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Review of Australian Geothermal Activities and Research

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ABSTRACT

Since the year 2000 when the first Geothermal licence applications were lodged in Australia, there has been continual and progressive growth in the Australian Geothermal sector with company expenditure to date amounting to AU$325 million over the current 383 geothermal licences. Most of the investment is focused on Hot Rock (HR) plays, but a significant number of companies also seek to commercialise Hot Sedimentary Aquifer (HSA) plays. Significant research studies have been completed relating mostly to Enhanced Geothermal Systems (EGS). Australia's geological environment lends itself to the development of different forms of EGS plays, and as such the technical advances needed for widespread international deployment of EGS are key to the advancement of geothermal energy use in Australia.

The Australian Geothermal Energy Group (AGEG), with members from geothermal companies, research institutions and governments, was formed in 2006 with the vision that geothermal resources will provide the lowest cost emissions free renewable base load and direct-use energy for centuries to come. The AGEG is working towards this vision through its Technical Interest Groups which have determined the research of the highest priority to the industry, closely aligned with the priorities of the IEA Geothermal Implementing Agreement (GIA), the International Partnership for Geothermal Technologies (IPGT) and the ENhanced Geothermal Innovative Network for Europe (ENGINE). The AGEG provides support for Australia's membership in the IEA GIA and contributes to IEA annual reports relating to geothermal energy.

This paper provides an update on the current status of geothermal development activity in Australia including the number of geothermal licences and licence areas, project milestones that have been reached and future developments expected. The significant research findings of projects completed for the AGEG by members such as the University of Adelaide and Newcastle University will also be reported. Of note are two projects completed to identify and evaluate the potential of risks due to EGS activity, in particular the risk management of induced seismicity due to fracture stimulation and a study on the potential for radiological hazards associated with EGS. These and other studies aim to reduce the uncertainties surrounding EGS and rather than deter development, provide knowledge to allow appropriate, safe and efficient management.

1. INTRODUCTION

Geothermal development in Australia is progressing despite difficulties that have been experienced due to the global financial crisis and subsequent tightening of investment markets. There have been some very significant milestones reached by the industry and positive supportive initiatives from the Australian Federal Government that are to be applauded. This paper will present these initiatives and an update on the activities of Australian geothermal companies.

Additionally, a joint AGEG and AGEA committee has produced the world's first uniform code for the reporting of geothermal reserves and resources. The AGEG has also been active in terms of priority research projects, with a number of research reports being released. The findings of these are discussed in more detail in this paper.

2. AUSTRALIAN GEOTHERMAL INDUSTRY ACHIEVEMENTS

The Australian Geothermal industry has achieved significant advancement since 2005. At the time of writing there are 48 companies working to explore for and develop geothermal energy in a total of 383 licence areas across Australia covering 358,400 km^2. A map of current geothermal exploration licences (green), exploration licence applications (orange), and acreage releases (pink) is shown in Figure 1 below.

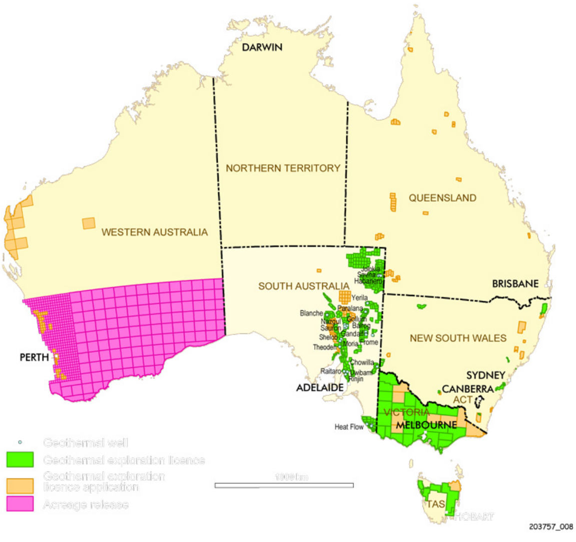

Figure 1: Australian geothermal licence areas and acreage releases as at April 2009

The first licences were granted in 2001 in South Australia, and there have now been successful acreage releases in Victoria, Queensland and Western Australia with new legislation to enable geothermal licence releases expected for the Northern Territory in 2009.

