EGS, such as that performed by the mining industry and the geoscience programs of DOE's Office of Basic Energy Sciences and the National Science Foundation, will be monitored, assessed, and adopted as appropriate. The Program will characterize the national EGS resource using data such as rock properties, depth to bedrock, thermal gradient, distance to load centers, and regional stress. That information will form the basis for supply curves and identify the best prospects for early EGS development.

Field projects provide a platform for testing and evaluating new technology, and serve as sites to create and test EGS reservoirs. Options for field projects include (1) EGS-related operations at active hydrothermal fields (e.g., Coso, Geysers, Dixie Valley), (2) cost-shared collaborative projects with industry, (3) currently active projects in other countries (e.g., Soultz-sous-Forets, France), and (4) a dedicated DOE-operated field site. The first three options allow the program to gather information in a variety of geothermal environments and leverage its investment. The last option offers the opportunity to test and analyze new technologies in a controlled field environment.

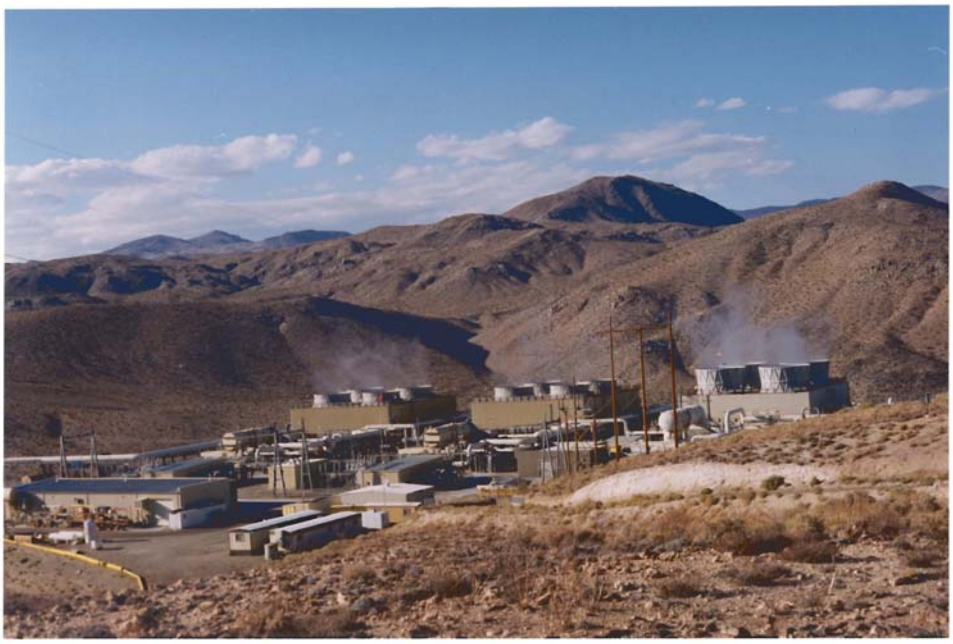

Figure 17.4 Coso geothermal power plant, California.

17.8.2 Exploration

As Dan Schochet, vice president of ORMAT International, has said: "the low-hanging fruit has already been picked, and the U.S. should get serious about researching the vast resources that are undoubtedly waiting to be found. More funding is needed to do research with exploring for geothermal activity using surface technology, not drills."

In response to this imperative, the exploration technologies portion of the GTP focuses on the evaluation and development of advanced methods to identify potential resource targets and remotely detect active permeable fracture systems that define a hydrothermal reservoir. Finding resources where there is little or no surface evidence of a geothermal system is an inherently difficult activity. Because the sensitivity and resolution of known geophysical techniques are not adequate for consistent identification of high quality resources, techniques with higher resolution are required. Currently, about one exploratory well in five discovers a viable geothermal resource. Investors are reluctant to assume such a high level of risk because costs generally exceed $1 million per well. In addition, the cost of exploration varies widely from one location to another.

