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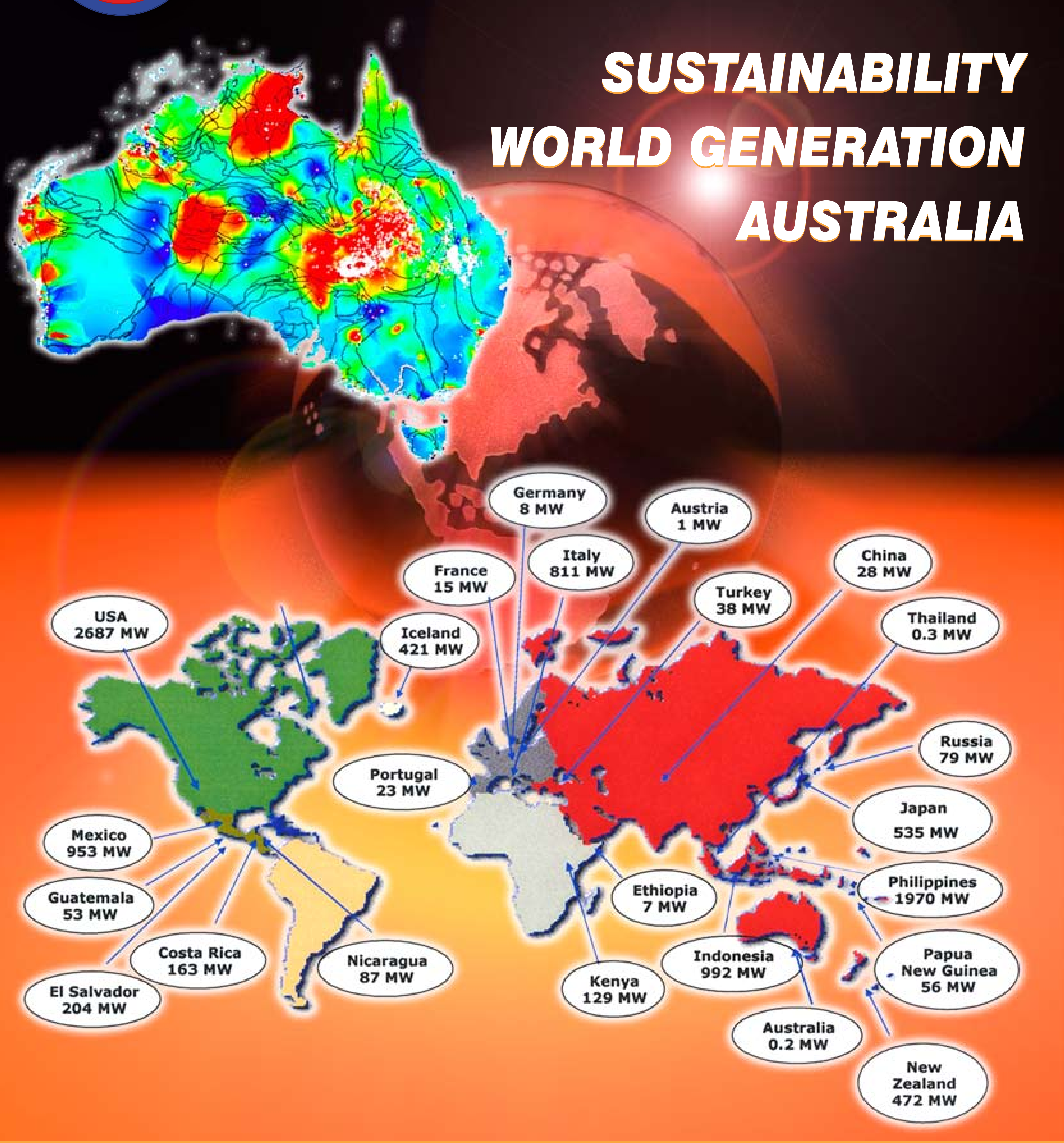
SUSTAINABILITY

WORLD GENERATION

AUSTRALIA



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GEO-HEAT CENTER QUARTERLY BULLETIN

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A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources

CONTENTS

Cover: Upper map - Approximate temperature distribution at a depth of 5km in the Australian crust, against broad tectonic elements (lines). Red is hot and blue is cold crust.

Lower map - World installed geothermal electric generators capacity in 2007.

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COMMENTS FROM THE EDITOR

This issue, which may be our last depending on funding, is devoted to topics from three well-known international experts in the field of geothermal energy. All three are newly elected members of the International Geothermal Association and represent Australia, Italy and Switzerland. Their topics are of current interest, as they address important issues being discussed by geothermal investors and developers. The recent report published by Massachusetts Institute of Technology: "The Future of Geothermal Energy – Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century" written by a committee of international experts chaired by Dr. Jefferson Tester, emphasis the importance and potential of geothermal energy in the United States and implications for similar development elsewhere in the world. The report states that over 100,000 MWe of installed capacity could be in place by 2050, given the resource, technical and economic incentives. This is certainly an appropriate and positive report.

Unfortunately, funding for the USDOE geothermal program appears to be in jeopardy and slated to be phased out in 2008 by the current administration. On the other side, Congress has several bills which include supporting the USDOE geothermal program and other R&D activities at even a higher level. Hopefully, by 2008, funding will be restored and new programs started to continue the development of geothermal in the U.S. Elsewhere in the world, funding appears strong in Europe, Philippines, Indonesia and Australia. Even though geothermal and other renewable energies will not play a major role in the near future, they must be promoted and developed as they will be significant in the long term.

Based on recent reports (see Bertani this issue) and data from the World Geothermal Congress 2005, the growth of geothermal appears strong worldwide. The current estimate for geothermal electric power is over 9,700 MWe of installed capacity generating 60,000 GWh/yr in 24 countries. The growth has been around three percent per year over the past ten years, with approximately 250 MWe of capacity added each year. Direct use has an installed capacity of around 29,000 MWt and annual energy use of 76,000 GWh in 72 countries. The growth of both installed capacity and annual energy use has been good at 6.5% per year over the past ten years (excluding geothermal heat pumps). Geothermal heat pumps have experienced the largest growth of all the geothermal applications, with the installed capacity growing almost 24% annually and the annual energy use growth at 20% in 33 countries. Since geothermal heat pumps use ground or groundwater temperatures between 5 and 30°C, they can be installed anywhere in the world, and used for both heating and cooling. The installed capacity growth for both electric power and direct-use over the past 30 years is shown in Figures 1 and 2. The rapid rise in direct-use growth since 1995 is due to the recently popularity of geothermal heat pumps.

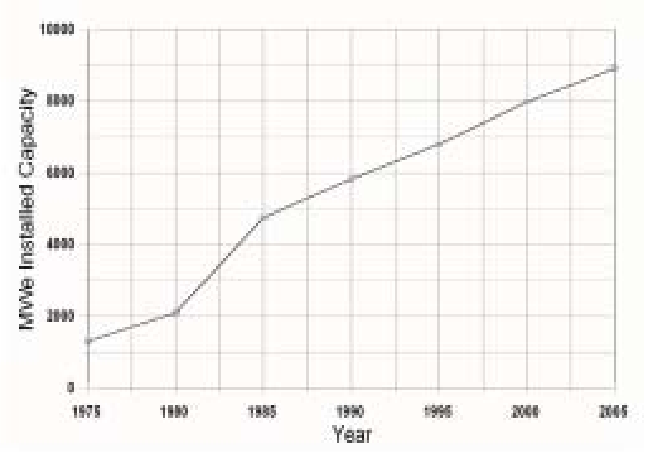

Figure 1. Worldwide growth of installed capacity of geothermal power.

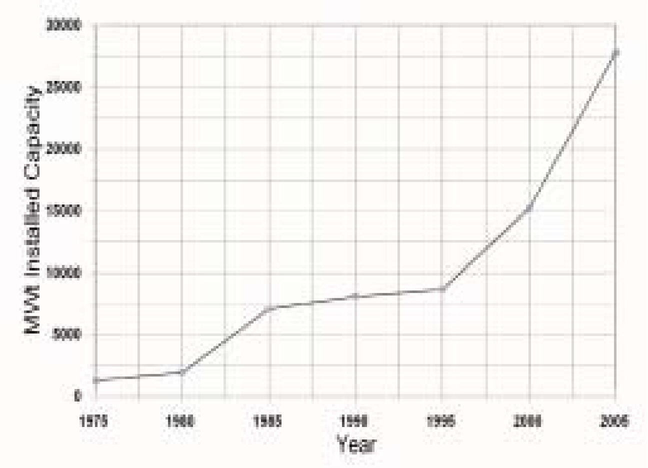

Figure 2. Worldwide growth of installed capacity of geothermal direct utilization (including geothermal heat pumps).

The funding for the Geo-Heat Center is presently limited and may be exhausted by the end of the year. Hopefully, funding in the U.S. House and Senator energy bills, and from other public and private sources, may restore our program, we just have to wait and see what develops for 2008. Thus, this may be the last issue of our Quarterly Bulletin, which has been in existence since 1975, or we may only provide issues in electronic format on our website, as we now do for back issues once they have been printed and mailed. We will let you know.

John W. Lund, Editor

GEOTHERMAL SUSTAINABILITY

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ABSTRACT

Geothermal energy is classified as a renewable resource, where "renewable" describes a characteristic of the resource: the energy removed from the resource is continuously replaced by more energy on time scales similar to those required for energy removal. Consequently, geothermal exploitation is not a "mining" process. Geothermal energy can be used in a "sustainable" manner, which means that the production system applied is able to sustain the production level over long periods of time. The longevity of production can be secured and sustainable production achieved by using moderate production rates, which take into account the local resource characteristics (field size, natural recharge rate, etc.).

The production of geothermal fluid/heat continuously creates a hydraulic/heat sink in the reservoir. This leads to pressure and temperature gradients, which in turn – after termination of production – generate fluid/heat inflow to re-establish the pre-production state. The regeneration of geothermal resources is a process, which occurs over various time scales, depending on the type and size of the production system, the rate of extraction, and on the attributes of the resource. In general, production occurs over a certain length of time.

Time scales for re-establishing the pre-production state following the cessation of production have been examined using numerical model simulations for: 1) heat extraction by geothermal heat pumps; 2) the use of doublet system on a hydrothermal aquifer for space heating; 3) the generation of electricity on a high enthalpy, two-phase reservoir; and, 4) an enhanced geothermal system. The results show that after production stops, recovery driven by natural forces like pressure and temperature gradients begins. The recovery typically shows asymptotic behavior, being strong at the start, and then slowing down subsequently, and theoretically taking an infinite amount of time to reach its original state. However, practical replenishment (e.g. 95%) will occur much earlier, generally on time scales of the same order as the lifetime of the geothermal production systems.

INTRODUCTION

Renewability and sustainability are terms often used and discussed. It is important to stress that the former concerns the nature of a resource and the latter applies to how a resource is utilized (Axelsson, et al., 2002). The relevance of these ideas to geothermal energy utilization is described below.

The ultimate source of geothermal energy is the immense heat stored within the earth: 99% of the earth's volume has temperatures >1000°C, with only 0.1% at temperatures <100°C. The total heat content of the earth is estimated to be about 10^{13} EJ and it would take over 10^9 years to exhaust it through today's global terrestrial heat flow of 40 million MWt. The internal heat of the earth is mainly provided by the decay of naturally radioactive isotopes, at the rate of 860 EJ/yr – about twice the world's primary energy consumption (443 EJ in 2003). Thus, the geothermal resource base is sufficiently large and basically ubiquitous.

Without utilization, the terrestrial heat flow is lost to the atmosphere. In this case, the isotherms run parallel to the earth's surface (i.e. horizontal in flat terrain) and the perpendicular heat flow lines point towards it. If, instead, the isotherms are deformed and the heat flow lines diverted towards heat sinks, the heat flow can be captured (Figure 1). Production of heat/fluid from geothermal reservoirs leads to the formation of such heat sinks and/or hydraulic pressure depressions. Their effects will be treated in more detail below.

Heat/fluid (along with its heat content) can be produced from a geothermal resource at different extraction rates. Excessive production could bring economic benefits, like earlier return of investment, but could also lead to resource depletion or even deterioration. However, by using moderate production rates, which take into account the local resource characteristics (field size, natural recharge rate, etc.), the longevity of production can be secured and sustainable production achieved.

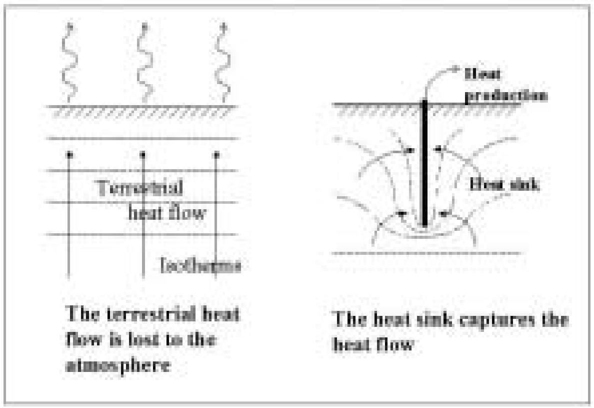

Figure 1. Principle of geothermal heat extraction and production

"MINING" GEOTHERMAL RESOURCES?

Geothermal heat and/or fluid extraction is frequently described as "mining", however, this analogy is absolutely wrong. When a mineral deposit is mined and the ore removed, it will be gone forever. Not so for geothermal; being renewable, the replenishment of geothermal resources (heat and fluid) will always take place, albeit sometimes at slow rates. This incorrect analogy also leads to legal problems and obstacles, and in reality, geothermal energy cannot be defined in physical terms as a mineral resource.