There is one geothermal power plant in operation in Australia and that is Ergon Energy's Birdsville geothermal power plant, which is a conventional style geothermal system producing 80kWe. Apart form this plant the geothermal projects planned are predominantly HR plays that are targeted to become Enhanced Geothermal Systems

(EGS). The most advanced HR project in Australia is a Hot Fractured Rock (HFR) play in the Cooper Basin. The second most advanced project in Australia is a Heat Exchange Within Insulator (HEWI) play near Mount Painter in South Australia. HEWI plays are a form of a HR EGS play where the reservoir lies above high heat producing granites, within insulating lithologies. The third most advanced project in Australia is a HSA play in the Otway Basin. Several examples of each of these play-types are targeted by companies across Australia.

A brief summary of some of the company's achievements will follow, considering those projects the furthest ahead in terms of exploration, drilling and development.

2.1 Geodynamics

Geodynamics Limited are, at the time of writing, the front runners in Australia with their Habanero project near the small town of Innamincka in South Australia's north east corner. This area of the Cooper Basin is also the location of most of South Australia's onshore oil and gas reserves, but could come to be known as the nation's geothermal energy province according to Geodynamics with their Hot Rock 50 project and vast potential for future scaling up.

Since 2003, Geodynamics have drilled five deep wells into the hot fractured rock. Habanero 1, 2 and 3 were drilled for their 1MW pilot plant and each reached a depth of more than 4.2 km. The closed loop for circulation of the water through the hot granite reservoir uses Habanero 1 as the injection well and Habanero 3 as the producer. Micro-seismic monitoring during the fracture stimulation at Habanero 1 and Habanero 3 showed that the fracture network extends 1.5 km wide by 3+ km long, and good communication was observed between the wells.

The most recently drilled wells are Jolokia 1 (drilled to 4.9 km) and Savina 1 (drilled to 3.7 km) which are 4.9 km and 3.7 km deep and lie approximately 9 and 19 km WNW of the Habanero wells, to further define the extent of the geothermal resource within the company's licence areas.

In March 2009 the company achieved 'proof of concept', (Geodynamics, 2009a) the completion of a set of tasks that demonstrated their capability to engineer the HFR system and prove that the technology was viable and ready for large scale execution. The next stage is demonstration of a working, reliable power plant to demonstrate the repeatability (reliability) of the technology and also to refine the equipment design and technology requirements as well as learning more about their reservoir in the lead up to the planned 50 MW and ultimately , 500 MW projects.

The development of their project has progressed through power plant design and onto construction of the 1MW power plant. The 1MW power plant will provide free electricity to the residents of Innamincka and be open to the many tourists who travel through the remote area each year. Commissioning of the power plant was due to begin in April 2009 until there was an incident at Habanero 3 involving the release of water and steam at surface. The well has since been controlled and (at the time of writing) the company is now completing a thorough analysis to determine the cause of the incident and the mechanisms that led to the incident to prevent another occurrence. It is expected that the 1MW plant will be commissioned in late 2009 or early 2010 (Geodynamics, 2009b).

Figure 2: The Innamincka 1MW pilot power plant and visitor centre. Photo courtesy of Geodynamics

Geodynamics have submitted an application for a grant under the Federal Government's Renewable Energy Demonstration Program (REDP), for their Commercial Demonstration Project. The AU$435 million REDP is part of the AU$500 million Renewable Energy Fund (REF) and will provide grants for up to one third of the eligible expenditure on demonstration projects (RET, 2009).

In April 2009 Geodynamics announced a commitment of AU$5 million to go towards co-funded research on topics to advance their geothermal projects. While intended specifically for Geodynamics projects this significant contribution to EGS research will no doubt aid the advancement of the industry as a whole.

2.2 Petratherm

Petratherm are the second company in Australia who will drill deep geothermal wells, with their Paralana 2 well due to be spudded in mid 2009. In March 2009 Petratherm were granted AU$7 million under the Australian Federal Government's Geothermal Drilling Program (GDP). The AU$50 million GDP provides grants for drilling for proof of concept projects, with a competitive selection process and grants of up to AU$7 million of matched funds per project. At the time of writing applications were open for the second round of GDP submissions, and the successful applicants from this round should be announced in December 2009. To be able to drill Paralana 2 a new 'state-of-the-art' rig, Rig # 828, has been commissioned and arrived in Australia in May 2009.

