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RESEARCH PRIORITIES FOR THE AUSTRALIAN GEOTHERMAL INDUSTRY

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ABSTRACT

The Australian Geothermal industry has had two projects drill into deep EGS reservoirs and two into deep sedimentary reservoirs. All four projects have encountered significant technical challenges in developing these resources. These challenges have also added to the uncertainty around the development of other geothermal projects in Australia. The Australian geothermal research community has established the Geothermal Research Initiative (GRI) to provide a mechanism for coordinating research activities to address these challenges. The goals of the GRI are to assist the industry in demonstrating the technical viability of geothermal energy in Australia and to then develop technologies that help to drive down the costs of energy produced from geothermal resources, providing a secure competitive energy source for the nation's future. This paper provides an overview of the research priorities identified by the GRI through a review of the progress the industry has made so far and in close consultation with the geothermal sector in Australia. We also outline the research program that is developing to tackle these priorities and the opportunities to implement this program provided by the demonstration projects under development in Australia.

INTRODUCTION

The potential of geothermal energy to contribute to Australia's future energy needs has been well documented (Geoscience Australia and ABARE, 2010). Geothermal energy could provide a substantial amount of clean energy as Australia seeks to cut its CO_2 emissions. The national geothermal resource promises centuries of supply, and therefore energy security, with stable pricing not strongly affected by volatility in commodity markets. The characteristics of geothermal energy would allow it to provide baseload capacity that most other renewables cannot emulate.

Recent modeling by the Australian Treasury forecasts that geothermal energy could contribute up to 23% of Australia's electricity mix by 2050, representing 105 TWh of electricity sent out (Australian Treasury, 2010). For these forecasts to become a reality the technical and economic viability of geothermal energy resources to be developed routinely and

provide large scale generation capacity, must be demonstrated in Australia.

The Australian geothermal industry grew rapidly during the last decade in response to this potential and to the growing need for low emissions energy. Fifty-six companies have taken 411 license areas (covering 474,000 km2) between January 2000 and May 2011 and spending AU$670 million (US$645 million in January 2012) from 2002 to 2010 (Bendall et al., 2011). However, no new generating capacity has been installed in that time, with only modest gains in large direct use systems (compare Burns et al 2000 and Beadsmore 2010).

The Australian geothermal industry has suffered from challenges arising from: the technical difficulties encountered by the more advanced projects, including low fluid flow rates; the high costs of drilling; difficulty in raising capital funds due to the global financial crisis; and a lack of policy certainty around carbon pricing.

The Australian geothermal research community is working to develop a large, integrated and collaborative research program to assist the industry in addressing these challenges. This paper reports on the research priorities that have been identified and the progress in developing the research program.

Australia's Geothermal Resources

Geothermal resource quality is a function of the geothermal gradient and the porosity and permeability of the formations that host the formation (Hildigunnur et al. 2008). Figure 1 shows the spectrum of geothermal resources in these terms. The majority of the world's geothermal resources exploited for electricity production are high grade hydrothermal resources typically associated with tectonic/volcanic activity along plate boundaries (Sanyal, 2010). As continental Australia is set within the Indo-Australian Plate there is no evidence to suggest that these conditions will occur in Australia. The Australian geothermal industry has therefore focused on two broad categories of geothermal resources – Enhanced (or engineered) Geothermal Systems (EGS) and Hot Sedimentary Aquifers (HSA). The distinction between these two styles is primarily the permeability or connectivity of the reservoir rocks, with HSA confined to sedimentary systems which are assumed to have high primary permeabilities, and EGS covering anything that requires enhancement of the permeability or fluid content. In reality these represent the two end-members of a continuum and all but the most permeable HSA systems will require some form of engineering to flow. Figure 2 is a schematic representation of the geothermal targets currently favoured in Australia.

The potential for quality EGS resources in Australia is considered high because of the following factors:

- widespread occurrence of basement rocks (typically granitic) with unusually high concentrations of radiogenic elements, particular granites of Proterozoic age which occur throughout northern and central Australia;
- widespread, thick Paleozoic basins that provide insulation to trap heat produced in the basement; and
- tectonic setting that produces horizontal stresses that are higher than the vertical stress, favouring horizontal fractures;

The first two of these factors are also favourable for HSA resources because of the high geothermal gradients created and the presence of thick sedimentary basins. The assessment of Australia's geothermal resource potential is a continuing process and greater understanding of the styles of geothermal resources will be gained as the geothermal sector develops.

