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Australia — Country Update

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ABSTRACT

What a difference five years makes! The past five years have seen a boom in the geothermal sector in Australia, driven by supportive government policies at State and Federal levels and the presence of attractive non-conventional geothermal targets. The Australian continent has historically been thought of as 'cold', due to its location in the middle of a tectonic plate. In spite of this, however, it plays host to world class 'hot dry rock' prospects, has the world's largest hot artesian basin, and a significant number of identified shallow and deep hot sedimentary aquifers.

As of September 2009, the Birdsville geothermal power plant accounts for Australia's entire geothermal power output, generating 80 kWe net electrical power from a 98°C artesian well in Central Australia. By the time of the WGC2010, however, it is conceivable that one or more companies will be generating several megawatts of electrical power from Engineered Geothermal Systems and/or hot sedimentary aquifer resources. By the time of WGC2010, also, all states and territories in Australia will have introduced specific legislation to allow for the exploration and/or development of geothermal resources. While activity is currently concentrated in the state of South Australia, several projects are well advanced in other parts of the country.

As well as power generation, focus has also turned to direct use applications for Australia's substantial low temperature geothermal resources. A number of new direct-use projects have come online since WGC2005 and this paper highlights a few of them. Likewise, ground source heat pumps are being installed in greater numbers than at any time in the past.

With supportive government policies, extensive prospects, a large number of companies and an environment of cooperative research, the future for non-conventional geothermal energy in Australia appears bright.

1. INTRODUCTION

1.1. Geothermal legislation

The Commonwealth of Australia (Figure 1) is a federation of states and territories. Under the constitution of Australia, mineral rights belong to the states, and regulation of geothermal resources also falls under the control of the states. The different approaches taken by the different states in terms of geothermal legislation has had a significant impact on the amount of activity seen in each state.

In Western Australia, The Petroleum Amendment Act (2007) was introduced to amend the Petroleum Act (1967) to provide for the exploration and recovery of geothermal energy. The amended Act is known as the Petroleum and Geothermal Energy Resources Act (2007). It allows the Western Australian Government to progressively release blocks of land for open tender. As of May 2009, three acreage releases have resulted in a favorable response from industry, with in excess of $560 million in work program commitments forecast for the next 6 years. The fourth and last block of acreage was releases in September 2009.

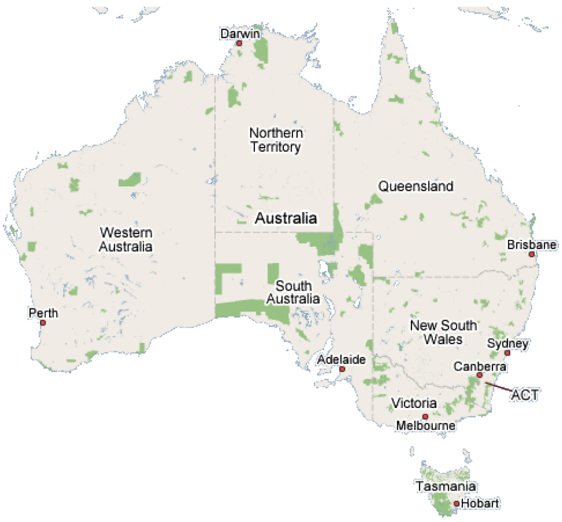

Figure 1. The Commonwealth of Australia, showing state and territory boundaries and capital cities.

The Petroleum Act (2000) regulates geothermal resources in South Australia, although a new Petroleum and Geothermal Act was close to being enacted as of September 2009. The Petroleum Act (2000) allows 'over the counter' applications for geothermal licenses and this flexibility for individual companies to decide for themselves where the prospective areas are has been one of the key drivers for the high number of applications for exploration licenses in South Australia. The new Act will be very similar in intent.

The Geothermal Energy Resources Bill (2005) governs exploration for geothermal resources in the state of Victoria. The Bill allowed the state government to release blocks of land across the entire state for open tender. In September 2009, 23 out of a possible 31 blocks were under license.

Geothermal resources are classified as 'Category 6' minerals under the Mineral Resources Development Act (1995) in Tasmania. The Act allows 'over the counter' applications for licences. This has resulted in a large proportion of the state being licensed for exploration.

In New South Wales, the Mining Act (1992) defines a geothermal substance as "any substance occurring naturally underground that is heated by the natural processes of the earth to a temperature in excess of 100°C.” The Act allows ‘over the counter’ applications but the associated license fee structure and issues with overlapping minerals (especially coal) licenses are possible reasons for the low number of applications compared to other states.

The Geothermal Exploration Bill (2004) treats geothermal energy as a specific and unique ‘substance’ in Queensland. The bill facilitates exploration for geothermal energy through a tender process on areas selected by the Queensland Government. Development and exploitation will be dealt with by new legislation, expected by the time of WGC2010. As of May 2009, only one exploration license had been granted in Queensland, although many more were under application.

A Bill to facilitate and regulate the exploration and extraction of geothermal energy in the Northern Territory was passed by Parliament in 2009 and should be active by the time of WGC2010.

1.2. Financial support from Governments

By May 2009, the geothermal sector had received financial support from governments at Federal and State levels to a combined value of AU$112 million. At the Federal level, Geodynamics received AU$2 million in 2005 under the Greenhouse Gas Abatement Program to build a 13 MWe ‘Kalina Cycle’ waste heat power plant at Mt Keith in Western Australia (completion of this project awaits work by the operator of the Mt Keith Mine). The now superceded Renewable Energy Development Initiative granted a total of AU$22.4 million to seven different geothermal projects between 2005 and 2007. The current ‘Geothermal Drilling Program’ (GDP) is a AU$50 million fund committed by the current Australian Government to help offset the high cost of deep geothermal appraisal drilling. As of September 2009, two grants of AU$7 million each have been awarded from the fund.