Figure 3: Rig #828 at Petratherm's Paralana project site. Photo courtesy of Petratherm (Petratherm, 2009)

In 2006 the geothermal test well at Paralana was extended to 1807 m, where thermal gradients were measured to be 81ºC per km. Extrapolation from temperature logging of the well suggests 200ºC can be expected at 3.6 km within the insulating sedimentary rocks.

Petratherm's EGS concept and target is different. While many companies are seeking to enhance the high temperature deep fractured granites, Petratherm's HEWI model involves fracture stimulation and reservoir creation within the overlying insulating sedimentary layer. After completion of their first deep well in 2009, Petratherm plan to spud their second deep well in early 2010, followed by circulation tests between the wells. Their first power plant to demonstrate the HEWI concept will be a small scale 7.5 MW power plant to supply power to the nearby Beverly mine.

Petratherm have submitted an application to the Australian Federal Government Renewable Energy Demonstration Program, applying for a grant to cover one third of the cost of their commercial demonstration plant.

2.3 Panax Geothermal

Panax have multiple petroleum exploration wells and water wells in its tenement areas of the Limestone coast project in southeast South Australia which show large scale heat flow anomalies. Three slim-hole wells were drilled to confirm the heat flows. The company's next stage, since being awarded an AU$7 million grant from the Federal Government GDP round 1, will be to drill their first deep well using the newly commissioned Rig #828 after Petratherm. Their first deep well, Salamander 1, is planned to have a total depth of approximately 4 km and is expected to spud in late 2009.

2.4 Green Rock Energy

Green Rock Energy have plans to drill their first deep geothermal well in 2010, after encouraging results from their Blanche 1 well located 8 km from the Olympic Dam mine at Roxby downs in South Australia. Blanche 1 reached a depth of 1935 m followed by 1216m of homogeneous hot granite. The granite is thought to extend to depths of 6km over a large 400 km^2 area. Green Rock have taken cores and wireline logs of Blanche 1 as well as a mini fracture stimulation program to assist the design of their deep well stimulation.

2.5 Torrens Energy

Torrens Energy were the first company to provide an inferred geothermal resource estimate under the new Australian Geothermal Resources and Reserves reporting code, the development of which will be described in more detail in this paper. The Parachilna Play Statement of Inferred Resources was released in mid-2008, after drilling 6 wells in this project area. In 2008-9 Torrens Energy drilled a further 8 wells in its Port Augusta, Adelaide Plains and Lake Torrens Projects and plans to drill a further 20 heat flow wells for 2009 and 2010 to delineate heat flow trends in their project areas. This work will lead to determining the location of their deep proof of concept wells which will additionally be close to the national electricity market grid.

2.6 Geothermal Resources Ltd

Geothermal Resources Limited are exploring in their Frome project area in the east of South Australia. The Frome project is close to potential geothermal energy markets with connection to the national electricity grid 120 km away at the town of Broken Hill.

Geothermal Resources have drilled a number of wells to conduct temperature logging. Their well Frome 12 reaches 1716m and samples from this well show granite with well developed sub-horizontal fracturing. Two further wells of at least 1800m will be completed in 2009. The results from these wells will be combined with seismic data to select the location of their deep well.

2.7 KUTh Energy Ltd

KUTh Energy have conducted a systematic shallow well drilling program across their geothermal tenements in eastern Tasmania to establish heatflow in the area. KUTH has found high heat flow granites and a sedimentary pile above the granites averaging 3-5 km in depth. This shallow drilling program will lead to locating deep drilling locations. The Australian Federal Government has offered KUTh an AU$1.8 million REDI Grant to explore for geothermal resources in northeastern Tasmania.

2.8 Greenearth Energy Limited

Greenearth Energy is one of a few companies exploring for both petroleum and geothermal resources under separate but coincident licences. Greenearth have obtained valuable information for an HSA play from three of its petroleum wells within its geothermal licence areas in the state of Victoria. Greenearth has lodged an application to compete for a grant from the Federal Government's Renewable Energy Demonstration Program (REDP) to support a 10.7 MW HSA project, scalable to 48 MW, near Geelong in Victoria.

3. THE AUSTRALIAN GEOTHERMAL ENERGY GROUP AND TIG RESEARCH

Australian Geothermal Energy Group (AGEG) was formed in 2006 and its members are geothermal companies, both licensees and service providers, research centres such as Universities, Geoscience Australia and the CSIRO and both federal and state government departments. The vision of the AGEG is for geothermal resources to provide the lowest cost emission free renewable base load and direct-use energy for centuries to come.