Australian geothermal resources will cover the full spectrum shown in Figure 1 with the exception of the high grade hydrothermal resources. There is limited potential for higher grade hydrothermal resources around some of the young volcanic provinces such as the Newer Volcanic Province in Victoria and South Australia, with volcanic activity as recently as 5000 years ago.

Australia's Geothermal Industry

Prior to the 21st century, Australia had no geothermal industry save a few megawatts of direct use for heating and a small power plant in Birdsville, Queensland using 98°C water from a sedimentary aquifer (Beardsmore and Hill, 2010). Over the last decade, Australia's geothermal industry has begun to develop. While a great deal of activity has taken place in developing preliminary resource assessments, there have been only four projects that have tested their resources by deep drill wells, two EGS and two HSA.

Innamincka Deeps

The Innamincka Deeps is Australia's pioneering and best known EGS project. Located in northeast South Australia, the project is a joint venture between Geodynamics Ltd. and Origin Energy Ltd. operated by Geodynamics. The project is targeting a high heat producing granite buried under the Cooper and Eromanga basins. Five wells have been drilled across

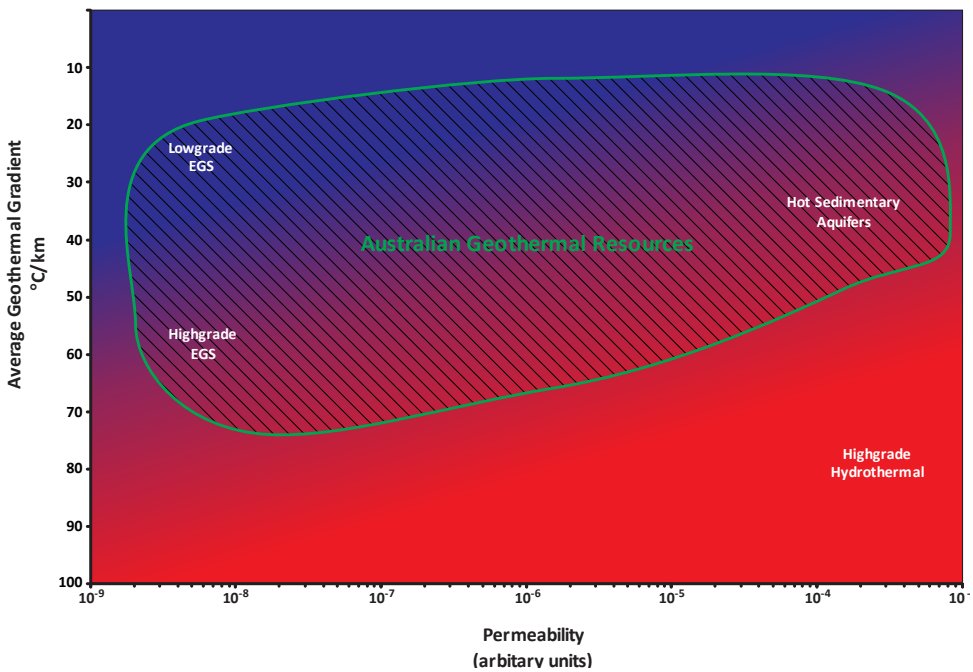

Figure 1: Geothermal resources as a function of average geothermal gradient and permeability. The resource styles currently targeted in Australia cover the broad spectrum of highgrade Enhanced Geothermal Systems (EGS) through to Hot Sedimentary Aquifers(HSA) with permeability as the key variable due to the absence of the very high geothermal gradients associated with highgrade convective hydrothermal systems. After Hildigunnur et al. 2008).

three fields to depths between 3,700 and 4,911 m including Jolokia-1, which had a bottom hole temperature of 274 °C, making it the hottest geothermal well drilled anywhere in the world outside of a hydrothermal system. At the Habanero field, three wells have been drilled with a successful stimulation program and circulation of reservoir fluids through a closed loop at a sustained rate of just under 20 kg/s. However, Geodynamics have also experienced several technical setbacks that have delayed their progress. The Habanero 2 well was abandoned due to poor well stability and the resulting loss of drilling gear in the well; Habanero 3 was abandoned after a blow out caused by a casing failure; and the poor results from the stimulation of Jolokia-1.