At the state level, South Australia committed AU$2.5 million to geothermal projects between 2005 and May 2009 through various grant and funding schemes. In November 2008, Geodynamics Ltd received a grant of AU$10 million from the NSW Climate Change Fund Renewable Energy Development Program to develop its Hunter Valley Project. Victoria awarded $230,000 to the ‘Mantra—Deep Blue’ resort project (see Section 4.3) from its Renewable Energy Support Fund. Other state governments have provided support for geothermal in the form of research grants and seed funds for research centers, as described in the following section.

1.3. Geothermal research

A number of Australian universities have developed geothermal research groups in the past few years. In July 2007, the South Australian Government committed AU$500,000 to the University of Adelaide as seed funding for a ‘Research Centre of Excellence in Geothermal Energy’. A further AU$1.6 million was pledged in early June 2009 to support full-time staff and research projects over two years. In September 2007, the University of Queensland received a AU$15 million grant from the Queensland Government to set up the ‘Queensland Geothermal Energy Center of Excellence’. In February 2008, Western Australia followed suit with the WA Government announcing AU$2.3 million for a ‘Western Australian Geothermal Centre of Excellence’ to be co-hosted by the University of Western Australia, Curtin University and the *Commonwealth Scientific and Industrial Research Organization* (CSIRO). Although not supported by any targeted government assistance, the University of Melbourne, University of Tasmania, Newcastle University, RMIT University and others are also pursuing geothermal research programs.

Australia joined forces with the United States and Iceland in August 2008 to sign the Charter Agreement for the *International Partnership for Geothermal Technology* (IPGT). The purpose of the IPGT is to accelerate the development of geothermal technologies such as engineered geothermal systems and supercritical systems through international cooperation.

1.4. Investment by geothermal companies

Perhaps uniquely in the world, the identification and development of geothermal energy resources in Australia is largely being driven by the commercial sector. Features of the regulatory framework across all Australian states and territories ensure that this is a particularly transparent process. In all jurisdictions, data collected for geothermal exploration must be submitted to the regulator and becomes public, typically after a period of two to three years. In combination with the requirement for public reporting by ASX listed companies, the dissemination of knowledge amongst the industry is quite high. Financial, engineering and exploration achievements and difficulties are all regularly reported to the market, forming a valuable database of knowledge not only for the Australian market, but also for the rest of the world.

The industry is forecast to spend about AU$182 million on exploration and development in 2009, bringing total expenditure over the past five years to about AU$486 million.

1.5. Geothermal organizations

Australia recommenced its membership in the *International Energy Agency’s Geothermal Implementing Agreement* (IEA-GIA) in November 2005. Since then, two organizations have emerged to coordinate sector-wide activities. The Australian Geothermal Energy Group (AGEG) and the Australian Geothermal Energy Association (AGEA) have overlapping membership and complimentary aims.

AGEG is a collegiate body composed of companies, government agencies and academic institutions with a common interest in progressing geothermal energy development in Australia. AGEG was formed to provide support for Australia's membership in the IEA-GIA. In August 2009, AGEG became a legally incorporated body. Its aims include:

—facilitate engagement with the international geothermal community;

—foster the commercialization of Australia's geothermal energy resources;

—cooperate in research and studies to advance geothermal exploration, proof-of-concept, demonstration projects;

—cooperate to develop, collect, improve and disseminate geothermal related information;

—identify opportunities to advance geothermal energy projects at maximum pace and minimum cost;

—disseminate information on geothermal energy to decision makers, financiers, researchers and the general public.

Launched in November 2007, AGEA is the national association of the geothermal industry. Its members are exploration, development and service companies with a predominant interest in geothermal energy. AGEA's mission is to foster and accelerate the development and commercialization of Australia's geothermal energy resources by:

—clearly and accurately articulating the advantages of geothermal energy and the progress of the industry;

—cooperating across the industry to develop, collect, improve and disseminate information about geothermal energy; and

—developing good and constructive relationships with government, the investment community and the broader Australian community.

2. GEOLOGY BACKGROUND

Continental Australia lies wholly within the Indo-Australian tectonic plate. No active plate boundaries encroach onto the land surface. Large earthquakes are limited to intra-cratonic events. Most surface thermal features are clearly of artesian origin and none have yet been shown to have a volcanic origin. The age of the crust across most of the country is such that the heat of crustal formation should have dissipated long ago. Australia is barren of conventional high enthalpy hydrothermal geothermal energy resources.

There are, however, geological features of the country that make it prospective for low enthalpy and unconventional geothermal resources.

Australia can be broadly divided into three provinces based on the age of the underlying basement (Figure 2). In the west, the Western Shield Province is characterized by Achaean aged crust. Through the middle of the country the Central Shield Province is composed of Proterozoic crust. The relatively young crust of the Eastern Province is of Phanerozoic age.

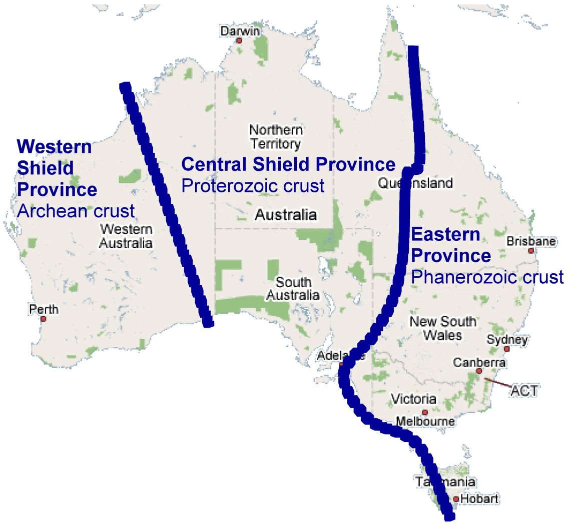

Figure 2. Broad divisions of the Australian continental crust, based on basement age.