The AGEG was formed to bring together all parties involved in geothermal development in Australia in order to work together and cooperatively advance the industry as a whole. The priorities of the AGEG and its Technical Interest Groups (TIGs) are well aligned with those of the IPGT and IEA GIA.

The method of this advancement is through the work of the TIGs which are broadly separated into the stages of a geothermal project and so encompass land access and exploration through to power systems and transmission or connectivity to the NEM. The ten AGEG TIGs are briefly described in Table 1 below.

The TIGs have transformed somewhat since their conception in 2007. In particular the TIG for policy advice has led to the creation of the Australian Geothermal Energy Association, the industry advocate. TIG 2 has become the joint AGEG and AGEA Resource and Reserves Code Committee, who released and now administers the first uniform geothermal reserves and resources reporting code. TIG 5 has held some informative workshops and has led to the AGEA working group on issues relating to the national electricity market. The scope and findings of some of the research projects that will be or have been completed within the Technical Interest Groups will be described further.

The AGEG and the AGEA have agreed to coordinate research efforts through the AGEG's 10 Technical Interest Groups. This will facilitate Australian companies, research experts and government agencies (including regulators) to convey and take note of international best practices for the full-cycle of below-ground and above-ground geothermal energy operations and stewardship.

Table 1. The AGEG's Technical Interest Groups.

TIG 1	Land Access: management of environmental concerns & potential impacts of geothermal energy
TIG 2	Reserves and Resources: now the joint AGEG AGEA Resource and Reserves Code Committee
TIG 3	Policy issues: advice to governments. Through TIG 3 the Australian Geothermal Energy Association was formed.
TIG 4	Outreach: foster awareness, share information, produce educational material, website, and convene the AGEG-AGEA Australian Geothermal Energy Conference.
TIG 5	Getting to Markets: electricity network and National Electricity Market issues in terms of technology and methodology.
TIG 6	Geothermal Power Generation
TIG 7	Direct Use of geothermal energy
TIG 8	Reservoir characterisation and modelling including EGS
TIG 9	Data management: database design, contents and ongoing enhancements
TIG 10	Field operations: Both drilling operations and geophysical operations

Results from studies undertaken under the auspices of the AGEG (and more) will be available through the AGEG website.

The AGEG's TIGs will have active links to the IEA's geothermal research annexes, the IPGT, and will aim to attain strong linkages to all other reputable international geothermal research clusters, to ensure that Australia's comparative advantages in HFR geothermal resources can be leveraged into accelerated development of high priority geothermal technologies, methods and the sharing of lessons learnt. On this basis, the AGEG and the AGEA have agreed that the AGEG should become the Australian affiliate for the International Geothermal Association.

Already some significant projects have been completed within the AGEG TIGs. The Department of Primary Industries and Resources SA (PIRSA) commissioned research studies for the TIG for land access and environmental issues on the potential for induced seismicity associated with the fracture stimulation of EGS wells in the Cooper Basin (Hunt and Morelli, 2006) followed by a report on the analysis and management of seismic risks (Morelli, 2009). These studies were completed at the Australian School of Petroleum at University of Adelaide. Key conclusions from these studies are:

The Cooper Basin in South Australia is ideally suited to HR EGS activities in terms of natural background seismicity levels (Hunt and Morelli, 2006);

Reactivation of any basement faults in the region is unlikely in the vicinity of the Habanero Site (Hunt and Morelli, 2006);

Seismic events induced by reservoir stimulation at the Habanero well site in the Cooper Basin were of low magnitude (intensity) and fell below the background level that the government's current building design standards allow for (Hunt and Morelli, 2006); and

Protocols can be established to assess and manage potential induced seismicity risks arising from geothermal reservoir stimulation and production operations. The context are forecast EGS operations in the Adelaide Geosyncline in South Australia with global application. This will enable appropriate project management and regulatory frameworks for potential risks associated with induced seismicity (Morelli and Malavazos, 2008);

Morelli (2009) recommended consultation with all stakeholders as early as possible, determining the natural seismicity levels and potential induced seismic activity, working out the elements that would be affected by any seismic event and combining all of these to work out the overall risk of induced seismicity and then manage the risk.

PIRSA also commissioned a project by Cibich (2008a) involving a literature review to study the reservoir fluid behaviour in an EGS system and also the development of a geothermal model to predict pressure losses in an EGS system. Cibich went on to further refine the model and completed a second report as an honours project (Cibich 2008b). The geothermal model is very useful to conduct quick yet detailed calculations of pressure and even flow regime for geothermal wells. Both of these reports and the model will be made available through the AGEG website.