The regeneration of geothermal resources is a process that occurs over various time scales, depending on the type and size of the production system, the rate of extraction, and the attributes of the resource.

After production stops, the resources recover by natural processes. The production of geothermal fluid/heat continuously creates a hydraulic/heat sink in the reservoir. This leads to pressure and temperature gradients, which in turn–both during production and after its cessation– generate fluid/heat inflows towards re-establishing the pre-production state (Rybach, et al., 2000). The question of regeneration boils down to the rate of fluid/heat re-supplies. The time scales for re-establishing pre-production states are examined below for four resource types and utilization schemes: 1) extraction of shallow heat by geothermal heat pumps; 2) hydrothermal aquifer, used by a doublet system for space heating; 3) high enthalpy, two-phase reservoir, tapped to generate electricity; 4) enhanced geothermal systems (EGS). Numerical model simulations were used.

GEOTHERMAL REGENERATION TIME SCALES

Geothermal Heat Pumps

Geothermal heat pumps (GHP) are ground-coupled heat pumps; they operate with subsurface heat exchanger pipes (horizontal or vertical), or with groundwater boreholes (for an overview see Lund, et al., 2003).

The question of sustainability of GHPs in general, and of borehole heat exchanger (BHE)-coupled heat pumps boils down to: how long can such systems operate without a significant drawdown in production, i.e. becoming economically unviable. Therefore the long-term production behavior of BHE-based GHPs needs to be addressed.

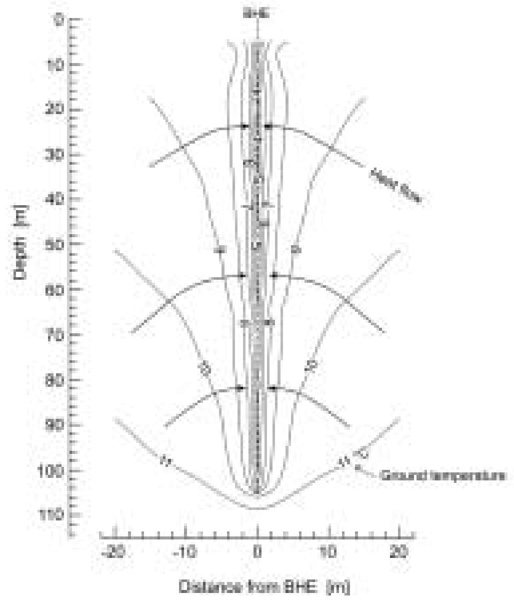

Figure 2. Calculated temperature isolines around a 105 m deep BHE, during the coldest period of the heating season 1997 in Elgg, ZH, Switzerland. The radial heat flow in the BHE vicinity is around 3 W/m^2 (from Rybach and Eugster, 2002).

After a period of operation, the BHE creates a cylindrically shaped heat sink in the ground with isotherms concentrated near the BHE (for details see Eugster and Rybach, 2000). The pronounced heat sink forms a cigar-shaped isotherm pattern, with the BHE as its center (Figure 2). The heat sink creates strong temperature gradients in the BHE vicinity, which in turn lead to heat inflow directed radially towards the BHE, to replenish the deficit created by the heat extraction. The heat flow density attains rather high values (up to several W/m^2), compared to the terrestrial heat flow (80 – 100 mW/m^2).

During the production period of a BHE (operating in the heating-only mode), the drawdown of the temperature around the BHE is strong during the first few years of operation (Figure 3). Later, the yearly deficit decreases asymptotically. Fol-

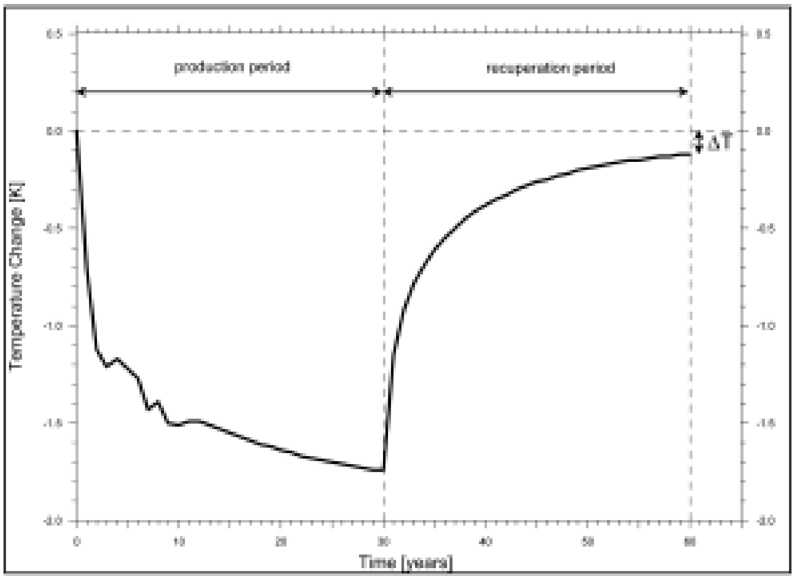

Figure 3. Calculated ground temperature change at a depth of 50 m and at a distance of 1 m from a 105 m long BHE over a production period and a recuperation period of 30 years each (from Eugster and Rybach, 2000).

lowing heat extraction shutdown, regeneration of the resource begins. During this recovery period (after an assumed 30 years of operation), the ground temperature shows a similar behavior: during the first years, the temperature increase is rapid, but then tends with increasing recovery time asymptotically towards zero (Eugster and Rybach, 2000). The time to reach nearly complete recovery depends on how long the BHE has been operational. Principally, the recovery period equals the operation period.

The results of numerical modelling for a single BHE shows that the long-term performance of the BHE/HP system stabilizes at a somewhat lower, but quasi-steady level, relative to initial conditions, after the first 10 years. Thus, sustainable operation can be achieved. The basic studies of long-term performance presented here apply to a single BHE. Similar studies of multiple BHE systems yielded comparable results (Signorelli, et al., 2005).

Doublet System Using a Hydrothermal Aquifer

The heat content of a deep aquifer can be utilized by producing the aquifer's fluid. The fluid's heat is transferred through a heat exchanger to a district-heating network (often via a heat pump), and the cooled water is reinjected into the aquifer by a second borehole at a sufficient distance from the production borehole (doublet operation). Due to this geothermal circuit, the produced hot fluid is continuously replaced by cooled injected water. This leads to an increasing volume of thermal drawdown propagating from the injection to the production well. After the thermal breakthrough time, the temperature of the produced fluid will decrease at a rate depending on the production rate, the distance between the boreholes, as well as on the physical and geometric properties of the reservoir. The increasing thermal gradients in the reservoir cause a corresponding increase in conductive thermal recovery. Hence, a thermal steady state will be reached after a sufficient circulation time, which yields a practically constant production temperature; and production at that rate can be sustained.

The town of Riehen, near Basel, hosts the first and only geothermal based district heating system in Switzerland, with a capacity of 15 MWt. The use of the doublet system started in 1994. In 1998, an extension of the district heating network into the neighbouring German town of Lörrach was established. For this system, it is essential to secure the production temperature without a considerable drawdown for about 30 years. Numerical simulations performed with the FE-code FRACTure (Kohl, 1992; for details about the modelling and the site see Mégel and Rybach, 2000) demonstrated that the geothermal circuit fulfills this condition.

The steady state production temperature is not reached even after 300 years. The development of the temperature can be characterized by considering the temperature change ΔT over a given time period, e.g. 10 years. This curve indicates the asymptotic behavior of the production temperature. The maximum value of -0.7°K/10 years is obtained after 20 years production, with the temperature drop decreasing to -0.15°K/10 years after 300 years production. Thus, practically constant heat production can be sustained.

Practical proof of sustainable doublet system operation is provided by the operational experience with the numerous doublet installations in the Paris Basin. Most of these systems have operated since the early 1970s and, so far, no production temperature or water level drawdowns have been observed (Ungemach and Antics, 2006).

High-Enthalpy Two-Phase Reservoir

Resources of this type are widely used to generate electricity. Some of them show strong signs of pressure depletion. Although this can be beneficial to some reservoirs by locally stimulating increased hot fluid recharge, if a new pressure equilibrium is not established before the pressures drop too far, then well production rates become uneconomical.

Reinjection schemes are increasingly being introduced to help sustain pressures and overcome this problem. Reinjection, however, can cause temperature decreases in the resource volume. This problem, together with the high production rates dictated by economic constraints, rather than by balancing the natural re-supply, can limit the productive lifetime of power plants to a couple of decades.

A thorough theoretical study of the electrical production/recovery cycle of a hypothetical reservoir with operational characteristics typical of lower-permeability two-phase reservoirs was conducted by Pritchett (1998) using a maximum permeability (both horizontal and vertical) of 10 md and a relatively high production ratio [(produced energy)/(natural energy recharge)] estimated to be ~6.1 (O'Sullivan and Mannington, 2005). This ratio can vary widely depending on local resource characteristics. The study addressed the change in electricity generating capacity with time for 50 years of continuous two-phase fluid production; then examined the subsequent recovery after shutdown of the power plant operation.

The study shows that pressure recovery occurs much faster than temperature re-establishment. Table 1 shows that the relative recovery increases slowly with time and that it takes several times longer than the production duration to reach a reasonable recovery (say 90%). The recovery rate is strong in the beginning but decreases subsequently, and complete recovery is reached theoretically only after an infinite time (asymptotic behavior).

Enhanced Geothermal System (EGS)

Such a system attempts to extract heat by semi-open circulation through a fractured rock volume, at considerable depth (several kilometers), between injection and production boreholes. The degree of fracturing is enhanced by technical means (man-made fracturing).

The thermal output of an EGS depends on the efficiency of heat exchange in the fractured reservoir. The more heat exchange surface that is encountered by the circulated fluid,

Table 1. Relative recovery of a two-phase reservoir after 50 years production (data from Pritchett, 1998).

RESERVOIR PROPERTY	YEARS AFTER PRODUCTION SHUT-DOWN		
	50	100	250
Pressure	68 %	88 %	98 %
Temperature	9 %	21 %	77 %

the more efficient is the heat extraction. The output temperature (and that of the EGS reservoir) will gradually decrease, though the decrease can be accelerated by effects such as short-circuiting, whereby the circulated fluid follows preferential pathways instead of contacting extended heat exchange surfaces, and additional cooling of the rock mass if significant water losses in the system are replenished by adding cold water to the injection flow at the surface. On the other hand, special effects like the creation of new heat exchange surfaces by cooling cracks might enhance the heat recovery. More field experience is needed to assess the efficiency and development with time of this effect.

In any case, the issue of EGS sustainability boils down to the question of thermal recovery of the rock mass after production stops. The lifetime of EGS systems is usually considered to be several decades. It can be expected that the recovery duration extends over time periods of similar magnitude, although the time-scale could be beyond economic interest. With favorable conditions like at Soultz-sous-Fôrets (France), hydraulic-convective heat and fluid re-supply from the far field can be effective, thanks to large-scale permeable faults (Kohl, et al., 2000). More detailed theoretical studies using numerical simulation are needed to establish a reliable base for EGS sustainability.

Further studies are also needed to determine, in a general sense, the residual heat, which remains in an EGS reservoir when excessive production rates are applied. Production at lower rates and/or using production enhancement techniques enables the extraction of more heat and thus prolongs the economic life of a given reservoir. In particular, various operational strategies such as load following, variable well flow rates and innovative reservoir/power plant management (e.g. by matching power plant design to reservoir production) should be considered.

Regeneration Time-Scale Summary

In summary, the following general comments about geothermal regeneration can be made. Production of geothermal fluid and/or heat from a reservoir/resource decreases its fluid/heat content, but also increases the natural recharge rate into created pressure and temperature sinks (i.e. dynamic recovery). A new and sustainable equilibrium condition can be established. The recovery process begins after production stops, driven by natural forces resulting from pressure and temperature gradients. The recovery typically shows asymptotic behavior, being strong at the beginning and slowing down subsequently, with the original state being re-established theoretically only after an infinite time. However, practical replenishment (e.g. 95% recovery) will be reached much earlier, generally on time-scales of the same order as the lifetime of the geothermal production systems.

THE KEY ISSUE: THE SUSTAINABLE PRODUCTION LEVEL

When producing from a geothermal resource the sustainability will depend on the initial heat and fluid content and their regeneration rates (Wright, 1995). In addition, the reaction of the resource to production will largely depend on the rate of heat/fluid extraction. With high extraction rates the energy yield will be correspondingly high at the beginning (and with it the economic reward) but the energy delivery will decrease significantly with time, and can cause the breakdown of a commercially viable operation.

Lower production rates can secure the longevity of production, i.e. relatively constant production rates can be sustained. In addition, sustainable production rates can provide similar total energy yields to those achieved with high extraction rates. To demonstrate this, the results of a study comparing high and low level production from an EGS model are summarized (for details see Sanyal and Butler, 2005). The model reservoir had an area of 3.66 km x 3.66 km, with a vertical extension between 1.22 km and 2.74 km depth. The average initial reservoir temperature was 210°C. A three-dimensional, double-porosity, finite-difference numerical scheme was used to calculate power generation from this hypothetical EGS reservoir. A five-spot borehole array (injector at the model center and production well at each corner of a square) with high 1800 t/hr (500 l/s) and low 454 t/hr (126 l/s) production rates was considered (injection flow rate = production flow rate).