Although old when compared to most other parts of the Earth's crust, large sections of Proterozoic crust in the Central Shield Province have been shown to host unusually high concentrations of heat producing radioactive elements such as uranium and thorium (McLaren *et al.*, 2003). As well as giving Australia the world's largest uranium mine (Olympic Dam in South Australia), this unusual chemical enrichment also keeps the crust warmer than it otherwise would be. Heat flow values are much higher through central Australia than might normally be expected for a terrane of that age (Cull, 1982).

Most of the Australian continent is in a state of tectonic compression (Hillis and Reynolds, 2000), consistent with plate boundary forces arising from a complex collision of the Indo-Australian plate with South East Asia. The direction of maximum compressive stress rotates from a roughly NE–SW trajectory in the north of the country to E–W in the southwest, to NW–SE in the southeast.

The eastern portion of Australia has experienced regular volcanism throughout the Tertiary era (Figure 3). For example, Mount Fox in Queensland erupted as a pyroclastic cone about 560,000 years ago (http://www.ga.gov.au /archive/volcanoes/GA0763.jsp), while charcoal from beneath basalt flows at Mount Schank in South Australia has been dated at about 18,100 years (Sheard, 1990). Similar tests from nearby Mount Gambier suggest ages as young as 4,700 year (Sheard, 1990). While there is a general younging of events from north to south, the trend does not fit a model for a mantle hot spot and the underlying cause of the volcanism is still a topic of some debate.

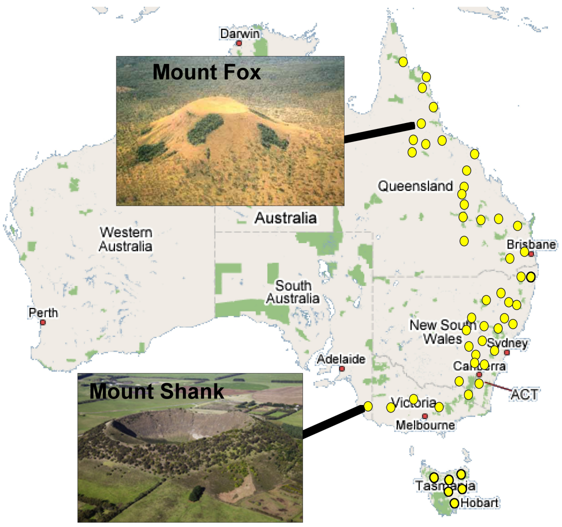

Figure 3. Locations (yellow) of Tertiary-aged volcanic eruption centers in eastern Australia.

Seismic tomography data have shed some light on a potential source of the volcanic material. Low seismic velocity anomalies that may indicate parts of the upper mantle with elevated temperature have been interpreted beneath southern Queensland, the south coast of Victoria, and northeast Western Australia (Saygin and Kennett, in press; Graeber *et al.*, 2002). Some of these anomalies coincide with known regions of elevated heat flow.

From a geothermal perspective, no surface thermal manifestations have been identified in association with the volcanism. This is surprising for a volcanic zone with hundred of identified vents arising from eruptive events spanning several million years, with the most recent only a few thousand years ago. One possible explanation is the fact that the youngest surface features coincide with regionally extensive shallow unconfined aquifers in southeast Australia. These aquifers may ‘wash away’ any steam or hot water discharge before it reaches the surface. The same aquifers also effectively mask the underlying heat flow over much of region, hindering the exploration for geothermal resources.

Much of the country is overlain by Phanerozoic sedimentary basins of various size and depth. While some of these are filled with highly silicic material, others contain large amounts of clay and/or coal. The Gippsland Basin in the southeast of the country, for example, contains some of the world’s largest deposits of brown coal, while basins throughout New South Wales and Queensland are well endowed with black coal. These basins provide excellent thermal insulation to retard the flow of heat to the surface and elevate average thermal gradients.

3. GEOTHERMAL RESOURCES AND POTENTIAL

Estimates of the geothermal resource potential of Australia are based on ‘stored heat’ assessments for EGS developments. As such, the derived numbers are large. For example, Budd *et al*. (2007) used a stored heat method to estimate a resource base of 1.9×10^{10} petajoules (6.0×10^{11} MWt.Yrs) of heat between the 150°C isotherm and 5,000 m depth. Just one percent of that heat is equal to 26,000 years of Australia’s primary energy usage in 2004!

Geothermal resources in Australia generally fall into the categories of engineered geothermal systems (EGS), hot sedimentary aquifers (HSA) and shallow warm aquifers. Figure 4 shows the locations of exploration licenses across the country in early 2009, which roughly correlates to the distribution of the most promising resources, as perceived by the industry.

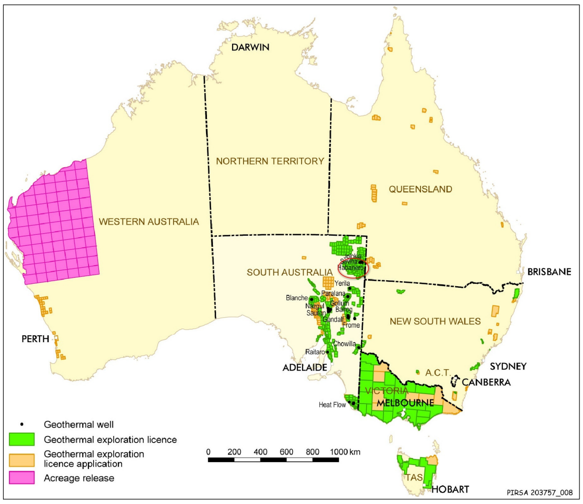

Figure 4. Australian exploration licenses, applications and acreage releases as of April 2009. Red oval in central Australia marks the Cooper Basin.