A project being completed within the petroleum and geothermal group of PIRSA aims to establish the materiality of future Hot Rock and HSA development, worldwide. There have been a number of estimates of the amount of geothermal energy generation that can be expected in Australia and also of the size of reserves and resources within individual geothermal companies' licence areas. Further the MIT (2006) report and Geoscience Australia (Budd et al., 2008) have both made estimates of geothermal energy stored in the US and Australian crust respectively. By compiling the various estimates and assigning levels of probability of success, and by making a number of broad assumptions that are chosen to provide a conservative result, an estimate of the average recoverable HFR resource is determined for the world.

Some estimates of the prospective materiality of developing HFR and HSA resources follow. All assume success in demonstration and proof of concept projects is followed by economic development.

The Electricity Supply Association of Australia concluded that 6.8% of all of Australia's power could come from geothermal energy by 2030 under a "scenario that assumes no nuclear power and (CO_2) emissions reduced to 70% of 2000 levels by 2030" (ESAA, 2006). The forecast 6.8%

represents 5.5 GW in generating capacity from EGS. At roughly 2% growth, Australia's power demand will grow from approximately 50 GW current generation capacity to approximately 80 GW in 2030.

Geoscience Australia estimates that reaping just 1% of the geothermal energy stored from 150°C to 5 km in the Australia crust corresponds to 190 million PJ, equivalent to ~26,000 yrs of Australia's power use (Budd et al., 2008)

Geodynamics Limited estimate the hot, wet, fractured rocks in its Cooper Basin licences in South Australia can fuel more than 10,000 MW of electricity power generation capacity (Geodynamics, 2008)

Petratherm Limited estimate its 'Heat Exchange Within Insulator' (HEWI) targets in its Paralana geothermal project area in the South Australian Flinders Range will exceed 1 km thickness over 20 km and average at least 200°C, and this would suffice to fuel 520 MW over 25 years (Petratherm, 2008);

Panax Resources Limited estimate the HSA play in its Limestone Coast Geothermal Project (covering 2,674 km2) in its Otway Basin geothermal licences in South Australia has potential to fuel more than 1,500 MW of electricity generation capacity (Panax, 2008)

The Australian Geothermal Energy Association forecast up to 2,200 MW of Australia's base-load capacity can come from geothermal energy by 2020 (AGEA, 2008)

Now making broad assumptions, such as;

- that the global extractable geothermal energy resource follows a log-normal distribution;
- that 10 MWe is a conservative estimate for the 99% probability level (of certainty) for deployment of EGS in the world by 2050 (as displayed in Fig 4);
- that the MIT (2006) estimate that development of EGS resources between 3 and 10 km depth in the USA would fuel 100,000 MWe of power generation capacity by 2050 can reasonably be assigned as the 10% probability level of the geothermal resource developed for all regions in the world by 2050 (as displayed in Fig 6);
- that a 90% capacity factor for geothermal power plants that supply base-load electricity; and
- that the geologic conditions spread across the land area of the USA are roughly as variable as average land areas around the world*;*

then the method is to take the ratio of the world's land area (135,385,500 sq km) to the USA land area (9,629,091 sq km) which is 14.1; multiply by the Swanson's Mean of the log-normal distribution defined by above assumptions (which is 31,561 MWe). This provides an estimate of 443,750 MWe as the potential deployment of EGS-fueled electricity world-wide by 2050.

Choosing to be conservative in estimates, and assuming sufficient investment, expected world EGS development by 2050 is suggested to be roughly between 90,000 MWe, assuming a 20% composite chance of success and 130,000 MWe, if assuming a 30% composite chance of successful deployment.