The three wells at the Habanero field all intersected open sub-horizontal fractures. An unexpected discovery in the three fields drilled is that the reservoir is highly overpressured. All wells have been completed without casing the reservoir interval.

The variability in the results from these wells highlights the difficulty in predicting flow and reservoir conditions in crystalline rocks that are relatively homogeneous in composition, but have a heterogeneous distribution of fractures.

Innamincka Shallows

The Innamicka Shallows is targeting HSA resources within the same licence areas as the Innamincka Deeps. This project is a joint venture between Geodynamics Ltd. and Origin Energy Ltd. operated by Origin Energy. The Celsius-1 well was drilled to 2,416m to test the potential of the Hutton Sandstone. While achieving suitable temperatures (in excess of 145 °C at bottom of hole), the permeabilities were significantly lower than expected.

Paralana

The Paralana project, also in South Australia, is operated by Petratherm Ltd on behalf of its joint venture partners. The project is targeting an EGS resource targeting a reservoir in faulted low grade metamorphic rocks above a crystalline basement containing high heat producing granites. One deep well has been drilled, Paralana-2, to a depth of 4,003m. This well was stimulated in July 2011 and microseismic monitoring indicates that this stimulation was effective.

The Paralana-2 well also found that the reservoir rocks were overpressured. This overpressure combined with fractured ground led to the collapse of

the lower 300m of the well before casing could be set.

Salamander-1

The Salamander-1 well was drilled to a depth of 4,025m in the Otway Basin, South Australia by Panax Ltd. The well targeted an HSA resource. The flow rates achieved and reservoir permeability were much lower than expected. Investigations are continuing to determine if the low flow rates are the result of low primary permeability, formation damage due to the drilling muds used, or fines migration.

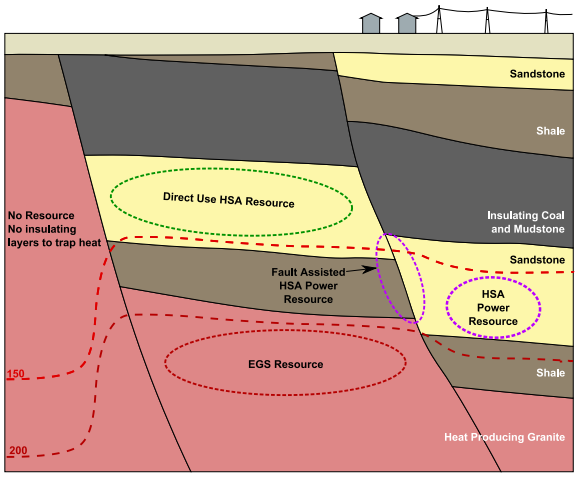

Figure 2: Schematic showing some of the geothermal resource styles under development in Australia.

Australia's Geothermal Research Sector

A focused research sector in Australia has only begun to emerge over the last five years. The sector is based on Australia's strong track record in the earth sciences and resource extraction. There are now three research centres with a focus on geothermal energy, as well as strong research programs in the national science agency and geological survey. The leading research organisations have established the Geothermal Research Initiative (GRI), bringing together the eight key players in geothermal energy research in Australia who have agreed to collaborate on the research and development of geothermal energy resources across a broad range of technologies and geographical locations in Australia. The GRI's aim is to perform research that supports the development of commercial and sustainable large scale geothermal power generation (electricity and heat) in Australia. The GRI was formed in August 2010 and has developed a collegiate and collaborative working style. The GRI members and their research focus are outlined below:

The Commonwealth Scientific and Industrial Research Organisation

The CSIRO is Australia's national research agency. CSIRO's research capabilities in the geothermal arena are broad, due to the organisation's research diversity and ability to integrate multidisciplinary skills. CSIRO is deploying its research expertise in hydraulic fracturing, reservoir engineering, wellbore stability,rock petrophysics, numerical modelling and microseismic monitoring to geothermal projects.