Radioactive Proterozoic granitic bodies outcrop and subcrop in a wide band running north to south through the center of the continent. Where these granites lie beneath layers of thermally insulating sediments, they are capable of generating anomalously high crustal temperatures in purely conductive heat flow terranes. This is one of the most popular exploration concepts through central Australia, and radioactive granites are also known to outcrop in Victoria, Tasmania and Western Australia.

Australia hosts one of the world’s largest artesian basins. The Great Artesian Basin (GAB) covers about one fifth of the continent and straddles the states of Queensland, New South Wales, South Australia and the Northern Territory (Figure 5). Where drilled, the main aquifer of the GAB discharges water at up to 100°C (Habermehl and Pestov, 2002). In May 2009, this resource supplied Australia’s only operating geothermal power plant, at Birdsville in SW Queensland.

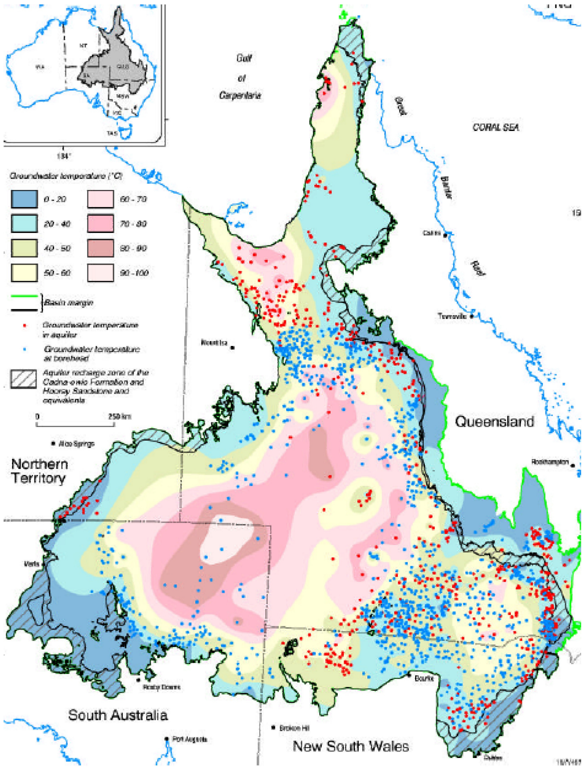

Figure 5. The Great Artesian Bain covers approximately one fifth of the Australian landmass and discharges water with well head temperatures up to 100°C. From Habermehl and Pestov (2002).

Aquifers at temperatures in the range 30–60°C are distributed throughout the country and represent an as-yet poorly utilized resource of direct geothermal heat. Arguably the best utilized resource of this kind is in the Perth Basin in Western Australia, where the Yarragadee Aquifer delivers fresh 40+°C water from depths between 800–900 m. The Otway Basin in Victoria and South Australia hosts the Dilwyn Aquifer. The depth of burial of the Dilwyn varies substantially across the basin, and that is the main determinant of the aquifer’s temperature. In the west, the Dilwyn delivers water at about 30°C from about 300 m depth. Towards the middle of the basin, however, the aquifer is at about 1,200 m and about 60°C.

4. GEOTHERMAL UTILIZATION

4.1. Present and planned production of electricity

At the end of 2009, Australia has 50,000 MWe of electricity generation capacity (Table 1). Over 80% of generation capacity (41,000 MWe) is powered by fossil fuels. Of the remainder, 7,800 MWe comes from hydro and 1,700 MWe from a combination of wind, biomass and biogas. Geothermal contributes just 80 kWe.

A further 8,000 MWe is under construction in 2009. This is composed of 2,300 MWe of wind and solar, and 5,800 MWe of new fossil fuel capacity. 140 MWe of new hydro is under construction, and Geodynamics Ltd's 1.0 MWe geothermal pilot plant is close to commissioning. By 2015 as much as 100 MWe of geothermal capacity may have been commissioned around the country.

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

The Birdsville geothermal power plant is Australia's only operating source of geothermal electric power in Australia at the end of 2009 (Table 2). The organic rankine cycle binary plant operates on 98°C water flowing at 27 liters per second from a 1.2 km deep well to generate a net 80 kWe. Ergon Energy, the operator of the plant, is considering plans to drill a new high-capicity bore and to increase the capacity of the geothermal plant to more than 300 kWe.

In September 2009, Geodynamics Ltd was close to commissioning a 1.0 MWe pilot plant at its Habanero EGS project near Innamincka in South Australia. The 1 MWe plant is the first stage in a planned 40 MWe initial development at the site.

4.3. Utilization of geothermal energy for direct heat as of 31 December 2009 (excluding heat pumps)

Australia's only geothermal district heating system, at Portland in Victoria, was unfortunately decommissioned in 2006 for environmental reasons (spent water was being discharged into a surface stream). This system constituted a large proportion (92%) of Australia's total estimated consumption of direct geothermal heat in the 2005 'Country Update' (Chopra, 2005). Consequently, the total estimated direct heat use is now lower.

In spite of this, geothermal energy is increasingly being recognized as a cheap source of thermal power around Australia (Table 3). For example, the Yarragadee Aquifer in the Perth Basin in Western Australia is utilized for a number of direct heat purposes. The public swimming pool in the Perth suburb of Claremont draws 43°C water at up to 13.7 liters per second from an 864 m deep bore. The water is passed through a heat exchanger to maintain a constant pool temperature of 26.5°C. Spent geothermal water is reinjected into the same aquifer at 29°C. The system utilises about 15.3 TJ of thermal energy per year at a capacity factor of 0.61. Similar systems operate from the same aquifer to heat swimming pools in the suburbs of Christchurch and Craigie, and at the sporting arena 'Challenge Stadium'. Geothermal energy is also used to heat domestic hot water at the arena.

At Robe in South Australia, barramundi (edible tropical freshwater fish) are grown in tanks that hold fresh geothermal water pumped directly from a 335 m deep bore in the Dilwyn Aquifer. The water comes from the bore at 29°C, in the optimal temperature range for growing barramundi, and provides over 43 TJ of thermal energy per year. The company *Robarra* employs 22 local people and has earns annual revenue of AU$2 million.