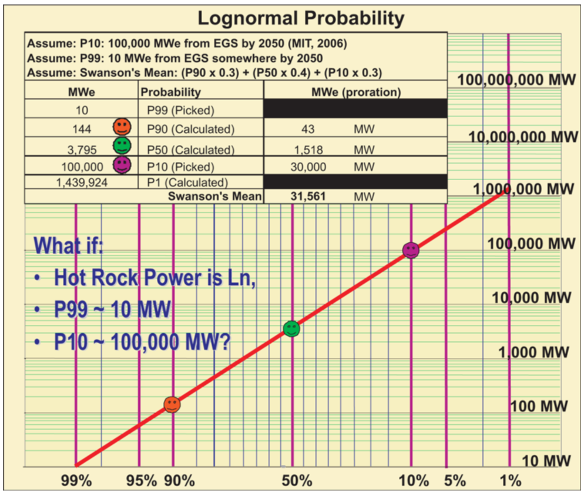

Figure 4: Estimate of potential capacity to generate electricity from Hot Rock energy

As well as these studies ten key projects addressing a diverse range of critical uncertainties and issues have been initiated through the AGEG with support from PIRSA tied grants and geothermal company contributions. These projects include scaling and corrosion in HDR energy extraction systems, reserve and resource definitions, reservoir characterization, 3D modeling, life cycle of water in HDR operations, forward prediction of spatial temperature variation from 3D modeling, assessment of the impact of geo-fluid properties on power cycle design and a comparison of the performance of state of the art power cycle design. The findings of these research projects, four of which are completed with the remainder due for completion in 2009 will be made freely available on the AGEG website, and the experience gained will inevitably be leveraged into further valuable research and the development of a service sector for the geothermal industry. This initiative will be complementary to any/all other proposals from the Australian Federal Government and other Australian jurisdictions to support geothermal research. Each research project is described in more detail below.

3.1 The Australian Code and Lexicon for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves

The Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves, "the Code", has been developed as a joint initiative between The Australian Geothermal Energy Group (AGEG) and the Australian Geothermal Energy Association (AGEA) (GCC, 2008). This is the world's first uniform code to guide the reporting of geothermal data to the market and is designed to underpin the quality of the Industry's relationship with the market.

The development of a Geothermal Reporting Code, and its adoption by operating companies to shape the way they report their geothermal exploration results, resources and reserves, is an important step in the development of Australia's geothermal energy industry.

The Lexicon for Geothermal Exploration, Resources and Reserves has been prepared to facilitate understanding of geothermal energy concepts and the methods used to determine geothermal resources and reserves. However, it does not form part of the Geothermal Code.

The Code is intended to be a living document, and the second edition of the code should be released in late 2009.

3.2 Geochemistry, Corrosion and Scaling in Hot Dry Rock Energy Extraction Systems

This report will investigate an important element of the Hot Rock geothermal energy system, the potential for and cause of corrosion and scaling in pipes in the above ground equipment of a geothermal power plant due to the geo-fluid chemistry and also maintaining open pores within the underground reservoir, avoiding clogging of the fracture network which could be caused by mineral precipitation.

The project has involved the sampling of the geo-fluid from a Hot Rock EGS system and also of the rock itself to determine the mineralogy and composition of each. The researchers at the University of Adelaide and the Museum of South Australia then intend to re-create the above ground and below ground conditions experimentally. Using a specially designed experimental apparatus they first study the interaction between the geo-fluid and the rock at temperatures and pressures equivalent to those in the geothermal reservoir. The results of these experiments will be used to calibrate and further develop geothermal modeling tools to determine potential scaling and pore blockage issues and consequently possible solutions.

3.3 Characterisation of Adelaidean Rocks as Potential Geothermal Reservoirs (Heat Exchange Within Insulator)

The main objectives of this project are to determine the extent of available data necessary to characterise the reservoir parameters of the Adelaidean formations within the Adelaide Geosyncline, available as pre-competitive data for the geothermal industry. This will involve reviewing and compiling all available data and publications and also further information if provided by companies with geothermal licences in this area. Further to this, maps would be compiled to show the areas in the region possibly suitable for both geothermal development and geosequestration, with the intention to provide a temperature gradient for the region.

3.4 Three Dimensional Reconstruction of the Adelaide Geosyncline – Application to Geothermal Exploration

Backé and Giles (2008) developed a robust integrated methodology to construct a 3D model of the Lake Torrens – Central Flinders zone in South Australia using Gocad that has incorporated various tectonic structures (including faults, folds and mini-basins) without geomorphic expression at the surface.

The Geocad model was then exported into 3D thermal modeling software to provide an inferred geothermal resource over the Parachilla area, southern Flinders Ranges, South Australia.

3.5 Full Life-Cycle Water Requirements for Deep Geothermal Energy Developments in South Australia

Cordon and Driscoll (2008) documented likely water usage for each stage of geothermal exploration and development, including issues of water loss, and compiled an atlas of water resources of South Australia to assist explorers in understanding of the quality, availability and legislative requirements associated with these resources. Although the atlas of this report is for South Australia, the full life-cycle water requirements for deep geothermal energy developments that are outlined in this report are applicable world-wide.