Production at the high rate yielded higher power generation capacity at the beginning (45 MWe). A parasitic load of nearly 10 MWe was needed to pump the high fluid circulation rate through the system. The fluid production temperature decreased with time and reservoir depletion resulted in production stopping after 20 years (Figure 4). The total energy produced amounted to 245 MWe-year. At the lower circulation rate, the starting capacity was only 12 MWe (Figure 5), but the pumping load was nearly negligible. The temperature decline was also much less and the power generation capacity prevailed well beyond 30 years. The total energy produced over 30 years, 250 MWe- year, was very similar to that from the excessive production.

This example demonstrates that with lower extraction rates, longevity of the resource, and thus sustainable production, can be achieved and still generate as much energy as from excessive production. The level of sustainable production depends on the utilization technology as well as on the local geological conditions and resource characteristics. Its determination needs specific studies, especially model simulations of long-term production strategies.

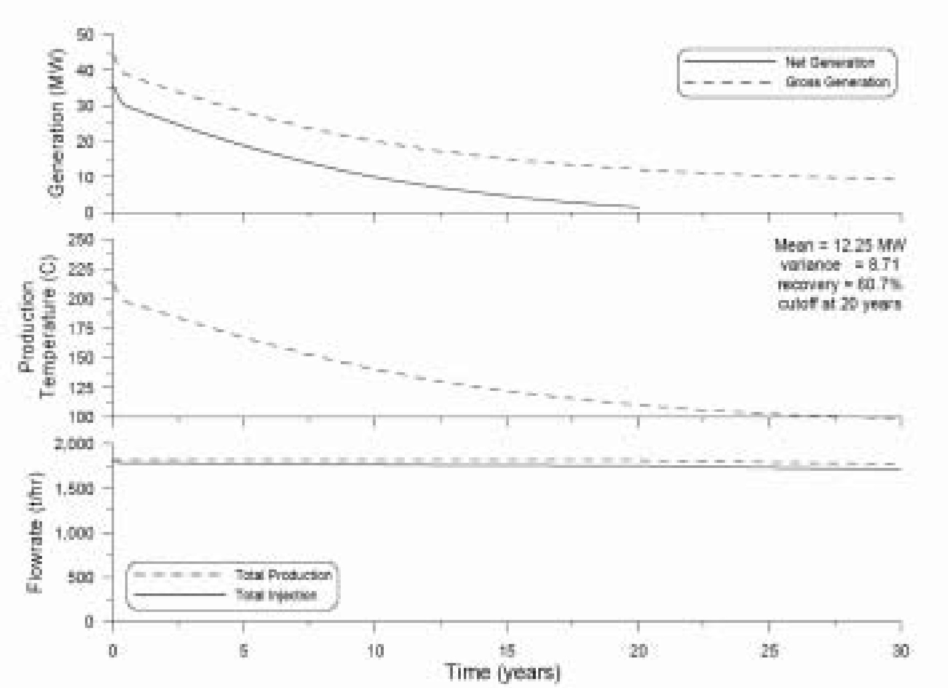

Figure 4. Power generation from an EGS system with high circulation rate (500 l/s) starts with 45 MWe capacity but terminates after 20 years with a total generation of 245 MWe -years (from Sanyal and Butler 2005).

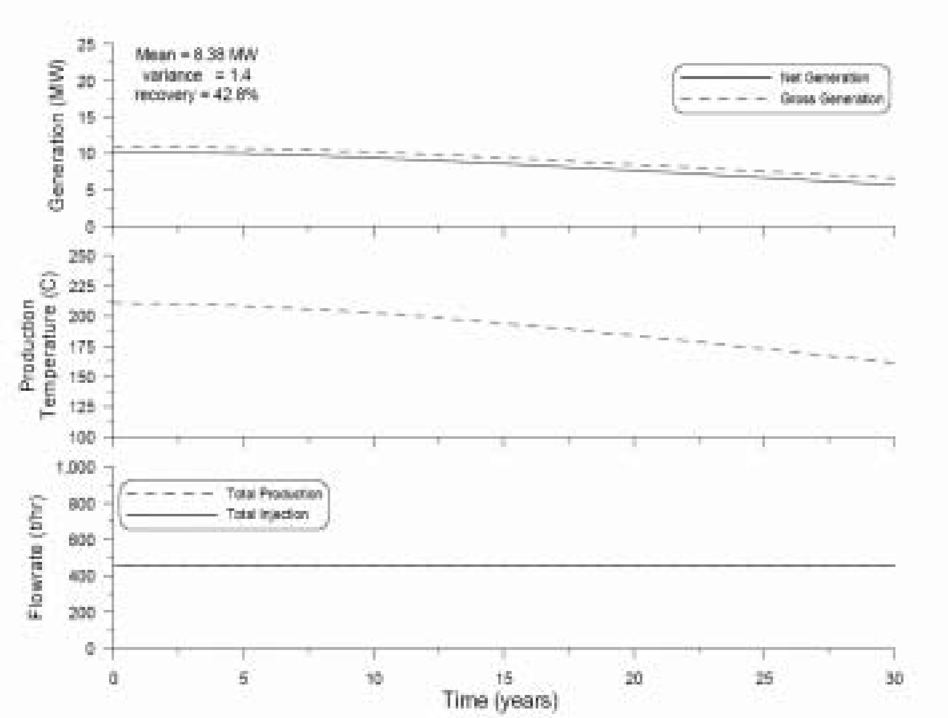

Figure 5. Lower circulation rate (126 l/s) yields long-lasting power production with total generation of 250 MWe-years (from Sanyal and Butler, 2005).

CONCLUSIONS

Any “balanced” fluid/heat production by a geothermal utilization scheme, i.e. which does not produce more than the natural recharge re-supplies, can be considered “fully” sustainable. A natural thermal spring, issuing since Roman times, is an impressive example.

Production of geothermal fluid and/or heat from a reservoir/resource decreases its fluid/heat content, but also increases the natural recharge rate into created pressure and temperature sinks (i.e. dynamic recovery). A new and sustainable equilibrium condition can be established.

Production rates that exceed the long-term rate of recharge will eventually lead to reservoir depletion, which could stop economic production.

The continuous production of geothermal fluid and/or heat creates a hydraulic/heat sink in the reservoir. This leads to pressure and temperature gradients, which in turn– both during and after termination of production– generate fluid/heat inflow towards re-establishing the pre-production state.

Unlike for mining (e.g. mining out an ore body), there will be geothermal resource regeneration. The recovery typically shows asymptotic behavior, being strong at the beginning and slowing down subsequently, the original state being re-established theoretically only after infinite time. However, practical replenishment (e.g. 95% recovery) will be reached relatively early, generally on a time-scale of the same order as the lifetime of geothermal production systems.

Recovery of high-enthalpy reservoirs is accomplished at the same site at which the fluid/heat is extracted. In addition, for the doublet and heat pump systems, truly sustainable production can be achieved. Thus geothermal resources can be considered renewable on time-scales of technological/societal systems, and do not need geological times as fossil fuel reserves do (coal, oil, gas).

For geothermal energy utilization, sustainability means the ability of the production system applied to sustain the production level over long times. Sustainable production of geothermal energy therefore secures the longevity of the resource, at a lower production level.

Long-term production from geothermal resources should be limited to sustainable levels, although short periods of extra production may be an appropriate means of rapidly establishing pressure and temperature sinks, and thereby encouraging greater flows of hot recharge from much larger underlying or peripheral resources.

The level of sustainable production depends on the utilization technology as well as on the local geothermal resource characteristics. Its determination needs specific studies, especially model simulations of long-term production strategies, for which exploration, monitoring and production data are required.

Further sustainability research is needed in several areas.

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WORLD GEOTHERMAL GENERATION IN 2007

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BACKGROUND

The major activities carried out for geothermal electricity generation since WGC2005 are analyzed in this paper.

Data are presented for the countries where some new addition to the existing capacity has been realized, with exception for the European countries, which is presented with some updated information, even in cases where there has been no new addition. Reference is made to WGC2005 world update papers (Bertani, 2005a, 2005b and 2006) for further details and analytical description of the existing geothermal fields and on the relevant on-going activity.

New data has been taken from private communications from IGA members and Affiliated Organizations, and the author would like to acknowledge all IGA (international Geothermal Association) friends for their valuable help. Other updates have been collected from websites of private and public organizations involved in geothermal development. Plants under construction, which are expected to be commissioned in 2007, are included in the installed capacity.

An increase of about 800 MW in the three year term 2005-2007 has been achieved, following the rough standard linear trend of approximately 200/250 MW per year.

INTRODUCTION

The total installed capacity from worldwide geothermal power plant is given in Table 1 and Figure 1.

Table 1: Total worldwide installed capacity from 1975 up to end of 2007 (estimated).

Year	Installed Capacity MW
1975	1,300
1980	3,887
1985	4,764
1990	5,832
1995	6,833
2000	7,972
2005	8,933
2007	9,732

Binary plant technology is playing a very important role in the modern geothermal electricity market. The economics of electricity production are influenced by the drilling costs and resource development (typical CAPEX (Capital Expense) quota is 30% for reservoir and 70% plant); the productivity of electricity per well is a function of reservoir fluid thermodynamic characteristics (phase and temperature), and the higher the energy content of the reservoir fluid, the lesser is the number of required wells and as a consequence the reservoir CAPEX quota is reduced.

Moreover, a binary plant can be an efficient way for recovering the energy content of the reservoir fluid after its primary utilization in a standard flash plant, achieving a better energy efficiency of the overall system. Whereas in the dry steam reservoir (Larderello-Italy, The Geyser-USA) the exploited energy of the fluid can be fully utilized, in all other situation worldwide the majority of the thermal energy from the extracted fluid is lost, being reinjected at high temperature and practically not used and wasted. The binary plants on the reinjection stream could be a very effective way of producing cheap energy, because there will not be any additional exploitation costs associated with this extra production. Utilization of low temperature resource can be achieved only with binary plant, increasing the overall exploitable potential worldwide. The author has included in this paper a selection of public domain pictures of existing (old and new) binary plants worldwide.

In Table 2 data from all the countries currently generating geothermal electricity are presented, with data for 2000 and 2005, 2007, and the present running capacity, as well as the increment since 2005 both in absolute terms and as a percentage. A forecast for 2010, considering the existing project in advanced stage of development, is also presented. In Figure 2, a world map of the year 2007 installed capacity is presented.

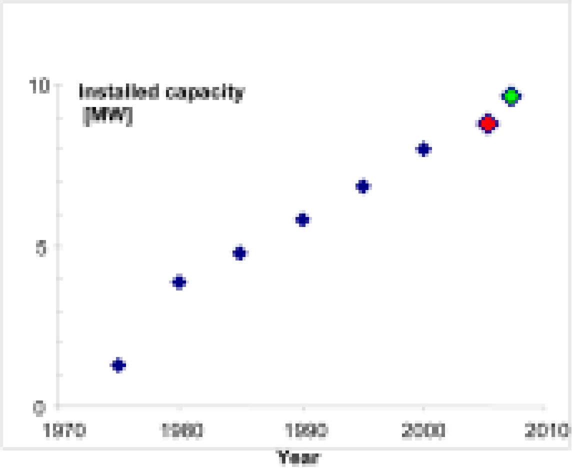

Figure 1: Installed capacity from 1975 up to end of 2007 and estimated to 2010.

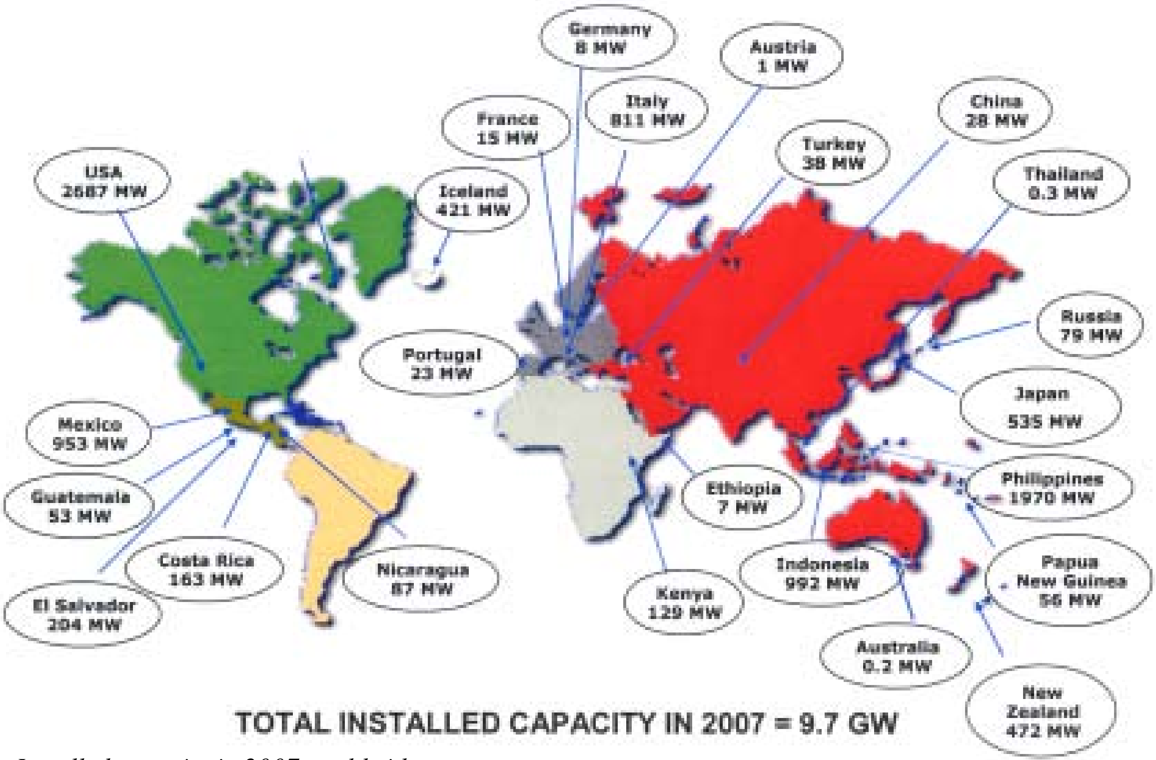

Figure 2: Installed capacity in 2007 worldwide.