Integrated field studies will test and apply various exploration technologies at two types of field sites. One field site will be associated with a known, but relatively undeveloped, geothermal resource, specifically selected to give the technologies a reasonable chance of success. The field study will develop a conceptual resource model of the site and propose well locations for confirmation. The second proposed field test will be directed at exploring for a "hidden" geothermal resource; that is, a resource with no apparent surface manifestation.

The Federal geothermal program also participates in a cooperative DOE/industry effort to find and evaluate additional geothermal resources throughout the western United States. The objective is to locate new geothermal resources and thereby increase the amount of proven geothermal resources that can be used for power generation in the United States. The technical challenge is to find and verify geothermal resources in previously unexplored areas. This is accomplished through cost-shared activities wherein industry has the responsibility to develop plans for exploration, drilling, and flow testing. The primary approach is through the

Geothermal Resource Exploration and Definition Program (GRED). GRED is a DOE/industry cost-shared effort to find, evaluate, and define additional geothermal resources throughout the western United States. A typical project might consist of surface exploration to discover probable geothermal resources and select a site for drilling an exploration slim hole; drilling a slim hole (15 cm or less in diameter); and flow testing to confirm the resource. GRED also serves as a field-testing laboratory for new exploration technology produced by the DOE research program.

Figure 17.5 Desert Peak well logging, Nevada.

17.8.3 Well Field Construction

Well field construction supports the DOE Geothermal Technologies Program (GTP) through development activities aimed at making geothermal drilling and related well field construction activities cheaper and more reliable. Drilling is involved in almost all aspects of a geothermal development cycle – exploration, production and injection, and well maintenance. The technical approach to planning for well field construction is to aggressively address needs across the full spectrum of activities associated with creating the well field. Opportunities for significant cost reduction exist across the range of activities that, taken as a whole, will be needed to achieve the cost goals.

Although much of the equipment for geothermal drilling comes from the oil and gas industry, the drilling itself is qualitatively different. Rocks are hard, abrasive, fractured, and, by definition, hot. Formation fluids are often highly corrosive and underpressured. These harsh conditions mean that many of the tools used in oil and gas drilling cannot be used in geothermal reservoirs. The requirement for geothermal wells to produce large volumes of fluid also means that they are larger in diameter than equivalent oil and gas wells of the same depth. All of these factors can drive the cost of typical geothermal wells much higher than oil and gas wells of comparable depth.

17.8.4 Power Systems and Energy Conversion

Energy conversion represents those technologies used to convert the thermal energy in geothermal fluids into electrical power. Geothermal conversion technology is viable today, but offers significant opportunities for improvement. The surface plant represents a substantial portion of the total investment in a hydrothermal geothermal energy system; and any improvement in conversion efficiency, reduction in initial investment, or decrease in operating and maintenance costs can significantly enhance the competitiveness of geothermal energy relative to fossil energy. Geothermal energy conversion efficiency cascades into other parts of the investment, including drilling. Higher conversion efficiencies mean fewer wells have to be drilled, reducing investment. Improved efficiencies also mean that a given geothermal resource will have a longer useful life or, for a given lifespan, will produce a greater amount of energy.

The goal of power systems and energy conversion research is to develop technologies that lower the cost of generating electricity from geothermal energy through increases in conversion efficiencies, reductions in initial power plant investments and the lowering of operating and maintenance costs. The program prioritizes technology development by targeting specific resource temperature ranges. The range of resource temperatures currently receiving the highest priority is between 130ºC and 175ºC. These resources are currently on the margin of what is economically feasible. As technology is developed that lowers the power plant costs, it will be possible to increase the viability of resources in this temperature range. This range also represents the lower temperatures that might be produced from EGS resources.

Technology development will focus on the use of sensible heat rejection with the binary cycles (air-cooled condensers). Emphasis is being placed on the use of this type of heat rejection because:

- Hydrothermal resources are typically found in the western U.S. where water may not available for make-up to evaporative heat rejection systems, and

- Conversion systems for EGS will likely use air-cooled condensing in order to minimize water losses from the subsurface heat exchange loop.