CSIRO has funding to develop a large scale direct use demonstration project in Perth. This project aims to produce water at approximately 70°C to run an adsorption chiller and provide cooling to a large building.

Geoscience Australia

Geoscience Australia is Australia's federal geoscientific agency. Through its Geothermal Energy Section, Geoscience Australia aims to improve the existing knowledge about the type and location of geothermal resources in Australia on a national scale. It also aims to encourage investment, exploration and exploitation of this energy source through provision of precompetitive geoscience datasets relevant to geothermal energy.

The Western Australian Geothermal Centre of Excellence

The Western Australian Geothermal Centre of Excellence is an unincorporated joint venture between the Commonwealth Science and Industry Research Organisation (CSIRO), the University of Western Australia (UWA), and Curtin University. The centre was established in February 2009 with funding from the Western Australian government and substantial in-kind and cash contributions from the centre's members. The centre is providing a scientific focus to the development of the geothermal industry in Western Australia, concentrating on the Perth Basin, and building educational programs around geothermal energy. The centre's three research programs focus on HSA geothermal plays and direct use of the heat produced from these resources.

The Queensland Geothermal Energy Centre of Excellence

The Queensland Geothermal Energy Centre of Excellence is based at the University of Queensland and was established with a grant from the Queensland Government. The centre has four research programs:

Power Conversion - developing technologies to enable production of 50% more electricity from binary plants using the same subsurface investment;

Heat Exchangers - development of natural draft dry cooling towers and other cooling solutions to increase by up to 15% the net output of geothermal plants that use air-cooled condensers;
Reservoir Geology - establish a geochemical/isotopic and geochronological database and improve understanding of geothermal resources in Queensland and develop routine exploration tools for hot rock geothermal systems; and
Transmission - research on electricity grid interaction with an emphasis on remote generation infrastructure.

The South Australian Centre for Geothermal Energy Research

The South Australian Centre for Geothermal Energy Research (SACGER) is based at the University of Adelaide within the Institute for Minerals and Energy Resources. The centre was announced by the South Australian Government as the first project to be funded from the South Australian Renewable Energy Fund. The SACGER research program focus is on subsurface factors in hot rock and EGS resources such as reservoir characterisation and modelling.

The Melbourne Energy Institute

The Melbourne Energy Institute represents energy related research involving more than 150 researchers across seven faculties at the University of Melbourne. It has a priority focus on large-scale sustainable energy systems with active research programs in bioenergy, solar, wind, geothermal and carbon capture and storage (CCS) including system integration, regulatory frameworks, economics and social justice issues. Geothermal projects span fundamental geothermics, deep geothermal resource targeting and direct use geothermal applications.

University of Newcastle Priority Research Centre for Energy

Located at the University of Newcastle, the Priority Research Centre for Energy has been working on geothermal energy research projects for a number of years through the research program on Renewable Energy Systems. The University of Newcastle has received AU$30 million from the Australian Government through the Education Investment Fund and AU$30 million matching funding from other sources to establish the Newcastle Institute for Energy & Resources. As part of this initiative, significant funding has been allocated for geothermal research, in particular for the establishment of a state of the art facility for pilot-scale experimental research. The focus of geothermal research at the University of Newcastle is on novel power generation cycles and the concept of a CO2 thermosiphon for EGS.

The Institute of Earth Science and Engineering

The Institute of Earth Science and Engineering is a Research and Development organisation in the University of Auckland. The Institute works on a range of topics in the areas of energy, hazards, and environment, especially as they relate to the earth between the deepest drill holes and tallest buildings. Accordingly, IESE has a strong focus on geothermal systems, covering areas of geothermal geophysics and geology, reservoir modelling, geothermal geochemistry and mineralogy, and the energy business. Geothermal project sites include the Americas, the Southwest Pacific, Europe, and the Middle East. IESE studies earthquake and volcano hazards, with particular reference to those in Auckland area and along New Zealand's Alpine fault.

THE CHALLENGE

The challenge of establishing geothermal energy as a provider of a substantial component of Australia's energy mix has many interdependent components. There are technical, financing, policy, and community issues that need to be addressed. Any attempt to achieve the overall impact of assisting the geothermal industry can not consider these components in isolation. The GRI is taking a system wide approach to developing plans for a national research effort. Figure 3 summarises the opportunity and the approach we are building.