Table 2: 2000, 2005 and 2007 installed capacity and forecast to 2010.

COUNTRY	**Installed Capacity in 2000 (MW)**	**Installed Capacity in 2005 (MW)**	**Installed Capacity in 2007 (MW)**	**Running Capacity in 2007 (MW)**	**Increment (MW)**	**Increment (%)**	**Forecasting for 2010 (MW)**
AUSTRALIA	0.2	0.2	0.2	0.1			0,2
AUSTRIA	0.0	1.1	1.1	0.7			1
CHINA	29.2	27.8	27.8	18.9			28
COSTA RICA	142.5	163.0	162.5	162.5			197
El SALVADOR	161.0	151.0	204.2	189.0	53	35%	204
ETHIOPIA	7.3	7.3	7.3	7.3			7
FRANCE	4.2	14.7	14.7	14.7			35
GERMANIA	0.0	0.2	8.4	8.4	8		8
GUATEMALA	33.4	33.0	53.0	49.0	20	61%	53
ICELAND	170.0	202.0	421.2	420.9	219	109%	580
INDONESIA	589.5	797.0	992.0	991.8	195	24%	1192
ITALY	785.0	791.0	810.5	711.0	20	2%	910
JAPAN	546.9	535.0	535.2	530.2			535
KENYA	45.0	129.0	128.8	128.8			164
MEXICO	755.0	953.0	953.0	953.0			1178
NEW ZEALAND	437.0	435.0	471.6	373.1	37	8%	590
NICARAGUA	70.0	77.0	87.4	52.5	10	14%	143
PAPUA-NEW GUINEA	0.0	6.0	56.0	56.0	50	833%	56
PHILIPPINES	1909.0	1930.0	1969.7	1855.6	40	2%	1991
PORTUGAL	16.0	16.0	23.0	23.0	7	44%	35
RUSSIA	23.0	79.0	79.0	79.0			185
THAILAND	0.3	0.3	0.3	0.3			0,3
TURKEY	20.4	20.0	38.0	29.5	18	90%	83
USA	2228.0	2564.0	2687.0	1935.0	123	5%	2817
TOTAL	**7973**	**8933**	**9732**	**8590**	**800**		**10993**

GEOTHERMAL POWER GENERATION STATUS SUMMARIES

Austria

In the country two small binary plants are installed: Altheim and Bad Blumau.

In Altheim a 106°C fluid is utilized both for district heating and for electricity production using a binary plant (Figure 3). The net output is 500 kW, after accounting for the 350 kW for submersible pump parasitic load, selling to the grid 1.1 GWh in 2006.

The Bad Blumau project with 110°C fluid is exploited for heating a spa facility and a binary plant of 180 kW net output.

The RES-E (renewable energy sources – electricity) target to be achieved in Austria by 2010 is 78% of gross electricity consumption. In 2004, the share of renewable energy in gross electricity consumption reached 62% (it was 70% in 1994); the geothermal installed capacity of 1.1 MW (0.7 MW net) plays a marginal role.

Figure 3: Altheim Binary Plant.

Costa Rica

No new power plant has been added to the country geothermal capacity, which is 163 MW at Miravalles. A 35 MW plant is planned in Rincon de la Vieja.

El Salvador

There are two major geothermal fields in this country: Ahuachapán and Berlín.

In the Ahuachapán area two 30 MW single flash and one 35 MW double flash are currently online; due to the reservoir decline, only 78 MW of net capacity are currently in operation. A project for reaching the full capacity loading of the units (Ahuachapán optimization) is under study. The possibility of further increase of the residual heat exploitation through a 3.5 MW binary plant is also under consideration.

In Berlín two 28 MW single flash units have been installed before 2005; two major additions have been placed online up to today: a bottoming cycle binary unit for 9.2 MW (Figure 4) and a single flash 44 MW unit, built by Enel (Italy) under a shareholder agreement with LaGeo (El Salvador, ownership and developer of the geothermal resources of the country).

The total installed capacity of the country is raised to 204 MW (189 MW running), with an increase of 35% from 2005.

Figure 4: Berlin Binary Plant.

France

The high enthalpy utilization for electricity production in France is only in the French Overseas Department, at Bouillante on Guadeloupe Island. The total capacity of 15 MW, which has not increased since 2005, produces 95.3 GWh, corresponding to 8% of the local consumption (Figure 5). The activity for the third unit of 20 MW is ongoing.

On the islands of La Martinique and La Réunion, geothermal exploration programs are planned in the near future.

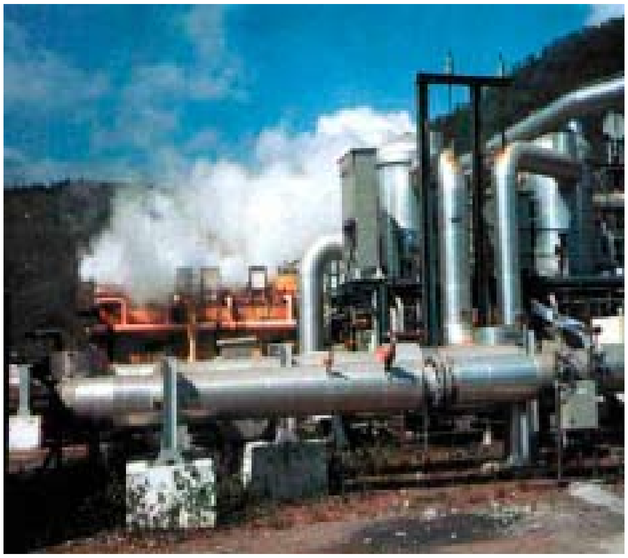

Figure 5: Bouillante Binary Plant.

The Hot Dry Rock (HDR) project at Soultz-sous-Forêts is now constructing a scientific pilot plant module of 1.5 MW. The enhanced geothermal system, exploited with a three-well system bored through granite to a depth of 5000 m, is expected to come into operation during 2008.

The RES-E target from the EU Directive for France is 21% RES-E share of gross electricity consumption in 2010. France's share of RES-E was 13% in 2004 (it was 15% in 1997). Geothermal electricity is not available on the mainland, but in the Caribbean islands it can reach up to 20% of electricity needs. HDR electricity will not be available at industrial level before year 2010.

Germany

The first geothermal plant for electrical power generation in Germany is at Neustadt-Glewe (Figure 6), with an installed capacity of about 230 kW with a binary cycle using 98°C geothermal fluid. In addition 10.7 MWt are used for district and space heating. The energy production is about 1.5 GWh per year.

Currently more than 150 permits for prospecting geothermal energy for power production have been given to companies by the German state mining authorities. Three new plants will start their operation in 2007: Landau/Pfalz (3.8 MW), Bruchsal (1 MW), Unterhaching (3.2 MW). The total installed capacity is foreseen about 8 MW.

For a minimum of at least three projects (Hagenbach/Upper Rhine Graben and two in the Munich region) drilling works are scheduled for the second half of this year. Works has also started on the biomass/geothermal energy hybrid plant at Neuried (Upper Rhine Graben). Research activities at the EGS R&D (enhanced geothermal systems) site at Groß Schöneck are ongoing.

The RES-E targets set for Germany are 12.5% of gross electricity consumption in 2010, and 20% in 2020. Substantial progress has already been made towards the 2010 RES-E target. Germany's RES-E share in 2004 is 9%, whereas in 1997 it was only 4%. The 2010 target is scheduled to break even this year.

Figure 6: Neustadt GleweBinary Plant.

Guatemala

In this country the geothermal resource is present in two fields, Zunil and Amatitlan.

Zunil, located to the west of Guatemala City, is divided in two areas; the first is the most developed until now, with temperatures up to 300°C , has an estimated capacity of 50 MW whereas the second one, with 240°C has an estimated capacity of 50 MW (28 MW installed).

Amatitlán geothermal area is located about 25 km to the south of Guatemala City in the active volcanic chain. This field, with 285°C of temperature, has an estimation of a total capacity of 200 MW. After the old 5 MW backpressure unit, a new 20 MW binary plant at Amatitlan has been commissioning this year, bringing the total installed capacity of the country to 53 MW, with an increase of 61% on the value of 2005. An exploration of the Tecuamburro area, aimed to a 40 MW project, is currently under preliminary stage of permitting.

Iceland

The geothermal electricity production in Iceland has increased significantly since 2005, with the installation of new plants in Nesjavellir, Hellisheidi and Reykjanes. The total installed capacity is as follows:

- Bjarnarflag, with a small 3.2 MW unit (the first plant in Iceland) and 40 additional MW under construction, in combination with an outdoor swimming pool, sauna and tourist center, following the "Blue Lagoon" model;
- Hellisheidi: 90 MW are on-line, and 120 MW are currently under construction, for a final total of 210 MW and 400 MWt of thermal output for district heating; the electricity is supplied mainly to local aluminum refineries;
- Husavik, with the first geothermal Kalina power plant in operation for 2 MW (Figure 7), using geothermal water at 124°C; the discharged fluid at 80°C is used for the district heating of the town, satisfying 75% of the heat demand;
- Krafla: two 30 MW double flash turbines for 60 MW total;
- Nesjavellir: four 30 MW units (total 120 MW), combining heat/electricity production with 300 MWt for district heating;
- Reykjanes: two 50 MW units for a total of 100 MW;
- Svarstenegi: two flash units (30 and 8 MW) and an 8 MW binary unit, for a total of 46 MW and hot water production of 150 MWt for district heating and the famous outdoor swimming/spa facilities of Blue Lagoon.

The total installed capacity of the country is 422 MW, and additional 160 MW under construction, with an increase on the 2005 capacity of 108%.

The Icelandic Deep Drilling Project (IDDP) has been moved near the Krafla geothermal area, in the northern part

Figure 7: Husavik Kalina Binary Plant.

of the country. The aim of the project is the exploitation of supercritical fluid at 4-5 km depth and 400-600°C of temperature.

An agreement has been signed between the Century Aluminum Co. and two major Icelandic geothermal producers (Hitaveita Sudurnesja and Orkuveita Reykjavikur) for supplying electricity to the production of an initial amount of 150,000 tonnes of aluminum per year, utilizing 250 MW of geothermal electricity. The initial stage of the project will be commissioned in 2010. The agreement is expandable up to 435 MW, for a production of 250,000 tonnes of aluminum. This will be a very efficient way of exporting the surplus of cheap and abundant geothermal electricity production from Iceland.

The Icelandic National Energy Authority has entered into an agreement with the German company Energie Baden-Württemberg (EnBW) to examine whether electricity can be transported from Iceland to Germany via an undersea cable.

The country with 300,000 inhabitants is 100% renewably powered, with 17% of its electricity and 87% of heating needs provided by geothermal energy.

Indonesia

After the economic crisis of the recent past, this country is starting geothermal activity again with important power plant construction and exploration. Only one area is still pending under arbitration after the litigation process due to the heavy local currency depreciation, but it is near to a positive conclusion; in all the other geothermal fields the situation is clarified and companies (local and international) are now investing and there are good perspectives and positive signals from the market, still to be confirmed over the next months.

The new plants commissioned or under very advanced stage of construction are 110 MW in Darajat, 20 MW at Lahendong and 10 MW at Sibayak, reaching the total installed capacity of 992 MW, with an increase of 24% on the 2005 value; its distributions is as follows:

- Darajat: two old units of 55 and 90 MW and a new one of 110 MW for a total of 255 MW; the geothermal resource is vapor dominated;
- Dieng: one unit of 60 MW;
- Kamojang: one 30 MW and two 55 MW units, for a total of 140 MW; 60 additional MW are currently under construction; this field is a dry steam reservoir;
- Lahendong: two 20 MW units, for a total of 40 MW installed and further 20 MW under construction;
- Salak: six similar units for a total of 375 MW;
- Sibayak: one 2 MW and two 5 MW units, for 12 MW in total;
- Wayang Windu: one 110 MW installed, a second 110 MW unit under preparation for construction.

Italy

There are two major geothermal areas in Italy: Larderello-Travale/Radicondoli and Mount Amiata, with a total installed capacity of 810 MW (711 MW running capacity, Buonasorte, et al., 2007).

Larderello and Travale/Radicondoli are two nearby parts of the same deep field, covering a huge area of approximately 400 km^2, producing super-heated steam. In the Larderello side the exploited area is 250 km^2, with 21 units for 562 MW installed capacity; in the southeast side of Travale/Radicondoli, covering a surface of 50 km^2, there are 160 MW (6 units) of installed capacity. The condensed water from Travale is reinjected into the core of the Larderello field through a 20 km long water pipeline.

Mount Amiata area includes two water dominated geothermal fields: Piancastagnaio and Bagnore. In both the fields a deep resource has been discovered under the shallow one. Serious acceptability problems with local communities are slowing down the project for the full exploitation of this high potential deep reservoir. Presently, there are 5 units with 88 MW of installed capacity: one in Bagnore and four in Piancastagnaio.

The addition since 2005 is a new unit in Larderello for 20 MW, for a modest 3% increase. Projects for further 100 MW are approved and will be realized in the coming years.