In Victoria, *Mainstream Aquiculture* operates a barramundi farm at Werribee, using 28°C fresh geothermal water directly to grow the fingerlings. *Midfield Meats* in Warrnambool uses geothermal water for washing down and sterilizing its industrial meat processing facility. At the *Mantra—Deep Blue* geothermal spa resort at Warrnambool, a 735 m bore produces 43°C water at a maximum of 50 liters per second. The bore provides the resort's domestic hot water and heats the resort's 122 rooms via a system of hydronic radiators. The geothermal water is projected to provide the resort with annual fuel savings of $40,000 and annual water/heat sales of an additional $60,000 (Sustainability Victoria media release, 9 November 2007).

At Rye, on the Mornington Peninsula close to Melbourne, the *Peninsula Hot Springs* spa resort draws 45°C water at an average of 4.5 liters per second from the Mepunga Formation at 637 m. At the time of writing (September 2009), the resort was undergoing a major expansion with ultimate plans for accommodation, aquiculture, green houses, space heating and balneology in a cascaded use of the geothermal resource drawing up to 50 liters per second.

Around the rest of the country, a number of recreational swimming and bathing centers use natural warm/hot spring water ranging in temperature from 28°C (Hastings, Tasmania) to 72°C (Innot Hot Springs, Queensland; Figure 6). The artesian geothermal water at Hastings is used in a single outdoor public swimming pool after passing through a filtration and chlorination system. The water at Innot Hot Springs is produced from a 56 m deep bore and warms a series of spas, pools and baths before being discharged into a cooling pond at the rear of the property. Other locations around the country where artesian water is utilized for bathing purposes include Moree (New South Wales; 41°C), Pillaga (New South Wales; 37°C), Lightning Ridge (New South Wales; 41.5°C), Mataranka (Northern Territory; 34°C) and Dalhousie Mound Springs (South Australia; 38–43°C), though this list is not exhaustive.

Figure 6. Outside the Innot Hot Springs, Queensland.

Utilization rates are difficult to determine for most of the springs measures above. Many discharge to the surface and 'outlet' temperatures are unrecorded. For others, the flow rate is poorly constrained. Table 3 includes all information available at the time of writing.

4.4. Geothermal (ground source) heat pumps as of 31 December 2009

The *Geoscience Australia* (GA) building in Canberra (ACT) remains the country's largest ground source heat pump (GSHP) installation (Table 4). The system supplies 2,500 kW of thermal power to 210 'Water Furnace Premier' ground source heat pump units of various capacity within a building with a floor space 40,000 m^2. The ground loops are arranged in 44 sets of eight vertical boreholes (total of 352 boreholes) drilled to 104 m depth in ground with an undisturbed temperature of 18.2°C. These loop-sets are connected to four flow and return headers in the plant room, each with its own primary circulating pump. The four pumps reject or extract heat evenly across the entire loop field.

There are three geothermal heat pump suppliers and installers presently operating in Australia. Statistics are not kept for all GSHP installations, but the company *Geoexchange Australia Pty Ltd* is one of the leading installers of GSHP systems and lists the following case studies (no distinction is made between GSHPs and water source heat pumps):

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

Australian Capital Territory—ACTEW Corporation, Geoscience Australia, Duntroon Military Headquarters, Airport Caltex (Pialligo), Australian National University Research Laboratory.

Tasmania—Grand Chancellor Concert Hall (Hobart), Queen Victoria Museum and Art Gallery (Launceston), Southern Cross Homes/Aged Care (Moonah), Antarctic Centre (Hobart), Westpac Call Centre (Launceston), Hobart Aquatic Centre (Hobart).

Victoria—Victoria University of Technology (Werribee), Paynesville Pool (Paynesville), Station Pier (Port Melbourne), Wangaratta High School, Monash University (Melbourne), Bandiana Army Logistic Training Center.

South Australia—Royal Adelaide Hospital, Bureau of Meteorology (Kent Town), Garden East Apartments (Adelaide), Coober Pedy Police Station, Mt Barker college of Technical and Further Education ('TAFE').

Queensland—University of Southern Queensland swimming pool (Toowoomba), Logan Institute of TAFE.

Northern Territory—Bureau of Meteorology (Darwin).

4.5. Summary of geothermal direct heat use as of 31 December 2009

Unfortunately, the absolute energy usage for direct heat and ground source heat pumps in Australia is very poorly constrained. The data are not routinely collated by any central organization. The authors of this paper have been able to collect the necessary data for a number of individual projects, but most remain unmeasured. The best-constrained are the set of swimming pools heated by geothermal water from the Yarragadee Aquifer in the Perth Basin (Table 5). Those projects have a combined heating capacity of 7 MWt, and consume a total of 62 TJ of thermal energy per year at a combined capacity factor of about 0.28.

Figure 7. The principal author (back-right) and students assessing the heating capacity of one of the pools at Peninsula Hot Springs spa report, Victoria.

4.6. Wells drilled for electrical and direct use of geothermal resources from 1 January 2005 to 31 December 2009 (excluding heat pump wells)

The 'Country Update' presented for Australia at the 2005 World Geothermal Congress in Antalya, Turkey, detailed just three geothermal exploration wells drilled between 2000 and 2005 (Chopra, 2005). Those wells summed to a total depth of 10.7 km. In the subsequent five years, geothermal exploration in Australia has accelerated. At the time of writing (September 2009), completed and planned geothermal drilling in Australia from 1 January 2005 to 31 December 2009 amounts to at least 84 wells with a total depth of 58.8 km (Table 6).

The majority of wells in the past five years have been drilled to explore for resources suitable for electricity generation. Many of these have been relatively shallow (<600 m) 'gradient wells' or 'heat flow wells', but a small number have been (or are planned by the end of 2009) deep appraisal wells. All deep wells are in South Australia.