17.8.5 Institutional Barriers

DOE's GeoPowering the West program works with the U.S. geothermal industry, power companies, industrial and residential consumers, and Federal, state, and local officials to provide technical and institutional support and limited, cost-shared funding to state-level activities. By demonstrating the benefits of geothermal energy, GPW increases state and regional awareness of opportunities to enhance local economies and strengthen our nation's energy security while minimizing environmental impact. By identifying barriers to development and working with others to eliminate them, GPW helps a state or region create a regulatory and economic environment that is more favorable for geothermal and other renewable energy development.

Geothermal energy represents a major economic opportunity for the western United States, an area characterized by a steadily increasing population that requires reliable sources of heat and power. GPW is pursuing this opportunity by:

- Bringing together national, state and local stakeholders for state-sponsored geothermal development workshops;
- Working with public power companies and rural electric cooperatives to promote use of geothermal power;
- Promoting increased Federal use of geothermal energy;
- Helping American Indians identify and develop geothermal resources on tribal lands; and
- Sponsoring non-technical educational workshops.

17.8.6 Focus Areas

17.8.6.1 Technical Assessment

DOE has implemented the Program Assessment Rating Tool (PART) to evaluate selected programs. PART was developed by the Office of Management and Budget (OMB) to provide a standardized way to assess the effectiveness of the Federal Government's portfolio of programs.

To validate and verify program performance, the Geothermal Technologies Program conducts internal and external reviews and audits with the assistance of experts from a variety of stakeholder organizations. Research is coordinated closely with the geothermal community to ensure that the program's research directions and priorities address the needs of power producers, consumers, and other interested parties and to ensure that these activities are within the realm of technical feasibility and properly aligned with market forces. Peer reviews are performed using expert independent reviewers from geothermal and related fields.

17.8.6.2 Program Documents/Planning

The Program's activities are documented in a Strategic Plan, which describes the program's goals, objectives, and priorities. A Multi-Year Program Plan, which will provide a description of program activities and schedules, milestones, and performance metrics is under development.

17.8.7.3 Program Management

The Manager of the Geothermal Technologies Program provides overall program direction and guidance. DOE staff within the Program direct national laboratories in carrying out planned research. There are three national laboratories leading the efforts. The Idaho National Laboratory conducts projects in geoscience and energy conversion; the Sandia National Laboratories work at reducing exploration and drilling costs; and the National Renewable Energy Laboratory develops ways to enhance power plant efficiency and reduce operating costs. Research also is performed through competitive solicitations by universities and industry and through cost-shared public-private partnerships.

17.8.7 Government Funded Research

The Federal Government has been supporting geothermal energy development since the 1970s. The DOE Geothermal Technologies Program funding by fiscal year since 2000 is presented in the following table:

Table 17.6 DOE Geothermal Technology Program funding.

US DOE Geothermal Technologies Program (US$ M)	
Year	**Funding**
2000	23.6
2001	26.6
2002	27.3
2003	28.4
2004	25.5

17.8.9 Industry Funded Research

The United States geothermal industry consists primarily of independent power generation companies, developers, service companies, and equipment manufacturers. These firms typically do not have research departments to develop the technologies they need to develop geothermal resources. However, there continues to be a high degree of interest in applying the results of DOE geothermal research in the exploration and development of geothermal resources. This has led to a number of DOE/industry cost-shared field projects particularly in exploration and resource definition, drilling, energy conversion, Enhanced Geothermal Systems, and operating and maintenance improvements.

17.9 Geothermal Education

There are a large variety of geothermal education activities in the United States supported and/or conducted by a large variety of organizations. Some of these are discussed in this section.

17.9.1 Geothermal Education Office

The purpose of the Geothermal Education Office (GEO) is to promote public understanding about geothermal resources and their importance in providing clean sustainable energy while protecting the environment. The GEO produces and distributes educational materials about geothermal energy to schools, energy and environmental educators, libraries, industry, and the public. GEO collaborates frequently with education and energy organizations with common goals, and, through its website (http://geothermal.marin.org , responds to requests and questions from around the world. The GEO is funded by the U.S. Department of Energy and by geothermal industry participation in joint education and public information projects.