The overall goal of the proposed research centre is to work with the industry to realise the potential of geothermal energy to provide Australia with secure, clean energy in a carbon constrained economy. The ability to produce energy from the styles of geothermal resources found in Australia has been established, the main detractors from its development are the high costs and high risks of developing these unconventional geothermal resource. The projected costs of generating geothermal energy using current technology makes it uncompetitive with other forms of renewable energy currently available or under development in Australia. A research program must help to develop the technologies to reduce the costs of geothermal energy and reduce the risks in developing geothermal resources.

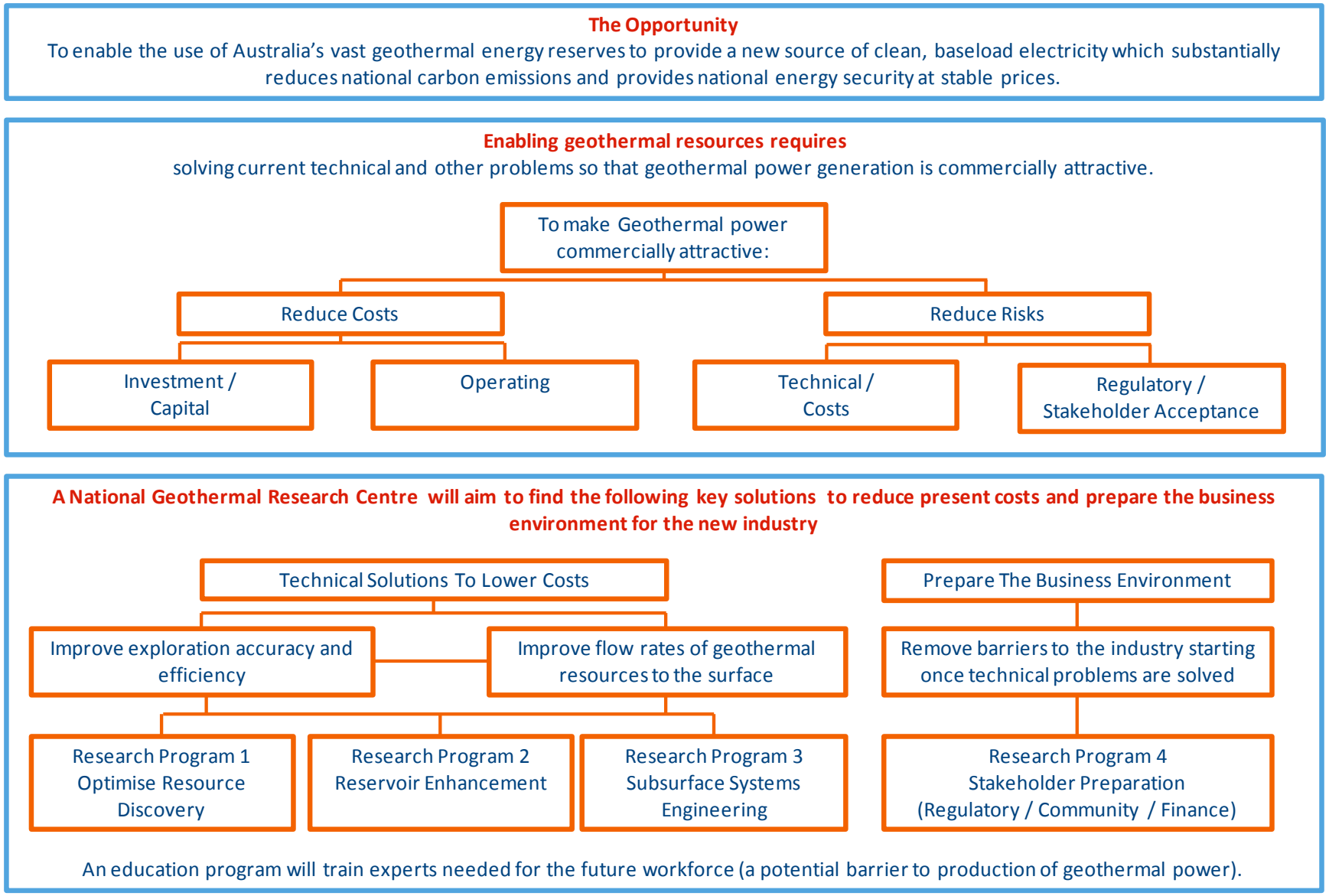

Figure 3:A summary of the opportunity and the integrated approach under development.