Since 2005, Geodynamics Ltd has added three more wells to its previous two in the 250°C, fractured granodiorite beneath the Cooper Basin. Habanero 3 reached 4221 m and became (with Habanero 1) part of the closed-loop circulation test successfully completed by Geodynamics early in 2009. In addition, Jolokia 1 was drilled to 4,911 m and Savina 1 to 3,700 m.

Petratherm Ltd and Panax Ltd each plan to drill wells to 4,000 m depth in the second half of 2009 in order to intersect and appraise potential geothermal reservoir formations near Penola (Panax well Salamander 1) and Paralana (Petratherm well Paralana 2). A new rig mobilized into Australia specifically for geothermal drilling will drill both these wells.

Petratherm Ltd, Green Rock Energy Ltd and Geothermal Resources Ltd all drilled wells to between 1500–2000 m depth to appraise the thermal state of their respective project areas at Olympic Dam, Paralana and Frome. Torrens Energy Ltd commenced drilling a 1500–2000 m well at its 'Parachilna Play' in May 2009.

More than 60 shallow 'gradient wells' or 'heat flow wells' have been drilled, or are planned, between the start of 2005 and the end of 2009. Scopenergy Ltd drilled the first three of these wells in 2005 in its exploration licenses in southeast South Australia—they reached depths of 392 m, 437 m and 532 m. KUTh Energy Ltd completed the most extensive shallow drilling survey, sinking 36 wells to about 250 m in eastern Tasmania. Torrens Energy Ltd completed seven wells (one co-funded by a minerals exploration company) to 400–600 m and one to 1,002 m (also co-funded) in South Australia prior to June 2009, and planned 10 similar wells in the remainder of 2009. Geothermal Resources Ltd completed six wells to 250–500 m prior to drilling its two deeper wells at Frome. Eden Energy Ltd and Granite Power Ltd each drilled at least one 'heat flow well' in their respective license areas in South Australia and New South Wales.

A number of direct use projects in Victoria and Western Australia drilled production and injection wells in the five years 2005–2009. These included the *Mantra—Deep Blue* and *Peninsula Hot Springs* spa resorts in Victoria, and a number of swimming pool heating projects in Western Australia.

4.7. Allocation of professional personnel (with university degree) to geothermal activities

Detailed employment statistics are not recorded for the geothermal sector in Australia, but significant growth has taken pace over the past five years. For the year 2004, Chopra (2005) estimated a total of 15 professional-person-years of employment dedicated to geothermal in Australia. The authors estimate professional employment within the sector in 2009 at 198 person-years (Table 7).

The private sector is the largest employer of professional personnel. Total professional employment in the private sector is estimated at 153 person-years for 2009. Geodynamics Ltd alone employs approximately 70 people, at least half of whom are estimated to hold university degrees. Petratherm Ltd is the next largest single employer, with 12 full-time professional staff. Specialist geothermal consultancy *Hot Dry Rocks Pty Ltd* employs 11 professional geoscientists. The forty-six remaining exploration license holders form a mixed group in terms of size, but generally range from 1–4 effective full time professional staff. Taken as a whole, they represent about 90 full time positions. Assorted service companies account for the remaining estimated employment numbers.

In the public sector, only one utility (Ergon Energy, Queensland) operates a geothermal power plant, requiring the equivalent of a single full-time professional to manage. Legislative and regulatory bodies at State and Federal level, however, maintain full-time staff focused on geothermal. The Department of Primary Industries and Resources (South Australia) employs approximately six equivalent full-time professional staff for geothermal. Other states average about two staff. In addition, GA and the CSIRO each have geothermal research groups. GA's group has about six people.

A number of universities have developed geothermal research groups over the past two to three years (Section 1.3). Each of these groups supports full-time academic staff and varying numbers of graduate students. The University of Queensland is the largest group, with about four effective full-time positions in geothermal. At least 10 other universities support staff members who commit varying amounts of time to geothermal pursuits.

A small number of foreign consultants are called upon at various times by companies operating in Australia. These probably amount to about five at any one time.

The growth in employment in geothermal has taken place at different rates and at different times for the different sectors. Employment in the private sector has grown almost exponentially over the past five years as awareness of the potential of the resource has spread through the market. Growth in the public sector has been more linear, with required legislative and regulatory work and staffing preceding commercial investment. Most states now have their regulations and basic staff in place but employment growth is predicted to increase at a steady pace to regulate the increasing number of development projects.

University research groups were relatively slow to develop, and it has only been in the past two years that strong growth in employment numbers has been seen there. We predict continued strong growth as the private sector increasingly looks to the universities to undertake the basic and applied research required to commercialize Australia's geothermal resources.

Over the past five years, we estimate that approximately 477 person-years of employment have been supported by the geothermal sector, up from 38 person-years in the period 2000–2004 (Chopra, 2005). We predict further strong employment growth in the future.

4.8. Total investments in geothermal for 2005–2009

Approximately AU$486 million has been spent (or is committed) for geothermal exploration and development in Australia in the period 2005–2009. Assuming a mean exchange rate of AU$1.00 = US$0.70, that equates to about US$340 million (Table 8). This compares to US$26.7 million reported for the five-year period 2000–2004 (US$23.5 million quoted by Chopra, 2005, adjusted for 13.8% growth in CPI over the intervening five-year period).

The thirteen-fold increase in expenditure reflects the significant increase in activity in the geothermal sector over the past five years. Of the US$340 million expended, approximately US$265 million has been spent by Geodynamics Ltd to begin development of the Habanero, Jolokia and Savina geothermal plays. Exploration by the rest of the industry for geothermal resources capable of supporting electricity generation accounts for most of the remaining US$75 million. Expenditure on drilling and development of resources for direct use probably amounted to about US$1.4 million.