17.9.2 Geothermal Resources Council, Davis, California

The Geothermal Resources Council (GRC) is a non-profit, educational association formed in 1970. With members in more than 20 countries, the Council actively seeks to expand its role as the primary geothermal educational association throughout the world. The GRC develops educational functions on a variety of topics that are critical to geothermal development. On a contract basis, the Council can provide comprehensive, professional meeting services to fulfil industry and agency needs. The GRC convenes special meetings, workshops, conferences, courses, and symposia on the full range of subjects pertaining to geothermal exploration, development and utilization. The website of the GRC is http://www.geothermal.org .

17.9.3 GeoHeat Center, Oregon Institute of Technology, Klamath Falls, Oregon

Since 1975, the GeoHeat Center (GHC) has been involved in a number of studies and projects, funded by a variety of sources including the Department of Energy. The transfer of technological information to consultants, developers, potential users, and the general public is an important element in the development of direct heat utilization of geothermal energy. Information developed through firsthand experience with hundreds of projects and through extensive research is provided to individuals, organizations or companies involved in geothermal development.

17.9.4 University Research

The Geothermal Technologies Program supports geothermal education at the graduate level through its university research program administered by the Golden Field Office and National Laboratories participating in the Federal geothermal program. Some universities which in the past have actively pursued geothermal research include:

17.9.4.1 Kansas State University

The focus of the Kansas State University GeoCrack simulation program is modeling flow in fractured rocks. The primary application is geothermal reservoirs, where such capability is needed to simulate systems in which re-injection is used to circulate the fluid. However, GeoCrack has also been expanded to other applications.

17.9.4.2 Southern Methodist University

The SMU Geothermal Laboratory is an educational/ research arm of the Department of Geological Sciences. The Geothermal Laboratory measures various parameters relating to the thermal field of the Earth and applies these observations to areas such the geothermal resources, plate tectonics behavior, and mapping of Earth's thermal properties.

17.9.4.3 Stanford University

The goal of the Stanford Geothermal Program is to develop reservoir engineering techniques for efficient production of geothermal resources. The primary focus is to investigate reinjection into vapor-dominated reservoirs such as The Geysers.

17.9.4.4 University of Nevada, Reno

The Great Basin Center for Geothermal Energy at the University of Nevada, Reno focuses on locating and optimizing geothermal energy resources. The Center's team of scientists specializes in geochemistry, hydrogeology, geophysics, thermodynamics, remote sensing, seismology and structural geology.

17.9.4.5 University of Utah

The Geothermal Energy Unit of the University of Utah performs basic and applied research in geothermal exploration, geophysical techniques, tracers, reservoir delineation, logging, and production. The University works closely with the geothermal industry to improve geothermal technology.

17.9.4.6 Virginia Polytechnic Institute and State University

The Regional Geophysics Laboratory in the Department of Geological Sciences at the Virginia Polytechnical Institute and State University, provides information on terrestrial heat flow and practical applications of low-temperature geothermal energy. The geothermal energy database includes temperature data from hundreds of temperature and other geophysical logs, rock thermal conductivity, and hear flow values from New Jersey to Georgia.

17.9.4.7 University of Alabama

Geothermal Heat Pump research activities at the University of Alabama are conducted in its GeoCool Lab. The laboratory includes a variety of ground-coupled, groundwater, lake water, and water-to-air heat-pump systems, as well as conventional HVAC equipment and an ice thermal storage system.

17.10 International Cooperative Activities

The United States is a Contracting Parties to the International Energy Agency “Implementing Agreement for a Co-Operative Programme on Geothermal Energy Research and Technology” (Geothermal Agreement) signed on 7 March 1997. The U.S. DOE participates in each of the technical Annexes to the Agreement as either an Operating Agent or Subtask Leader. The DOE Geothermal Technologies Program and its researchers have participated in many international conferences and meetings including the World Geothermal Conference in 2000. The DOE was also a sponsor of the World Renewable Energy Conference held in September 2004 in Denver, Colorado.

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APPENDIX A

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Members and Observers at the 12th IEA-GIA Executive Committee Meeting, Pisa, Italy.

APPENDIX D

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