Italy has a target of a RES-E share of 25% of gross electricity consumption by 2010. No progress has been made towards this. While Italy's RES-E share amounted to 16% in 1997, it is decreased to 15% in 2004.

Enel Green Projects

Enel has a very important program for the 2007-2011 period, with a four billion euro investment plan for renewable energy generation, aimed at saving 4 million tonnes of CO_2 each year. In particular, 1,700 MW of new capacity will be installed, (1,500 MW wind, 100 MW hydro and geothermal each) for 3.3 billion euro; the investment will be 1.6 billion in Italy, and 1.7 billion abroad. 800 millions euro will be invested in innovative projects for renewable energy generation (thermodynamic solar, photovoltaic research, off-shore wind generation, and other minor projects), energy efficiency and distributed generation, “zero emissions” and hydrogen frontier.

For the “zero-emission in geothermal program”, an important investment plan has been approved by Enel, in order to mitigate the H_2S and Hg effluent to the environment with a specific treatment, using a technology fully designed and developed by Enel (owner and operator of the geothermal resources in Italy): AMIS plant (Figure 8; Baldacci, et al., 2005), reaching a very high efficiency in H_2S and Hg removal, lower capital and O&M costs in comparison with commercial process, no solid sulphur by-products (liquid streams reinjected in the reservoir) and unattended operation (remote control). Approximately 80% of the effluents are currently treated by AMIS systems.

Figure 8: AMIS Plant.

Kenya

No new addition has been realized since 2005; however, a project for 35 MW at Olkaria has been approved and it is expected to be completed within two years.

Mexico

No new addition has been realized since 2005. However, the projects Cerro Prieto V (100 MW) and Los Humeros II (46 MW) have been approved and it is expected that both will be completed by 2010. The project Cerritos Colorados (75 MW), formerly known as La Primavera, has no programmed date since it must be approved by the environmental authorities first.

New Zealand

All the geothermal projects in this country are in the central North Island or the Northland region (Ngawha). Since 2005 two new plants have been realized: a binary unit of 14 MW at Wairakei and a second stage at Mokai for 39 MW, bringing the total installed capacity of the country to 472 MW (only 373 MW running, due to the fluid supply issues at Ohaaki and to a minor extent at Wairakei, and consent restrictions for the Poihipi station on the Wairakei field), with an increase of 8%. The geothermal areas are as follows:

- Kawerau: 8 MW flash and 6 MW binary, for a total of 14 MW (but with the primary steam supply being directed to the world’s largest geothermal industrial direct use application-Tasman); a new dual flash plant is under construction for 90 MW;
- Mokai: two flash units for 30+39 MW and four 4.5 MW binary plants, for a total installed capacity of 96 MW; a further binary plant expansion is under construction;
- Ngawha: two 4.8 binary plants for 9.6 MW; a new 15 MW unit is under construction;
- Ohaaki: four flash units, two of 11 MW (now decommissioned) and two of 43 MW, up to a total of 86 MW, but with only 45 MW running (and output recently reduced below 30 MW);
- Poihipi: one dry steam plant of 55 MW, but running in day-night mode averaging 25 MW normally due to consent restrictions;
- Rotokawa: one flash unit of 15 MW and three 4.5 MW binary plants and a 6 MW binary plant, for a total of 35 MW;
- Wairakei: several plants, flash and binary (Figure 9), for a total of 176 MW (but recently offering 146 MW due to supply restrictions) – there has recently been a suggestion to replace this fifty year old facility.

Figure 9: Wairakei Binary Plant.

Nicaragua

No new addition has been realized since 2005; however, a project for an additional 10 MW and subsequently 46 MW at San Jacinto is on-going, bringing the total installed capacity of this field up to 66 MW. No activities are scheduled for the other geothermal area of Momotombo.

An exploration program at El Hoyo-Monte Galan and Chiltepe, for two 44 MW projects each has been launched jointly by Enel and LaGeo; the deep exploration is expected to be completed by year 2009.

Papua - New Guinea

Geothermal power development is focused at a major gold mine on the tiny Lihir Island, located about 900 km northeast of the national capital. Its exploitation arises from an unusual combination of the geothermal resource, the gold mining environment and the isolated location remote from the power grid.

After an initial 6 MW back-pressure plant was constructed in 2003, a new 50 MW power station has been constructed and commissioned in stages over the last two years (one 30 MW and two 10 MW modules). This lifts the total capacity to 56 MW (Figure 10), with an increase of 833%.

Figure 10: Lihir Back-Pressure Steam Power Station.

Some 75% of the mining operation's current capacity needs are covered by geothermal electricity, with a significant saving estimated at approximately 40 million USD in 2007, replacing heavy fuel oil for power generation. It will also generate revenues of 3 million USD per year from the sale of carbon credits on the global market.

Philippines

The Philippines is the world's second largest producer of geothermal energy for power generation, with an installed capacity of 1,971 MW for a running capacity of 1,856 MW.

There was a minor increase since 2005, with the 49 MW at Northern Negros merchant plant (it will operate with electricity supply contracts between PNOC-EDC and electricity cooperatives and distributors) commissioned in 2007, with an increase of 2%.

The geothermal areas are as follows:

- Bac-Man: a small 1.5 MW back pressure turbine plant (combined with drying plant), two units for 55 MW and two for 20 MW, for a total of 151.5 MW;
- Leyte: five flash (661.5 MW), and 3 topping cycle (back pressure turbines), 1 bottoming (flash), and 1 bottom cycle binary plant (total optimization capacity 61 MW, Figure 11), for the optimization of the overall energy recovery from the geothermal system, for a total installed capacity of 723 MW;
- Mak-Ban: ten flash units and a 15.7 binary plant, for a total of 458 MW;
- Mindanao: two flash units (one single and one dual pressure) for 104 MW in total;

Figure 11: Leyte Binary Plant.

- Northern Negros: one flash (dual pressure) unit of 49 MW;
- South Negros: five flash units for 192.5 MW; an optimization project for 20 MW binary is under development;
- Tiwi: five flash units for 289 MW.

An intensive privatization process of the mining operator PNOC/EDC and of some power plants is planned for 2008.

Portugal

In Portugal, exploitation of geothermal resources for electric power generation has been developed successfully on the largest and most populous Azores island, São Miguel.

A second binary unit at Pico Vermelho of 10 MW has been installed, bringing the total island capacity up to 23 MW, with an increase of 44% (Figure 12).

The share of renewable energy generation in São Miguel is now 43%. On Terceira Island a project for installing 12 MW is ongoing.

The RES-E target to be achieved by Portugal in 2010 is 39% of gross electricity consumption. There was a sharp decline between 1997 (38%) and 2004 (24%).

Figure 12: Ribeira Grande Binary Plant.

Russia

No new addition has been realized since 2005. The geothermal resources of the country are located in Kamchatka and some small plants on the Kurili islands. However, projects for construction of binary Verkhne-Mutnovsky (6.5 MW, Figure 13) and the second 100 MW stage of Mutnovsky are under development.

Figure 13: Verkhne-Mutnovsky Binary Plant.

Turkey

Since 2005 several construction activities have been carried out. Three new binary units of 8 MW each has been realized (Figure 14), two for exploiting medium enthalpy reservoir and one on the downstream of the separated brine from the Kizildere plant, before its use for district heating.

A new 45 MW unit is also at an early stage of construction at Germencik, with the option of a further 45 MW as potential expansion.

The total installed capacity (taking into account only Kizildere and the binary units) is 38 MW, with an increase of 90% with respect to the 2005 value.

Figure 14: Salavatli Binary Plant.

USA

Geothermal electric power plants are located in Alaska, California, Nevada, Utah and Hawaii; the total installed capacity of the country is 2,687 MW, but with only 1,935 MW actually running, with a 5% increase on year 2005. A total of 130 MW is currently under construction.

Alaska

The first geothermal power plant in this state was installed in 2006, at Chena Hot Springs. It is a binary plant (Figure 15), producing 200 kW gross from the coldest geothermal resource worldwide: only 74°C.

Figure 15: Chena Binary Plant.

A second unit has been added, reaching the total installed capacity of 400 kW gross. At the end of the construction activity, a total of 1 MW will be installed.

California

No new plant has been realized; since year 2005, some re-powering at three units at The Geyser has been performed.

The relevant geothermal power plants are listed as following:

- The Geyser: 22 dry steam units, for a total of 1,531 MW installed capacity (but only 932 MW running);
- Imperial Valley-East Mesa, with 70 units for 100 MW of installed capacity;
- Imperial Valley-Heber, 94 MW of installed capacity with 14 units;
- Imperial Valley-Salton Sea, with 10 units for 327 MW;
- COSO, nine units for an installed capacity of 270 MW;
- Others, with 29 additional MW.

The total installed capacity of the state is 2,351 MW (1,715 MW running). Geothermal supplies 5% of California's electric generation, producing a net-total of 14,000 GWh/year.

Future developments are planned in Northern California, at Glass Mountain: 50 MW approved at Fourmile Hill, and 18 additional MW binary at Heber.

A new unit at Salton Sea for 185 MW has been announced. An exploration program at Surprise Valley, in northeastern California, aimed to a binary project of 45 MW has been launched by Enel.

Hawaii

No new addition at the existing ten flash+binary units of 35 MW installed capacity (30 MW running, after rehabilitation and work over) has been done since 2005. This power plant supplies approximately 20% of the total electricity need of the Big Island (160,000 inhabitants). A further 8 MW of expansion is also planned.

Nevada

A new 30 MW binary plant at Galena (Steamboat field) has been commissioned, with further two units planned by Ormat, for additional 25 MW.

The total installed capacity for the state is 275 MW (240 MW running). At Stillwater and Salt Wells, recently transferred to Enel, additional 40 MW are scheduled. At Steamboat Hills a 12 MW binary plant is also planned. Further additions are foreseen for Desert Peak (30 MW). A 30 MW binary unit is under construction at Fallon Naval Air Station.

Utah

The Cove Fort plant has been shut down; the only existing unit in the state is Roosevelt, with 26 MW of installed capacity. A further 11 MW are planned at this facility. Enel is launching a two step project of installing binary units at Cove Fort, with 25 MW in 2009 and an additional 40 MW in 2011.

GEOTHERMAL ENERGY AND OTHER RENEWABLES

At the world level, the most important renewable energy source is hydro, which represents about 93% of all the installed capacity. This quota is similar for all the continents except Europe, where wind plays a relevant role of 13%, as shown in Figure 16 (IEA, 2006).

Hydropower also has a relevant quota among the total power generation worldwide: 19% of the total electricity generation, with a growing rate of 2-5%; the largest markets are in USA, Canada, Brazil, Norway, and China. No relevant new European resources are being considered.

Wind energy provides 1% of world global power generation, with the most important countries being in Europe (Germany, Spain, Denmark) and USA. A very aggressive growth rate of 15-20% is expected, mainly in UK, China, India and Australia.

Geothermal energy provides approximately 0.4% of the world global power generation, with a stable long term growth rate of 5%. At present the largest markets are in USA, Philippines, Mexico, Indonesia, Italy and Iceland. Future developments are limited to certain areas worldwide, particularly under current technologies.

Solar energy plays a very limited role in global power generation, but it has a very high growth rate of 25-30%, especially in USA, Spain, China, Australia and India.

The growth of developing countries will produce a doubling of the global electricity demand over the next 25 years, from 15,000 TWh for 2005 to 30,000 TWh for 2030. The present renewable energy quota is 21.5% (mainly hydro), and the projected share will be 25.8% in 2030, with the distribution shown in Table 3.

The growth profile will be different for each RES region by region: in Western Europe, given the modest growth in overall electricity demand, renewable will subtract considerable market share to conventional sources.

Wind

From the present installed capacity of 74 GW, it is expected to reach 150 GW in 2010. It is a reliable technology, with attractive costs for onshore applications: the CAPEX is 0.9-1.3 euro/MW for onshore and 1.5-2.5 euro/MW for offshore, with generation costs in the range 30-60 euro/MWh for onshore and almost double for offshore.

The quality of the power and its availability is strongly dependent on the wind resource. The next generation is expected to use high power turbines (>5 MW), vertically rotating machines and dedicated offshore applications.