3.6 Preliminary Assessment of the Impact of Geo-Fluid Properties on Power Cycle Design

While the effects of geo-fluids in terms of corrosion and scaling are known, there has not been a thorough assessment of the scope of these issues for Australian geothermal projects, and in particular with reference to the power cycle design to accommodate these issues. Information on the expected water composition is difficult to find which causes great difficulty in forward planning for power plant design as these elements greatly affect the choice of systems and materials.

The first project aim was to compile a database of available water composition and quality from a consortium of AGEG members. This aim was revised for at the time the researchers were completing this section the only available data was from the Geodynamics wells. From this data set the most difficult set of conditions will be selected and a preliminary design will be completed using these conditions in order to provide guidance for how to manage them. The preliminary design will also allow further investigation of where opportunities lie for geothermal companies to achieve cost savings through better design and highlight areas of further research. This project is expected to be completed in 2009.

3.7 Preliminary Assessment of the Potential for Underground Cooling on Power Cycle Design

Dally et al. (2009) have reported on a novel concept of using a large underground network of pipes instead of large cooling towers, unlikely due to their water requirements, or large air coolers. Underground cooling offers the possibility to provide increases in efficiency for power cycles when ambient temperatures in many geothermal plant locations will be very high.

A thermodynamic model of the underground pipe was used to determine the required length of pipe and depth of burial for a set of harsh conditions and a 5 MW power plant output. The model results were then used to determine the feasibility of such a design. The authors found that a length of 25 km of pipe was needed but this would only need to be placed 10 cm deep to be beneficial – this requires a total area of approximately 5 km^2. While this is a large area it was estimated that the cost for the system would be lower than for an air cooled system and provide more constant output including greater output than a fan/air cooler system during peak daytime temperatures.

3.8 State-of-the-Art in Power Cycles for Geothermal Applications and Bottoming Cycles

Researchers from Newcastle University and the University of Adelaide are working jointly on this study to compile a detailed comparison of existing geothermal power plants and their performance and operating conditions compared with the conditions expected for the Australian geothermal industry. Using models of the Kalina, Super critical, flash and Organic Rankine cycles the research aims to estimate modifications that would be required to adapt those existing power plants to Australian conditions.

3.9 The Development of a Geothermal Power Plant Preliminary Cost Estimator – Stage 1: Basic Estimates

Stage 1 of this project aims to develop a cost estimator for power generation by a geothermal power plant in Australian conditions, specifically South Australia. The estimator will initially be designed around a set of assumptions which define the geothermal system, providing the ability for the user to specify the values of certain variables such as the geo-fluid temperature, the ambient conditions, well depth, reservoir porosity and surface pressure. The cost estimator will calculate the average cost of power generation for a specified period and the predicted net power under a range of conditions.

This model will be designed to be used in conjunction with the MIT cost calculator (Herzog et al., 1997), and to include some factors important for the Australian geothermal industry namely the effect of ambient conditions on the cooling cycle, the effect of the water quality and the effect of the reinjection pressure. The model will also be designed to be able to expand over time and include more options for power cycle design, a range of options for working fluids and different cooling systems and corrosion mitigation methods.

3.10 Forward Prediction Modeling of Spatial Temperature Variation from 3D Models

This report was prepared by Intrepid Geophysics and involved the development of a software module in 3d GeoModeller to calculate 3D temperature directly from a 3D geology model. 3D temperature prediction incorporated heat flow contributions from conductive and in situ heat production sources and honoured known boundary conditions.

During unit testing, a simple case of heat advection, honouring a known internal boundary condition was proven. Furthermore, the capacity to compare outcomes of model-generated temperatures, with observed temperatures and heat flows was demonstrated on real–world 3D geology models in the Mount Painter and Cooper Basin regions of South Australia.

The ability to commence a forward 3D temperature run, starting with a non-GeoModeller 3D geology model was demonstrated for the Cooper Basin, South Australia.

3.11 An Assessment of Radiological Hazards in HR Geothermal Systems

Battye and Ashman (2008) were commissioned by PIRSA to conduct a literature review and some modeling to assess the risk of radiological hazards for HR geothermal systems. The study found that isotopes of Uranium, Radium, Thorium, Radon and Lead will be likely to be present in the circulating ground waters.