It's About The Flow

Producing adequate fluid flows from geothermal resources has been recognised as the key technical challenge facing unconventional geothermal resources (e.g. Tester et al 2006, Hildigunnur et al. 2008). Gurgenci (2011) used GETEM (Entingh et al 2008) to test the sensitivity of the levelised cost of electricity (LCOE) of an EGS geothermal resource to various technology improvements. The baseline for the model is based on what is known about the current EGS projects in Australia. The LCOE of the base case is 26.9 c/kWh. Several scenarios were then run to test the impacts of various technology improvements. They were doubling and tripling the flow, reducing drilling costs, increasing conversion efficiency, use of natural draft cooling towers (reducing parasitic loads), and supercritical cycles.

The results of this modeling are shown in Figure 4. The baseline assumption has flow at 30 kg/s. This is based on the results reported for all major EGS projects throughout the world, and is slightly higher than the flows achieved by Geodynamics at its Innamincka project. Doubling or tripling the flow has the biggest single impact on the LCOE. Reducing drilling costs (moving from the high to medium cost curves in GETEM) has the next highest impact with the other technologies showing incremental gains.

ADDRESSING THE CHALLENGE

The GRI are to seeking to establish a national geothermal energy research centre to help the Australian geothermal sector address these challenges. The centre will have a technology focus on increasing flow rates. This focus does not mean research solely on reservoir stimulation. Rather it will provide an integrated approach from resource discovery, reservoir enhancement, ancillary engineering and community, regulation/policy and financial systems. While the research plan is still evolving, the current view is that it will be structured around the following four research programs.

Optimising Resource Discovery

The aim of this program is to develop the technologies and work flow to target the most prospective areas for geothermal energy production, with an emphasis on discovering areas with the right environment to reduce and optimise any fracture stimulation needed to achieve the desired flow rates. The program will have one section that will aim to develop an understanding of the setting and key