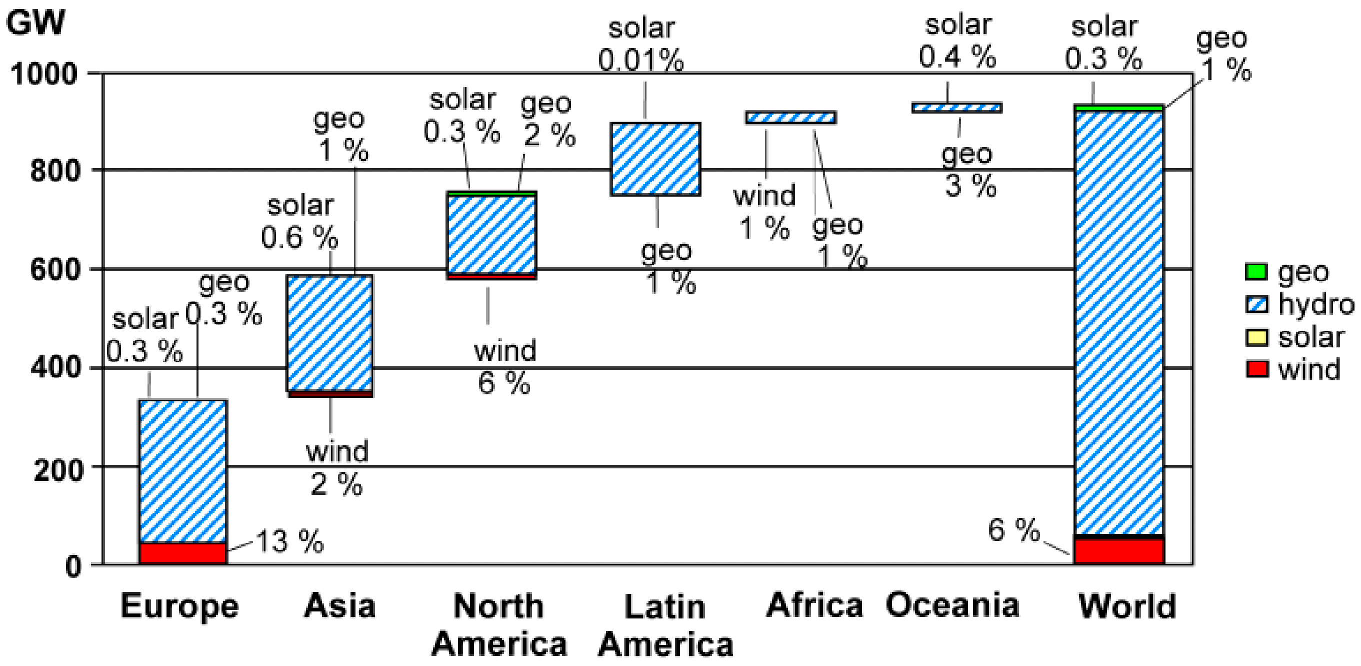

Figure 16: RES distribution by source and continent (source: IEA, 2006 - based on 2004 data).

Geothermal

The present installed capacity of 9.7 GW will increase up to 11 GW in 2010. It has medium investment costs, depending on the quality of the resource (temperature, fluid chemistry and thermodynamics phase, well productivity), ranging approximately from 2 to 4.5 euro/MW, and with very attractive generation costs, from 40 to 100 euro/MWh. It is a resource suitable for base load power.

It can be considered as broadly cost-competitive, despite its relatively high capital costs for the development of the geothermal field (resource evaluation, exploitation risk, drilling and piping) for its very high availability and the stability of the energy production.

Table 3: RES quota today and projection for 2030 (source: IEA).

RES	2004	2030
Hydro	19. 0%	16. 3%
Biomass	1. 5%	3. 3%
Solar	0. 0%	0. 8%
Wind	0. 6%	4. 8%
Geothermal	0. 4%	0. 6%
Tidal/Wave	0. 0%	0. 1%
Renewable Quota	**21. 5%**	**25. 8%**
Total Demand	**15,000 TWh**	**30,000 TWh**

For the next generation it is expected to see the implementation of the Enhanced Geothermal System (EGS) production and an intensive increasing of the low-to-medium temperature applications through binary cycle and cascade utilizations.

Solar

It is expected to reach 20 GW for 2010 through PV generation, with an increase of 35%. The costs are the least promising, from 4 to 5 euro/MW of CAPEX and 250 to 450 euro/MWh of operation. It is a peak power, non programmable and highly discontinuing. For the future, large scale technologies and cost reduction through thin-film and organic material for PV generation can be foreseen.

Europe

Restricting our analysis to Europe only, the availability of the different RES can be seen in Figure 17, where the level of wind resources at 50 m above ground level, the global solar irradiation, the gross theoretical hydraulic energy potential and the geothermal heat flow density are shown.

For geothermal electricity production, the highest concentration of resource in the continental Europe is located in Italy, Iceland and Turkey; the present exploited value is only 0.3% of all the renewable market.

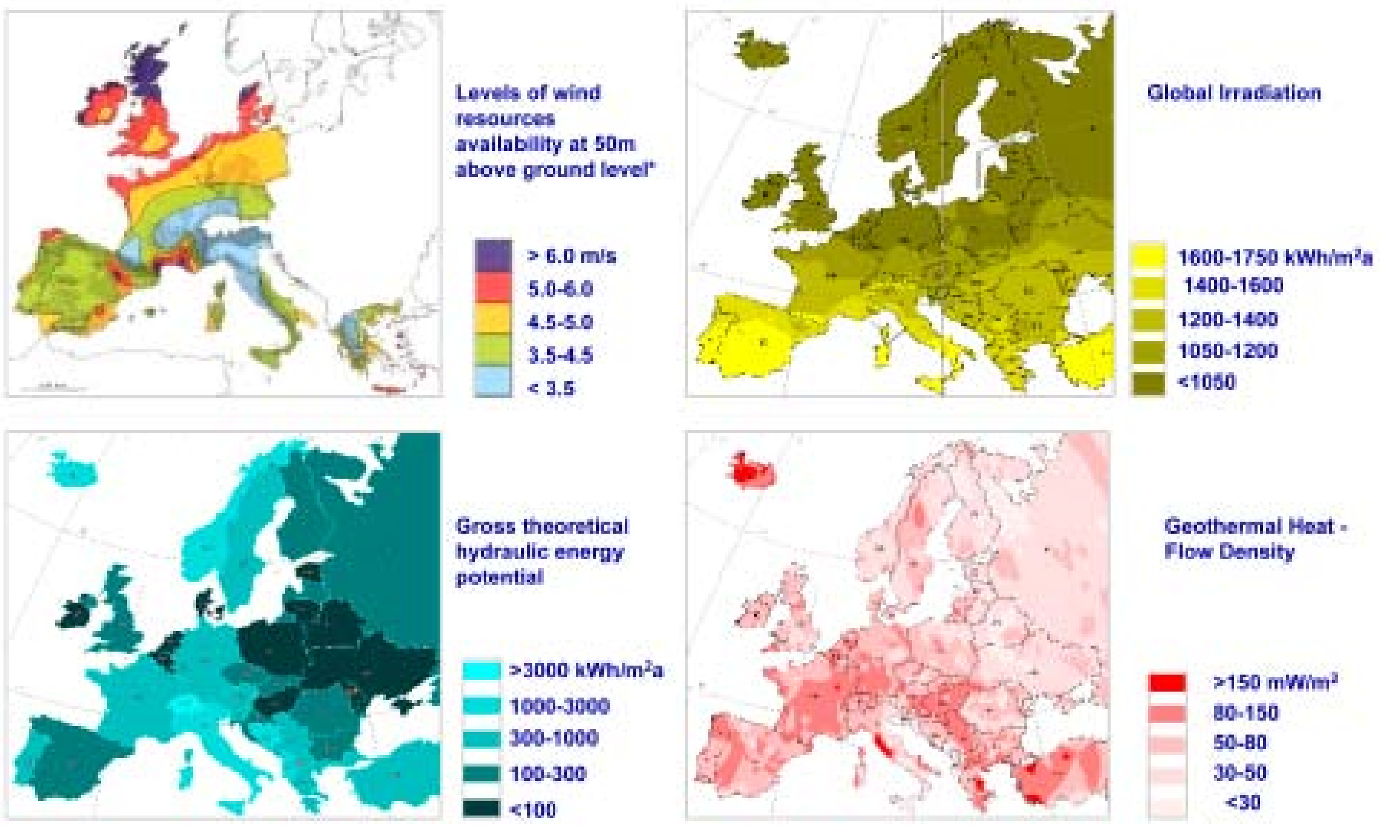

Figure 17: RES availability in Europe.

The possibilities for geothermal energy to expand its penetration in Europe is mainly from the Enhanced Geothermal System (EGS); whereas the drilling technology is already in a mature stage, and efforts can only be done to reduce the drilling costs, the stimulation technologies are still in the pilot stage.

There are many geothermal prospects with high temperature but lacking fluid in the formation or the rock permeability is too low for permitting fluid circulation. These systems can be enhanced by engineering the reservoir through stimulation activities: acidizing, and hydraulic fracturing. The development of these technologies will make a huge geothermal potential available.

The best results worldwide have been obtained from the Soultz project. The critical aspect is the seismic hazard induced by the hydraulic fracturing.

Without the EGS contribution, the expected value of the installed capacity in Europe from geothermal energy will be 1,800 MW in 2010, with an increase of 400 MW approximately.

CONCLUSION

The geothermal electricity installed capacity is approaching the 10,000 GW threshold, which can be reached before the next World Geothermal Congress (WGC2010) in Indonesia.

The most important and active country, both for absolute capacity increase and for the relative percentage value since 2005 can be considered Iceland, with about 220 MW of new plant commissioned and with a 110% increase.

The combined utilization of geothermal energy both for electricity and district heating, the cascade integrated development, the increasing of export of electricity through aluminum manufacturing, the presence of strong and motivated industry, the existence of well developed geothermal culture and expertise could be considered the key elements for the success of the Icelandic geothermal experience; very good prospects are still present for a further increase of their potential.

A special mention should be addressed to the Papua New Guinea: this country reached 56 MW, covering 75% of the electricity needs through geothermal, and realizing an unique integrated example of joint development of a gold mining activity with geothermal electricity generation, using some common infrastructures and taking the maximum advantage of the mining environment and the isolated remote location (no access to grid).

Indonesia, defined in 2005 as the “sleeping beauty”, can be considered now as an “awake giant”, after the closing of the pending arbitrations and the private/public investments for realizing about 200 MW (25% increase from 2005 value) and with very good prospects. If the present economic situation of the country could be considered as stabilized and promising for foreign companies and the regulatory/tariff framework will be considered as attractive, there is no doubt of the realistic possibility of a huge increase in the installed capacity in the country over the coming years, reaching an appreciable quota of its enormous potential of some tens of GW.

Very positive developments from the three Central American countries of El Salvador, Guatemala and Nicaragua, with approximately new 80 MW in total and promising perspectives in the near future.

Turkey, after a long period of standby, initiated an important construction activity, with about 20 new MW and further 50 MW under an advanced stage of development.

The overall geothermal electricity potential of approximately 200 MW could be realistically reached in the next few years, using mainly binary plants from medium enthalpy resources and traditional flash technologies.

The electricity needs of the São Miguel - Azores Islands (Portugal) are now covered 43% from geothermal energy, almost doubled since 2005. There are relatively good perspectives of future developments for some islands of the archipelagos.

A minor but important increase should be highlighted also for New Zealand, Philippines and the USA.

We should consider as very good and positive signals the new binary plants of Austria and Germany (and Alaska), proving the possibility of producing some geothermal electricity also from low temperature resources.

In Italy, after 100 years of continuous development, reaching the relevant value 800 MW, it’s necessary to invest for achieving a better social acceptance of the geothermal development, increasing the emission abatement and reducing the environmental impacts of the geothermal industry, in order to receive more social and political support for the permitting and licensing for the future projects.

Larderello is still alive and productive, and we can consider it as the best example of the renewability and sustainability of the geothermal development and exploitation through a good management of the resources for more than 100 years. Reinjection strategy, deep drilling and well stimulation are the key drivers for keeping this valuable resource as a potential “treasure pot” for future generations and for producing a relevant economical return of the investment.

Among the other renewable energy resources, whereas hydro potential can be considered as already known and utilized; without important growth margin, only wind can be considered as a realistic competitor for geothermal. But they should not be considered to be in opposition: both the resources can be developed where they are more convenient and where their presence is assessed.

Wind is more widely diffused, but it is not generally constant during the day and its production is not easily predictable, especially in consideration with the very fast climate changes worldwide.

Geothermal energy is not present everywhere, but its base-load capability is a very important factor for its success. The utilization of binary plants and the possibility of production from enhanced geothermal systems (to be considered as possible future developments) can expand its availability on a worldwide basis.

Note: 1 Euro = 1.35 US$

ACKNOWLEDGEMENT

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THE BURGEONING AUSTRALIAN GEOTHERMAL ENERGY INDUSTRY

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INTRODUCTION

Australia has historically been considered a very "cold" country, geologically speaking; not a place that immediately conjures thoughts of geothermal power generation. It is not surprising therefore, that geothermal energy has not historically played a large role in Australia's energy mix, nor Australia in the global geothermal community. The past decade, however, has seen first a trickle and then a flood of interest in geothermal. This interest has been fuelled by a growing realization that Australia is blessed with world class "hot dry rock" and low temperature hydrothermal resources, coupled with a growing imperative to reduce Australia's carbon footprint. The result has been new State and Federal legislation, escalating levels of public and private investment, a spate of new companies dedicated to the identification and development of geothermal energy, and a growing number of commercial projects aimed at geothermal power generation.

GEOLOGY OF AUSTRALIA

The impression of Australia as a cold continent comes from the continent's position in the middle of the Australian Tectonic Plate (Figure 1), and the fact that the continent has large areas of exposed Archaean and Proterozoic crust. There are no plate margins, active volcanoes or surface geothermal manifestations (with the exception of a handful of warm to hot springs) on the Australian continental land mass. In spite of the lack of surface signs, however, there is a significant body of geological evidence to suggest that the continent may not be as cold as initially thought. Some of this evidence is presented below.

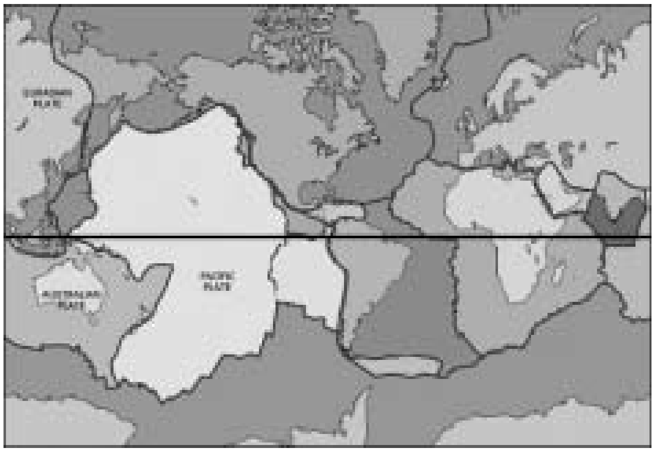

Figure 1. Tectonic plate boundaries, showing the Australian continent in a central position on the Australian Plate. Image modified after USGS.