The main risks of exposure to these Naturally Occurring Radioactive Materials (NORMs) for a HR geothermal system would be through exposure to radon gas if the geofluid and steam are emitted to atmosphere, or exposure to the scales and sludges that may form in the above ground system.

If the HR geothermal power plant is operated in an entirely closed loop configuration then there would be little to no risk of radon exposure. For an open loop situation the levels are probably still below the action levels for workplaces in Australia (1000Bq/m3) but are very dependent on wind speed and the residence time of the geofluid in the reservoir, so thorough monitoring should take place to ensure that the exposure is known and there is no risk, or else the risk is managed appropriately.

The other way there could be exposure is from the scales or sludges that may be deposited in the above ground equipment, depending on the geochemistry and the plant conditions. Experience from conventional geothermal systems and from the oil and gas industry shows that these scales and sludges can contain radio-nuclides that have been carried with solid particles suspended in the solution and then deposited, or from particles that precipitate out at surface. Only the Radium isotopes can emit gamma radiation that could penetrate the pipe work. Radium isotopes are less likely to be found in waters with low concentrations of barium and strontium sulphates, and the report states that as the radium concentrations will be expected to be lower than for the oil and gas industry the gamma radiation from these residues would be expected to be at insignificant levels.

The other isotopes that may be present could be hazardous if inhaled as a fine dust, so precautions should be taken during all cleaning operations.

3.12 Alternative Carriers for Geothermal Energy in SA - An Investigation of the Systems Needed to Generate Hydrogen and Methane from a 50 MW Geothermal Demonstration

Dickinson et al. (2009) were commissioned jointly by the Electricity Supply Industry Planning Council and PIRSA to assess the systems requirements for hydrogen production as a potential primary electricity load for a geothermal demonstration power plant output.

The objective of this study is to assess the possibility that hydrogen, methanol or synthetic methane production facilities co-located with geothermal energy production could have an attractive benefit: cost ratio. This study concludes costs to design and construct a 45MW electrolysis plant and an associated 5 MW refrigeration plant with all of the required pumps and ancillary equipment could be economically more attractive than using the same geothermal energy to fuel a 50MW capacity power plant to reach markets with a long distance and high voltage transmission line to connect to distant power markets. Locating the electrolysis plant near to existing gas transmission (pipeline) infrastructure suggests that synthetic methane could have the lowest transport costs.

Given the good results attained with its earlier grants, the South Australian Government announced the first project to be funded from a South Australian (state-based) Renewable Energy Fund will be the South Australian Centre of Excellence (CoE) for Geothermal Research at the University of Adelaide, which will receive AU$1.6 million over two years from 1 July 2009. The University of Adelaide is providing AU$400,000 for this CoE. The total AU$ 1 million per annum for at least two years will underpin priority research with material prospects for enabling efficient exploration and development of Australia’s vast renewable and low-emissions geothermal energy resources. In particular, the South Australian CoE will focus on subsurface factors in HR and EGS resources. The CoE will collaborate with experts (nationally and internationally) to foster fast progress towards the commercialisation of geothermal resources, with a key focus on HR and EGS plays.

Some of the Australian experts that the centre will be keen to collaborate with are those of the already established Queensland Geothermal Energy Centre of Excellence (QGECE) and the Western Australian Geothermal Centre Of Excellence (WAGCOE). The QGECE has four main areas of research: power conversion, transmission and generation, reservoir management and heat exchangers. The WAGCOE will be involved in a number of projects relating to the Perth basin and topics important for the first stages of geothermal uptake in Australia such as geothermal heat pumps and more efficient use of lower temperature resources as the technology in these areas has been demonstrated. The centre will encourage use of geothermal heat energy as well as conversion to electrical energy through cascaded systems and applications such as district heating, desalination, heating swimming pools and agricultural uses.

CONCLUSION

The Australian geothermal industry has advanced significantly since 2005 and is assisted by supportive government initiatives, the efforts of the Australian Geothermal Energy Association and the collaborative determination of industry priorities and research work through the Australian Geothermal Energy Group.

A number of interesting research projects are underway and have already been completed relating to topics that will aid the Australian geothermal industry, with many projects and research expertise focused in the area of EGS or HR geothermal systems and more specifically to adapting to the Australian conditions. Many of the outcomes of these research projects will be made available through the AGEG website.

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