The bulk of the funds (~92%) for these activities have come from private sources. The approximately 8% of direct funding from public sources took the form of renewable and clean energy development grants, and drilling subsidies. Many of the companies involved may have been eligible for tax concessions for the 'research and development' components of their projects, but these amounts are difficult to quantify.

5. DISCUSSION

The geothermal sector is receiving good legislative and regulatory support from governments at both State and Federal level, but activity on the ground is being driven by the commercial sector. The relative ease of access to risk capital in Australia has allowed tens of millions of dollars to be raised on the Australian Securities Exchange (ASX) for fundamental exploration and resource characterization work. A number of listed companies have also entered into Joint Venture agreements with large utility companies to help fund the more expensive drilling components of development projects.

Arguably the most promising EGS resource in the world lies beneath the Cooper Basin in the northeast of South Australia (indicated by the red oval on Figure 4). The Carboniferous aged Big Lake Suite granodiorite underlying the Cooper Basin plays host to the most advanced EGS project in Australia, and the hottest such project in the world. A temperature of 250°C at a depth of 4,400 m has been reported by Geodynamics Ltd from this region (Vörös *et al*., 2007).

In March 2009, Geodynamics announced that ‘proof-of-concept’ had been achieved, after the successful completion of a six-week closed-loop circulation test though an underground heat exchanger engineered by hydraulic stimulation of existing fracture networks at a depth of 4,400 m. Geodynamics’ marketing material predicts generation capacity of more than 10,000 MWe within its four licenses. As of May 2009, Geodynamics is close to commissioning a 1 MWe pilot plant at its Habanero project.

In the far south of South Australia, and along the southern coast of Victoria, several companies are developing projects to exploit hot sedimentary aquifer resources. Panax Geothermal Ltd operates the most advanced of those projects, the ‘Penola Geothermal Project’, with appraisal drilling of a reservoir at about 3,500 m depth planned to commence in September 2009. Panax Geothermal aims to produce water at an average temperature of 145°C from a naturally permeable formation (Panax Geothermal, 2009).

Geographically and conceptually between Geodynamics and Panax Geothermal, Petratherm Ltd is developing a project at Paralana in the central east of South Australia to extract heat from meta-sedimentary formations. Petratherm is scheduled to begin drilling an appraisal well to a depth of 3,500–4,000 m in July 2009, to test its *Heat Exchanger Within Sediments* (‘HEWI’) concept. Initial development plans call for a 7.5 MWe plant to deliver power to the nearby Beverley Uranium Mine.

In Tasmania, KUTh Energy Ltd has concluded an aggressive program of exploratory ‘heat flow’ drilling, and has delineated an area >4,000 km^2 of elevated heat flow (>90 mW/m^2) in the east of the state. KUTh is pursuing an EGS development, targeting radioactive granite beneath an insulating layer of sediment.

Other companies such as Torrens Energy Ltd, Green Rock Energy Ltd and Geothermal Resources Ltd have also spent a considerable amount of time and effort identifying hot granite or sediment targets beneath insulating layers in South Australia.

In Western Australia, the development focus is more on direct use of known resources in the Perth Basin. Green Rock Energy Ltd is collaborating with the University of Western Australia to investigate the application of geothermal heat to cool the university’s buildings with absorption chillers.

Activity in Queensland and the Northern Territory is slow at present (May 2009) because of regulatory restrictions. Both jurisdictions are working on new legislation to be enacted before the end of 2009, which should see an increase in exploration and development activity in both states.

The service sector is also active in Australia. Geological and geophysical consultancies, equipment service providers, legal and financial partnerships, all see the geothermal sector as a new and expanding market. For example, specialist geothermal energy consultancy Hot Dry Rocks Pty Ltd has developed targeted hardware, software and methodologies to facilitate the rapid exploration, identification and quantification of geothermal resources in thermally conductive regimes.

A growing number of Australian companies are investing in overseas projects and companies. Private companies are likely pursuing their own international opportunities, but of the ASX listed geothermal companies:

—Geodynamics Ltd is a shareholder in Icelandic geothermal company Geysir Green Energy ehf.

—Petratherm Ltd is majority owner of Spanish company *Petratherm España*, which holds exploration licenses on the Canary Islands and mainland Spain. Petratherm also has an active exploration program in China.

—Green Rock Energy Ltd holds 50% of *Central European Geothermal Energy Plc* (the other 50% is held by MOL Plc), which aims to become a market leader in geothermal energy in Hungary.

—Panax Geothermal Ltd is a joint venture partner in projects in India, the Kyrgyz Republic, and Slovakia.

—Greenearth Energy Ltd is 40% owner of *PT. Geo Power Indonesia*, which aims to develop geothermal projects across Indonesia.

—KUTh Energy Ltd is building a portfolio of projects across the South Pacific region, including Vanuatu, Fiji and Papua New Guinea.

6. FUTURE DEVELOPMENT AND INSTALLATIONS

The next five years should see the emergence of a strong and profitable geothermal power industry in Australia. A number of companies will have demonstration plants generating power from EGS technology, hot sedimentary aquifers, ‘heat exchanger within sediment’, and all geothermal plays in between. Investment in overseas projects by Australian companies will increase, driven by access to risk capital via the ASX. These projects will initially be conventional geothermal targets, but will increasingly draw on Australia’s developing expertise in unconventional plays to extend the geographical range of project areas.

Shallow geothermal resources in the Perth Basin, Otway Basin and other areas will be increasingly drawn upon to supply low grade heat for space heating, a burgeoning recreational spa industrial, and industrial applications. The district heating system at Portland in Victoria is expected to be decommissioned at some point in the next few years.

The increasing availability of direct exchange ground source heat pumps (copper pipes circulating refrigerant directly underground) in the Australian market promises a substantial increase in penetration of GSHP’s into the residential market. With appropriate policy support, the market could reach 5,000 units per year.