BOREHOLE TEMPERATURES

An assessment of the thermal resource beneath the Australian continent is hampered by the fact that there are relatively few published conductive heat flow measurements for the continent. The global heat flow data base lists just over 100 measurements across an area roughly equal in size to the 48 contiguous states of the USA. In comparison, there are many thousands of points published for the USA. This paucity of data makes it difficult to quantify the actual energy in the ground, but related data provide a broad indication that heat flow, and potential temperature resource, varies significantly across the continent.

Chopra and Holgate (2005) published a GIS analysis of temperatures reported from over 4,000 boreholes across the continent. They used a simple linear extrapolation method to estimate the temperature of the crust at a depth of 5 km. The results (Figure 2) suggest that large sections of the continent are underlain by relatively hot crust. Temperatures in excess of 200°C have, indeed, been intersected by petroleum exploration wells at depths little more than 3 km in the Cooper Basin in central Australia. In addition, Geodynamics Limited have reported temperatures approaching 250°C at a depth of about 4,400 m in the geothermal exploration well Habanero 1 in the same region. Figure 2 suggests that large tracts of the continent may be underlain by crust of similar temperature, although wells to the appropriate depth have not yet been drilled in any of the other areas.

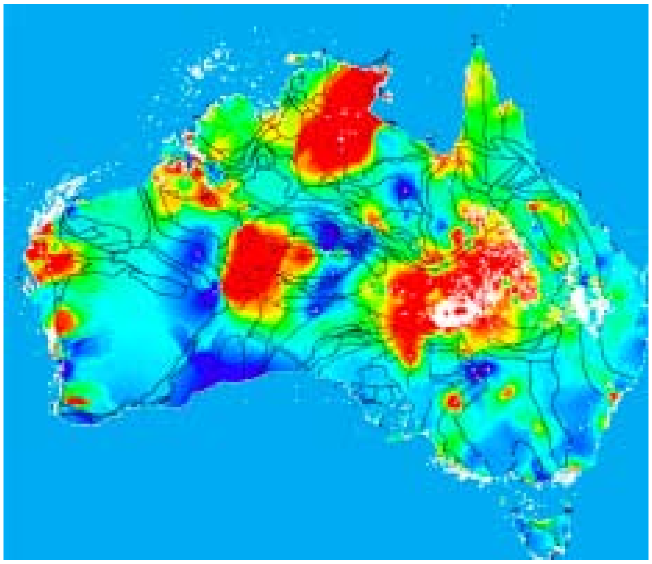

Figure 2. Approximate temperature distribution at a depth of 5 km in the Australian crust, against broad tectonic elements (black lines). Data points shown as white + symbols. Red is relatively hot crust, blue is relatively cold. From Chopra and Holgate (2005)(see cover for colors).

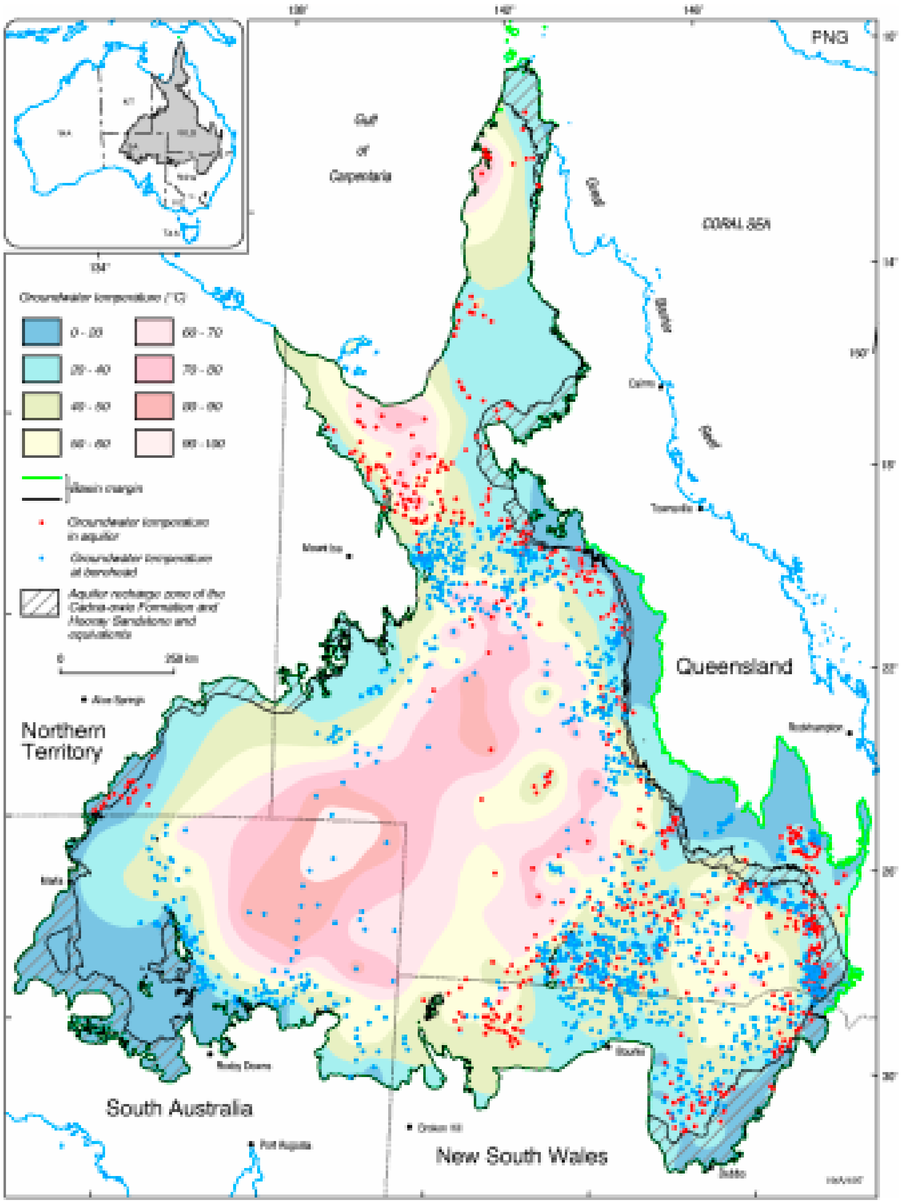

Figure 3. Groundwater temperature from the Great Artesian Basin. From Habermehl and Pestov (2002).

TERTIARY ERUPTION CENTERS

Australia is not generally considered an active volcanic region, but the eastern side of the continent, from the state of Queensland in the north to Tasmania and South Australia in the south, plays host to a large number of relatively young basaltic eruption centers. The state of Victoria in the southeast of continental Australia, for example, shows evidence of intermittent volcanism over the past 190 Ma (million years), with volumetric peaks between 5,742 Ma and 50 Ma (Price et al., 2003). The most recent event, at Mount Gambier just over the border in South Australia, has been dated at less than 5,000 years (Sheard, 1995). These volcanic features appear to be related in some manner to a series of rifted marginal basins along the same coast. The exact relationship is far from obvious, but with such a long, and potentially ongoing history of volcanic activity throughout the region, it is tempting to conclude that there may be young intracrustal igneous bodies or areas of elevated mantle heating, though no direct evidence of such phenomena has yet been found.

The most tantalising evidence that young volcanic features are associated with geothermal energy sources lies in the northern part of the state of Queensland, in the northeast of the country. A number of hot springs in the area known as the Atherton Tablelands discharge water at temperatures in excess of 70°C. The same area hosts some very young volcanic rocks (on the order of 10,000 years), including some spectacular lava tubes.

GREAT ARTESIAN BASIN

The Great Artesian Basin (GAB) is the world's largest artesian groundwater basin, underlying about 22% of the Australian continental landmass. Groundwater from the GAB comes out at wellheads at temperatures ranging from 30°C to 100°C (Figure 3), and in most cases has to be cooled before it can be used as town or stock water. The shear size and temperature of the underground water resource makes it an attractive geothermal target. In fact, the geothermal potential of the GAB was highlighted in the June 2002 edition of this very Bulletin (Habermehl and Pestov, 2002).

CURRENT USES OF GEOTHERMAL ENERGY IN AUSTRALIA

Chopra (2005a) described the state of the geothermal industry in Australia in 2005. Little has changed between then and now in the number of commercial operations, but governments and organizations across the country are beginning to recognize the potential of geothermal resources, and are exploring new possibilities for utilization. Geothermal utilization in Australia is currently restricted to a single small binary cycle power generator, and a handful of direct uses. Some examples follow.

Birdsville Geothermal Power Plant

Ergon Energy, the state-owned electrical power company in the state of Queensland, owns and operates the Birdsville Geothermal Power Plant. Birdsville (25°54'S, 139°22'E, population 100) is a small town in southwest Queensland, near the border with South Australia.

The town lies over 1,500 km from the nearest state capital city and many hundreds of kilometers from the nearest point on the national electricity network, so all electrical power is locally generated. A simple binary cycle geothermal generator supplies a net 80 kW of electricity, sufficient to supply Birdsville's off-peak demand. Diesel generators cut in at times of higher demand. The heat source for the geothermal plant is the town's water supply bore, which flows 98°C water at 27 liters per second. (see also Chopra, 2005b).

At the time of writing, Ergon Energy is funding a study into the feasibility of improving the capacity and efficiency of the geothermal plant. The study is looking at such things as improving the temperature and flow rate of the resource, potential for reinjection (currently most of the spent fluid is discharged to a surface stream), and decreasing the parasitic load from the cooling fans (current parasitic cooling load is on the order of 30% of gross power output).

Portland Space Heating Facility

Portland (38°20´S, 141°36´E, population 8,800) is a town on the west coast of the state of Victoria. It was host to Australia's only geothermal district heating system, operated by the Glenelg Shire Council. Bore water at 58°C was drawn at a rate of 90 liters per second from 1,400 meters in the Dilwyn Formation aquifer of the Otway Basin. The water was used between 1985 and 2006 to heat council buildings, a hospital, a police station, a motel and a public swimming pool. The capacity of the facility was 10.4 MWt. Initially, the geothermal water was used as Portland's drinking water after passing through the heating system, but this practice was discontinued in 1997 due to water quality concerns. Ironically, between 1997 and 2006 the spent geothermal water was air-cooled (with energy intensive fans which contributed a net positive amount of greenhouse gas to the atmosphere) and discharged to surface drainage. The system has been decommissioned since January 2006 because of the poor condition of the bore, the energy intensive cooling system, and because it was no longer deemed environmentally sustainable to discharge the spent geothermal water into surface drainage. There is growing political pressure to recommission the system, but it will require significant investment to drill a new production bore, and redesign of the system to incorporate reinjection.

Innot Hot Springs

The Innot Hot Springs (17°40'S, 145°14'E) lie in the Atherton Tablelands inland from Cairns in the state of Queensland. It is one of a handful of natural warm to hot springs that are utilized around the country for tourism purposes. The Innot Spa Resort is primarily a trailer and camping park, with an outdoor heated spa pool and three indoor heated spa pools (Figure 4). The source of the geothermal water is a 50 meter deep bore from which 70°C water is drawn. Natural hot water (also about 70°C) discharges along a short section of stream bed about 100 meters from the bore, and this natural warm "beach" has been used by visitors and locals alike for relaxation since being discovered by European settlers in the late nineteenth century. The source of the water and the heat is poorly understood, and the subject of a current research project by the Geological Survey of Queensland.

Other commercial hot spring operations are located at Maree in New South Wales, Hastings in Tasmania, Rye in Victoria (Davidson, 2006), and a new, multi-million dollar development is underway at Warrnambool in Victoria. This is not an exhaustive list, and there are early indications that a geothermal spa industry may develop.

Figure 4. The spa house at the Hot Springs Resort, Innot Hot Springs, Queensland.