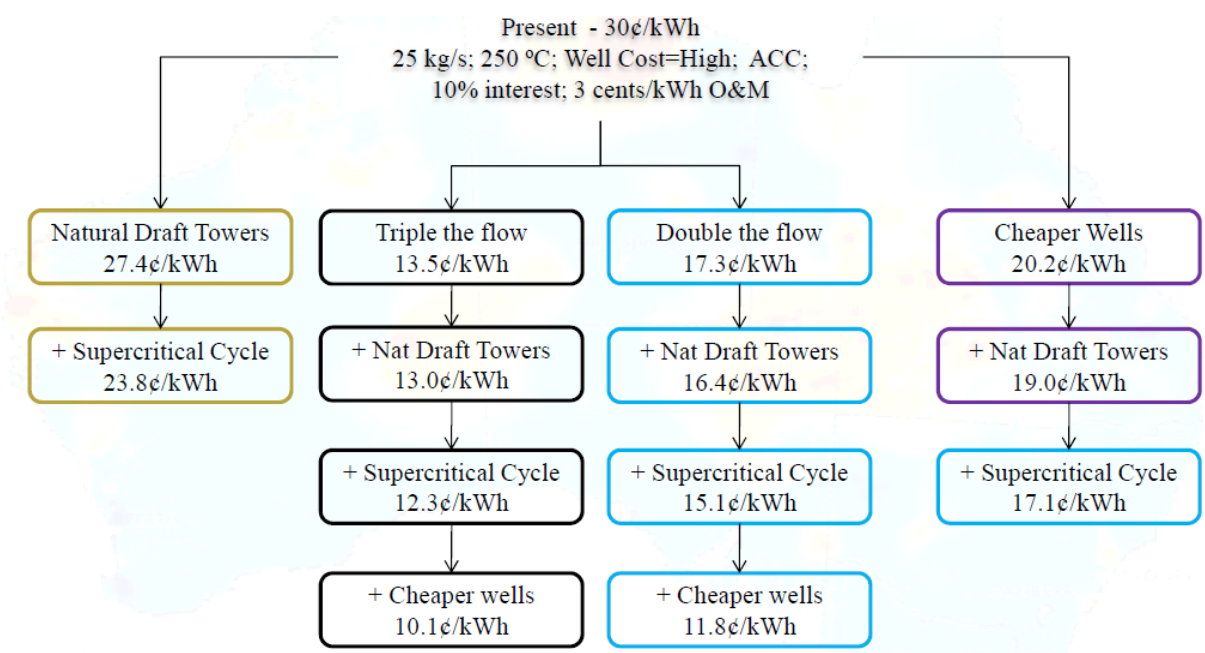

Figure 4:. Expected cost reductions by future technology improvements. From Gurgenci 2011.

components of Australia's geothermal resource through a Geothermal Systems Analysis approach. A second section will focus on the development and improvement of methods (geophysical methods including seismic and EM/MT, geochemistry and algorithms) used for exploring for resources and characterising them. These methods are applied to early exploration through to resource confirmation.

An example of the needs for this research is the unexpectedly poor flows found at Celsius-1 and Salamander-1. If the probability of finding formations with the required flow rates was better understood, these wells may not have been drilled or have targeted different localities.

The impact that this program will be to increase the chances of success of the first and subsequent wells, decreasing risks of failure and costs of resource discovery.

RESERVOIR ENHANCEMENT

This program will develop the technologies to enable the required flow rates to be achieved reliably. It will include further development of the numerical codes used to design and evaluate reservoir stimulation at well to formation, well to well and reservoir scales. These modeling tools will be underpinned by fully coupled THMC (thermo-hydro-mechanical-chemical) codes. The core of this program will be the design and trialing of reservoir stimulation methods at laboratory and field scales. These methods will include single and multiple zone stimulation of in situ fractures. There will also be a component looking at improvement of available reservoir stimulation monitoring methods (microseismic and magnetotellurics for example).

The need for improved stimulation methods is widely recognised throughout the geothermal industry. Reliable modeling tools are needed as the costs of experimenting in wells over 4,000m deep are very high and models that can be used for planning will be important. Improved fracture stimulation methods will be required to increase the flow rates achieved compared to the global experience in EGS projects to date, and may require a reexamination of fracturing processes at reservoir scale.

The impacts of this program will be stimulation methods that allow the required flow rates to be achieved reliably, modeling tools that will allow stimulation operations to be planned, conducted and reviewed to improve their efficiency and monitoring methods that will improve our understanding and management of stimulation activities.

Subsurface systems engineering

This program will aim to develop the well completion, well hardware, materials and reservoir engineering technologies required to support stimulation activities and to achieve and sustain high flow rates. This program will include a component to look at well completion technologies to enable long well life in conjunction with optimising well completion to support stimulation activities. A materials science stream will look at the development of materials for temporary sealing of fractures during drilling, diverting agents during stimulation, and cements and cement replacements for casing. A smaller component will be the development of reservoir models based on fully coupled THMC processes to predict the performance of reservoirs over their life.

Reservoir over pressures encountered in the Innamincka Deeps and Paralana projects also present specific engineering challenges that may be unique to Australia. These challenges will also be addressed in this program.

The impact of this program will be to improve reservoir stimulation efficacy through the optimised well completions, decreased drilling costs due to prolonged well life and risk reduction through a better understanding of reservoir performance through time.

Technology in Context

This program is important in ensuring the science and engineering activities can have impact by preparing the community, policy, regulatory and financial systems to work with the geothermal industry. The potential barriers to geothermal energy due to community concerns, lack of policy support, regulatory restrictions and the lack of suitable financing models could all prevent the industry progressing regardless of its technical viability.

The geothermal industry can learn from the current experiences of the coal seam gas and shale gas industries in Australia and worldwide. Technologies developed with due consideration to public concerns are more likely to succeed that technologies developed in isolation.

The impact of this program will be to reduce the potential of the geothermal industry stalling due to non-technical issues.