Australia will continue its enthusiastic membership of IEA-GIA, and build on its established research links with the United States and Iceland to contribute to, and benefit from, the development of cutting edge technological solutions to the constraints that are currently limiting the uptake of geothermal energy. The unconventional projects currently under development in Australia will become the world’s ‘proving ground’ for many of these technological advances.

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Table 1. Present and planned production of electricity

	Geothermal		Fossil Fuels		Hydro		Other Renewables		Total	
	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr
Operating December 2009	0.08	0.5	41,000	206,000	7,800	16,000	1,700[1]	8,000	50,000	230,000
Under construction December 2009	1		5,800		140		2,300[2]		8,000	
Total projected for 2015	~100		47,000		7,900	18,000	4,000		58,000	

1) wind, biomass, biogas
2) wind, solar

Table 2. Utilization of geothermal energy for electric power generation as of 31 December 2009

Locality	Power Plant Name	Year Commi-miss-ioned	No. of Units	Status[1)]	Type of Unit[2)]	Total Installed Capacity MWe	Total Running Capacity MWe	Annual Energy Produced 2009 GWh/yr	Total under Constr. or Planned MWe
Birdsville, QLD	Birdsville	1992	1		B (ORC)	0.08	0.08	0.5	0.3
Innamincka, SA	Habanero	2010?	1	N	B (H2O)	1.0	0	0	
Mulka, SA	Mulka	1987	1	R	B (ORC)	0.02	0	0	
Total						1.1	0.08	0.5	0.3

1) N = Not operating (temporary), R = Retired
2) B = Binary, ORC = organic Rankine Cycle, H2O = water Rankine Cycle

Table 3. Utilization of geothermal energy for direct heat as of 31 December 2009 (excluding heat pumps)

Locality		Maximum Utilization			Capacity	Annual Utilization		
	Type[1]	Flow Rate	Temperature (°C)			Average Flow	Energy	Capacity Factor
		(kg/s)	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	
Claremont, WA	B	13.7	43	29	0.802	8.3	15.3	0.61
Christchurch, WA	B	17	42	27	1.07			
Challenge Stadium, WA	B,O	60	41	28	3.26	19	32.6	0.32
Craigie, WA	B	14	39	28	0.644	7	10.2	0.50
Robe, SA	F	96	29				43.5	
Peninsula Hot Springs, Rye, Vic	B	50	45	39	1.26	4.5	3.56	
Mainstream Aquaculture, Werribee, Vic	F	6	28					
Mantra Deep Blue Resort, Warrnambool, Vic	B,H,O	50	43				10.5	
Midfield Meats, Warrnambool, Vic	I	11.6	45					
Hastings, Tas	B		27					
Moree, NSW	B		41					
Pilliga, NSW	B	650	37					
Lightning Ridge, NSW	B		41.5					
Mataranka, NT	B	260	34					
Innot Hot Springs, QLD	B	3	72					
TOTAL		1230			5.78		116	

1) B = Bathing, swimming, balneology; O = Domestic hot water, F = Fish farming, H = Individual space heating, I = Industrial process heat

Table 4. Geothermal (ground source) heat pumps as of 31 December 2009

Locality	Ground Temp. (°C)	Typical heat pump rating or capacity (kW)	Number of units	Type[1]	COP[2]
Geoscience Australia, ACT	18.2	2500	210	V	3.5

1) V = vertical ground coupled
2) COP = output thermal energy/input energy of compressor

Table 5. Summary table of geothermal direct heat uses as of 31 December 2009[1]

Use	Installed Capacity (MWt)	Annual Energy Use (TJ/yr)	Capacity Factor
Individual space heating			
District heating			
Air conditioning (cooling)			
Greenhouse heating			
Fish farming	2.3	43.5	0.6
Animal farming			
Agricultural drying			
Industrial process heat			
Snow melting			
Bathing and swimming[2]	7.03	61.6	0.28
Other uses			
Sub total	7.03	105	0.28
Geothermal heat pumps	24	130	0.25
Total	31	235	

1) Only quantifiable values are shown
2) Includes a minor component of domestic hot water heating

Table 6. Wells drilled for electrical and direct use of geothermal resources from January 1, 2005 to December 31, 2009 (excluding heat pump wells)

Purpose	Wellhead Temperature	Number of Wells Drilled		Total Depth (km)
		Electric Power	Direct Use	
Exploration[1]	(all)	71	--	45.9
Production	>150°C	--	--	--
	100–150°C	--	--	--
	<100°C	--	8	5.5
Injection	(all)	1	4	7.4
Total		72	12	58.8

1) Including 'gradient wells' and 'heat flow wells' greater than 100 m deep

Table 7. Allocation of professional personnel to geothermal activities (personnel with university degrees)

Year	Professional person-years of effort						
	(1)	(2)	(3)	(4)	(5)	(6)	Total
2004[7]	*0*	*0*	*4*	*1*	*0*	*10*	*15*
2005	5	1	4	1	0	17	28
2006	10	1	5	2	0	30	48
2007	17	1	6	3	0	51	78
2008	19	1	12	4	0	89	125
2009	21	1	18	5	0	153	198
Total ('05–'09)	72	5	45	15	0	340	477

1) Government
2) Public utilities
3) Universities
4) Paid foreign consultants
5) Contributed through foreign aid programs
6) Private industry
7) From Chopra (2005)

Table 8. Total investments in geothermal (2009 US$)

Period	Research and Development (incl. exploration drilling) (2009 US$million[1])	Field Development (incl. production drilling and surface equipment) (2009 US$million)	Utilization (2009 US$million)		Funding Type (%)	
			Direct	Electricity	Private	Public
1995–1999	--	--	--	--	--	--
2000–2004	1.7	25	--	--	70	30
2004–2009	75	265	1.4	--	92	8

1) Average exchange rate over 6 months to May 2009: AU$1.00 = US$0.70