Robarra Pty Ltd

Barramundi (giant perch, or Australian seabass) is a very popular eating fish native to northern Australian fresh waters. The optimum growth temperature for barramundi is about 28°C, typical of the tropical inland waters of the north. A thriving barramundi farm operates on the south coast of South Australia, however, where the average surface water temperature is around 12°C. Robarra Pty Ltd operates the farm at Robe (37°09'S, 139°45'E), utilizing warm water flowing at 30°C

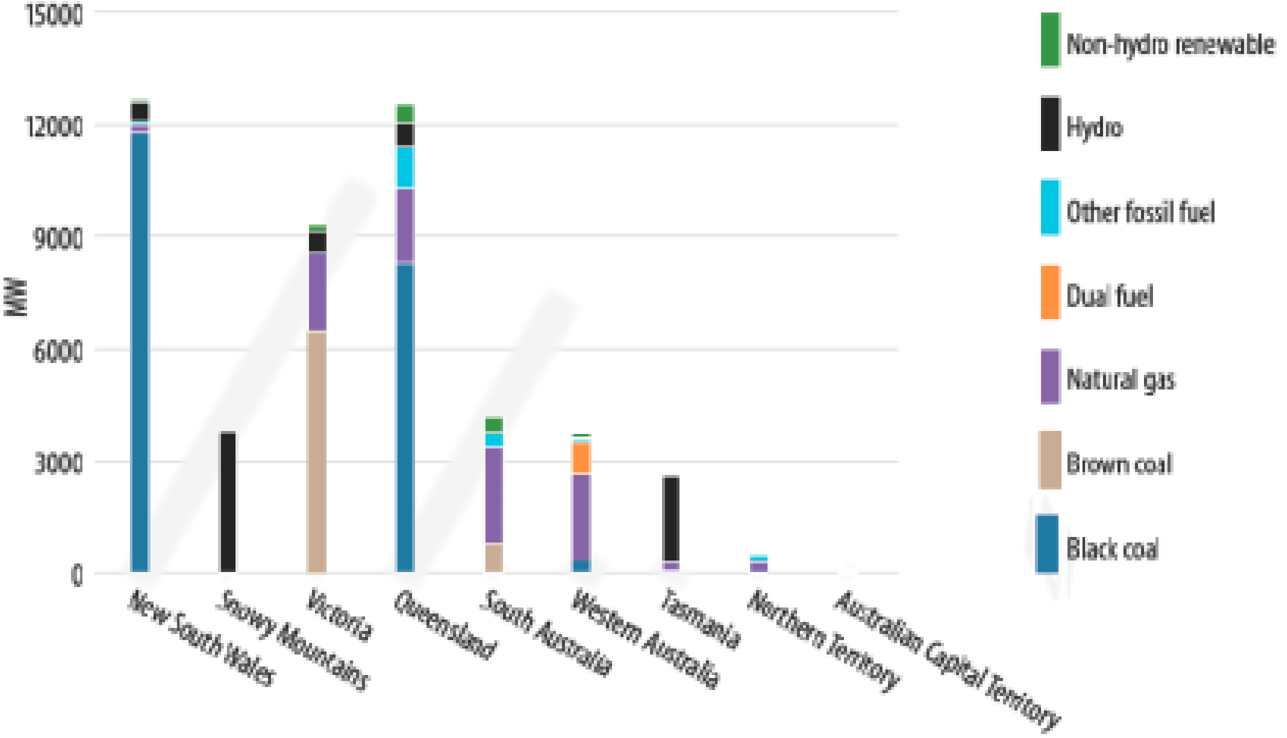

Figure 5. Sources of Australia's electricity generation, listed by state. Source CSIRO (2006).

from several hundred meters down in the Dilwyn Formation of the Otway Basin. The fresh geothermal water passes through adjustable boom jets directly into the grow out tanks. The operation provides employment for about 22 local people, and turns over about AU$2 million annually.

SOURCES OF ELECTRICAL POWER

In spite of the majority of geothermal energy being directly utilized at present, most attention is currently on developing new sources of electrical power.

Australia's electricity demand is about 50,000 MW (CSIRO 2006). About 7,000 MW is generated from renewable sources (mostly hydro and bio-waste from sugar processing facilities), but the great bulk of demand is met by fossil fuel sources; dominantly black and brown coal, but with a significant proportion of natural gas (Figure 5). This great reliance on fossil fuels for electricity generation is the primary reason that Australia rates as one of the most greenhouse gas polluting countries in the world. At 17.35 tonnes CO_2 per capita per year in 2003, it ranked fourth amongst Organization for Economic Co-operation and Development (OECD) countries (Source: OECD), behind Canada (17.49), the USA (19.68) and Luxembourg (21.96). The state of Victoria, where about 70% of electricity is generated from brown coal, is a particularly noteworthy polluter.

Australia's domestic supply of coal and natural gas is sufficient to provide electricity at current levels for over 500 years. Under the current pricing regime, the cost of electricity production from coal, in particular, is significantly lower than any current alternative. The current Federal Government, however, aims to introduce a carbon trading scheme by 2012, and such a scheme will force the coal-fired power industry to internalize the cost of carbon emissions. Several economic studies (e.g. McLennan Magasanik Associates Pty Ltd, 2006) have concluded that in a carbon-constrained economy, geothermal energy could provide the lowest cost base-load power. With demand increasing, therefore, there is scope for geothermal power to provide a significant portion of base load electricity capacity into the future.

POLITICAL SUPPORT

The Australian political system is divided into three levels; local, state and federal. Geothermal energy development is receiving significant support at all three levels. Local councils increasingly view sustainability and renewability as important parameters for development, often giving more weight to these over and above purely financial arguments. As an example, in 2006, Melbourne City Council opened Council House 2 ("CH2"), a ten story building in the heart of Melbourne (a city of three and a half million people) with energy and water efficiency as its core design feature. 22.1% of the construction cost was directly attributed to efficiency features (Melbourne City Council, 2004). While geothermal energy was not utilized in CH2, the same council incorporated geothermal heat pumps into the air conditioning system of the East Melbourne Library during a refurbishment in 2005, in spite of the premium cost of the system compared to natural gas systems.

At the state level, the Victorian Government introduced the Victorian Renewable Energy Target (VRET) scheme in late 2006. The VRET scheme requires energy retailers to purchase a minimum of 10% of their total power purchases from renewable sources by 2016. Since then, several other states have introduced equivalent schemes, with some setting more aggressive targets (e.g. South Australia's target is 20% renewable power by 2014). For geothermal energy, some states are matching legislation with financial support. South Australia and Queensland, for example, offer cost-sharing schemes to offset the cost of drilling.

The Australian Federal Government introduced the Mandatory Renewable Energy Target (MRET) in 2004. MRET requires that 9,500 GWh per year of new renewable electricity be online by the year 2010. The country is well on track to achieve this goal, largely due to strong growth in the wind energy sector. Other Federal Government schemes offering financial support to the geothermal energy sector include the Renewable Energy Development Initiative (REDI), which provides grants for renewable energy innovation and commercialization; Renewable Remote Power Generation Programme (RRPGP), which supports renewable energy in remote areas; Renewable Energy Equity Fund (REEF), which provides venture capital for small renewable energy companies. At the time of writing, six geothermal energy companies have received in excess of AU$21 million total in REDI grants alone. The current Federal Government has been a strong and vocal supporter of the geothermal energy industry, and, with a Federal election due by the end this year, the current Opposition Party has also indicated that, if elected, it will continue support for the industry, with AU$50 million earmarked for direct cost-sharing of deep drilling programs.

The Federal Government's geoscience institution, Geoscience Australia, operates out of a building in Canberra that utilizes geothermal heating and cooling.

COMMERCIAL GEOTHERMAL INDUSTRY

At the time of writing there are six companies listed on the Australian Stock Exchange (ASX) with geothermal energy development as one of their core activities. A seventh company is currently in the middle of an IPO, and several others are preparing to follow suit. The money is being raised through the public markets primarily to fund desktop analyses, surface exploration and shallow drilling programs designed to shed light on the nature of the geothermal resource in different parts of the country. About 25 individual companies hold exploration rights or have made application for over 170 exploration licenses across five states (Queensland, New South Wales, Victoria, Tasmania and South Australia.) The size of the exploration licenses range from about 100 km2 to over 12,000 km2. At the time of writing, the remaining two states of Australia (Western Australia and Northern Territory) are in the process of developing legislation to allow geothermal energy exploration and development.

Many geothermal companies have sprung from parent companies engaged in mineral or petroleum exploration, and almost without exception the focus is on electrical power generation. The distribution of activity, in terms of numbers of exploration licenses applied for and granted, is strongly influenced by state boundaries, with by far the most activity in South Australia (99 licenses granted, 39 current applications, and 10 retention licenses). This is due in equal parts to attractive geology and an accommodating State Government. The Department of Primary Industries and Resources, South Australian (PIRSA), has actively encouraged the growth of a geothermal industry centered on South Australia; with generous drilling subsidies, a simple application procedure for licenses, easily and freely accessible data packages, and by assuming a leadership role in coordinating the growth of the industry.

The range of exploration and development strategies is almost as wide as the list of companies in the industry is long, but a small number of case studies will serve to illustrate the different strategies being pursued. Listed companies Geodynamics Limited, Petratherm Limited, Green Rock Energy Limited and Torrens Energy Limited each have very different development strategies. The following summaries also highlight the international expansion of a number of Australian companies.

Geodynamics Limited

Geodynamics (GDY) is the leading geothermal energy development company in Australia by any objective measure. The company was the first to list on the ASX, is most advanced in its development, has the highest market capitalization on the ASX (AU$286.5m), and receives (arguably) the most media attention. The company holds two exploration licenses and 10 retention licenses (allowing them to maintain development rights for up to 15 years) in South Australia, but GDY's only project is near Innaminka in northeast South Australia. It is an engineered geothermal system project to extract power from 250°C granite at a depth of about 4,500 m. The company has successfully drilled a well (Habanero 1) into the granite to target depth, performed hydraulic stimulation to enhance the natural fracture network, and drilled a second well (Habanero 2) to intersect the fracture network. Unfortunate engineering difficulties resulted in the effective loss of Habanero 2 and set the project back almost two years. At the time of writing, however, drilling has commenced on Habanero 3 and the company is confident about achieving hydraulic connection with Habanero 1 within a few months. Their business plan calls for 40 MW of electrical power generation by 2010, with rapid expansion to at least 500 MW.

The major perceived barrier to commercial success for GDY lies in the geographic location of their project. Innaminka is at least 400 km from the nearest point on the national electricity grid, and substantial capital will be required to transmit generated electricity to the market.

This dictates that GDY's development will ultimately need to be several hundred megawatts capacity if they are to operate profitably, but the size of their resource will comfortably accommodate such output if the technology can be proven. GDY also has a subsidiary company (Exorka International Limited, now based in Germany) dedicated to the commercialization of the Kalina Cycle technology that will be utilized in the Habanero project.

Figure 6. Drilling of Haanero I in the Cooer Basin (Geodynamics, Ltd.)

Petratherm Limited

Petratherm Limited (PTR) holds nine exploration licenses in South Australia, has a subsidiary company exploring development opportunities in Spain, and has been endorsed by both the Australian and Chinese governments to investigate the development of hot rock technology in China. PTR was the second geothermal company to list on the ASX and has a market capitalization of AU$46m. Their main project lies at a locality called Paralana in South Australia. Their single test hole to this stage (Paralana 1) is about 1,800 m deep, and they have demonstrated levels of heat flow more than sufficient to generate attractive geothermal temperatures at depths less than 4 km. PTR aims to deepen Paralana 1 and use it to stimulate the development of an underground heat exchanger within the sediment column.

Paralana, like Innaminka, lies off the national electricity grid, but close to a major energy user in the Beverley uranium mine. PTR have signed a power purchase agreement with the operators of the Beverley mine, which values electricity generated at Paralana at a higher price than the normal national electricity price. This will allow PTR to receive a premium rate for generated electricity during their early commercialization stage, which will help them fund growth to the point where they can connect to the grid and compete on the national market.

Green Rock Energy Limited

Green Rock Energy Limited (GRK: market capitalization AU$20 million) holds a range of geothermal exploration tenements in South Australia; around the world's largest Uranium mine at Olympic Dam, around the top of the Spencer Gulf, and in the Cooper Basin. An early entrant into the geothermal industry in Australia, GRK is geographically positioned to take advantage of the enormous power requirements of a proposed four-fold expansion of the Olympic Dam mine. The company has drilled a 1,900 m deep hole into a granite body in their Olympic Dam area and demonstrated an attractive heat resource and stress regime for the development of an engineered geothermal system within the granite.

As well as its Australian interests, GRK also holds 32% equity in a combined heat and power development in Hungary. There, they are seeking high flow rate fluids of about 140°C. The company's initial drilling operation in Hungary achieved disappointing results from the point of view of observed fluid flow rates, but the project was the inaugural recipient of World Bank geological risk insurance for geothermal development in Eastern Europe. As such, GRK should receive much of their invested capital back, to reinvest in further exploration in Hungary.

Torrens Energy Limited

Torrens Energy Limited (TEY: market capitalization AU$18 million) has the stated objective to find the hottest rocks possible close to population centers and on the national electricity grid. TEY achieved first mover advantage in recognizing the geothermal potential of a geological feature known as the Adelaide Geosyncline, part of which lies under the city of Adelaide, capital of South Australia. TEY were recently awarded a AU$3 million REDI grant to undertake a drilling program and develop computer software to accurately model the temperature resource beneath their tenements. TEY also holds an exploration license under the northeastern suburbs of Melbourne, Australia's second largest city. They also intend to investigate the possibility of using geothermal energy to desalinate seawater.

The Australian Geothermal Energy Group

The geothermal industry in Australia is in the process of forming one or more collaborative organizations. At the time of writing, over forty companies, organizations and institutions are involved in a loose collaboration called the Australian Geothermal Energy Group (AGEG). AGEG has coalesced from a broad range of interested parties under the umbrella of Australia's involvement in the International Energy Agency Geothermal Implementing Agreement (IEA-GIA). The group is Chaired by PIRSA and includes commercial entities, state and federal government organizations, universities and research institutions.

To date, the geothermal sector has been unofficially represented in Canberra by the Renewable Energy Generators Association (REGA), but this situation is now considered unsustainable with geothermal's increasingly high profile and number of commercial participants. At the time of writing, the commercial partners within AGEG are exploring the possibility of incorporating an industry association with a full time secretariat and political lobbying as part of its role.

Australian company Geodynamics Limited leads the Enhanced Geothermal Systems Annex of the IEA-GIA, at least three Australian companies have interests overseas, and the first Australian (the author) has just been elected to the Board of Directors of the International Geothermal Association. As a country, Australia looks set to play an increasingly important role in geothermal energy development on the global stage.

Note: AU$1 = 0.827 US$ = 0.600 Euro

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