DEMONSTRATION SITES

Development of new technologies that have an impact on the geothermal energy sector requires close

collaboration between researchers and the industry that is operating development sites. The costs of drilling geothermal wells for experimental work are prohibitive for research organisations. Demonstration of new technologies, particularly in well completion and reservoir engineering will require access to deep wells drilled by the geothermal industry. In this regard Australia has the advantage of having two active EGS projects (Geodynamics Innamincka Deeps and Petratherm's Paralana projects), a direct use HSA project (CSIRO's SESKA geothermal demonstration project in Perth), and two completed exploration wells into HSA targets (Origin and Geodynamics Celsius-1 and Panax Ltd's Salamander-1). There are also a number of other projects proposed for development. Federal assistance is available from the recently established Australian Centre for Renewable Energy's Emerging Renewables Program. In July 2012, the Australian Renewable Energy Authority will be established to support the development of low emissions technologies including geothermal. There are also state government initiatives being pursued. It is highly likely that the over the next five to seven years there will be several more geothermal demonstration projects established in Australia.

International Collaboration

The GRI is actively seeking international collaboration on its research programs around geothermal energy. Establishing the viability of unconventional geothermal resources is a global challenge with the potential to have significant global impact. Australia is actively involved in international collaborative efforts to develop geothermal technologies including the International Partnership for Geothermal Technologies and the International Energy Association Geothermal Implementing Agreement. Australia is also a member of the International Geothermal Association through the Australian Geothermal Energy Group. The GRI has engaged with the newly established International Geothermal Data Federation and look forward to seeing how it develops. The GRI also welcomes direct engagement outside of these formal arrangements.

Our work with demonstration projects need not be confined to Australia. We will actively seek out collaboration with international projects that are aligned with our research program, and facilitate international researchers engaging with the Australian industry.

CONCLUSIONS

Geothermal energy has great potential to contribute to Australia's, and the world's, energy needs by providing clean, secure baseload power and heat for direct use. Realising this potential will require a range of technical, financial and societal challenges to be addressed. The Australian research community working collaboratively through the GRI is developing the integrated research program described here to address some of these challenges.

The GRI is preparing a submission to the Cooperative Research Centres program administered by the Australian Government through the Department of Innovation, Industry, Science, Research and Tertiary Education. The process of preparing the submission involves close engagement with the industry who will ultimately be the end users of the research outputs. In addition to this program the GRI will be exploring opportunities through the Australian Governments Clean Energy Future policies that have recently been legislated.

REFERENCES

Australian Treasury, (2011). Strong growth, low pollution modelling a carbon price. Canberra.

Bendall, B., Goldstein, B., Long, A and Budd, A. (2011). Converting Geothermal Plays to Projects in Australia — A National Review. *In: GRC Transactions, Vol.* ***35****.* 1155-1158.

Burns, K.L., Weber, C., Perry, J. and Harrington, H.J., (2000). Status of the geothermal industry in Australia. *In: Proceedings of the World Geothermal Congress 2000*. Kyushu-Tohoku Japan, May 28-June 10, 2000, 99-108

Beardsmore, G.R. and Hill, A.J. (2010). Australia – Country Update. *In: Proceedings of the World Geothermal Congress 2010*. Bali, Indonesia, 25-29 April 2010.

Entingh, D., Mines, G., Mansure, C., Petty, S., and Nix, G., 2008. GETEM: Geothermal Electricity Technology Evaluation Model. *In: Proceedings, Thirty-Third Workshop on Geothermal Reservoir Engineering.* Stanford University, Stanford, California.

Workshop on Geothermal Reservoir Engineering Proceedings.

Energy.Geoscience Australia and ABARE, (2010). Australian Energy Resource Assessment. Canberra.

Gurgenci, H. (2011). What will make EGS geothermal energy a viable Australian renewable energy option? *In: Budd, A.R. (editor) Proceedings of the Australian Geothermal Energy Conference, 16 – 18 November, Record 2011/43, 81-84.*

Hildigunnur, T., Augustine, C., Anderson, B. J., Moore, M. C., & Tester, J. W. (2008). The Impacts of drilling and reservoir technology advances on EGS. *In: Proceedings, Thirty-Third*

Workshop on Geothermal Reservoir Engineering. Stanford University, Stanford, California.

Sanyal, S. K. (2010). Future of Geothermal Energy. *In: Proceedings, Thirty-Fifth Workshop on Geothermal Reservoir Engineering*. Stanford University, Stanford, California.

Tester et al. 2006. The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century. Cambridge: Massachusetts Institute of Technology