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Externalities are the Dominant Cause of Faltering in Australian Geothermal Energy Development

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ABSTRACT

The Australian geothermal energy sector experienced a period of rapid growth from 2000, culminating in a 'heat rush' in the period 2006-2009. Since then, the sector has gradually declined. The reasons for the decline can be seen within the Geothermal Drilling Program (GDP). In 2008, the Australian Government established the AUD50 M GDP, which was designed to provide AUD7 M matched-funding to each of seven projects in order to drill two wells to achieve closed-loop flow and establish proof-of-concept. Ultimately, only two wells were drilled as part of the GDP. Examination of the reasons why this Program failed to meet Government's intentions provides important lessons for any future measures to stimulate geothermal development in Australia and possibly elsewhere.

Nine factors can be observed to have impacted the outcomes of the GDP. (1) The Global Financial Crisis (GFC), coming to prominence in 2008, was the major factor, as it caused a massive reduction in availability of capital, especially for high-risk ventures such as geothermal. (2) Against all predictions, power demand fell in the National Electricity Market. Most projects in the GDP had assumed that growth in demand in this network would provide their market. (3) Increase in cost of drilling – international demand for rigs for oil and gas drilling, including shale gas in the US, meant that rig costs in Australia rose and availability went down. (4) The GDP grants were ultimately too small – the AUD7 M per project grant amount was agreed at a time when wells were less costly and when capital was easy to raise prior to the GFC. (5) Technical 'failures' – the Habanero-3 well control incident, and low flow rates of Salamander-1 and Celsius-1 caused many to believe that geothermal would not work in Australia, impacting on investment. (6) Public misinformation on the induced seismicity risk potentially associated with geothermal development caused negative public reaction and a need to re-address risk measures in the GDP. (7) Adverse events in the Government-funded Home Insulation Program caused increased risk aversion across all Government Programs, and re-writing of the GDP's Guidelines. (8) Uncertainties and delays in the introduction of the Carbon Pollution Reduction Scheme and later taxation measures caused hesitation by investors in renewable technologies. (9) Flooding in project areas caused delays and cost increases.

The combined effect of the above was that delays caused by flooding and delivery of Government programs, combined with some apparent technical failures, meant that most geothermal developers in Australia have been unable to raise capital since the GFC and have not been able to progress projects. This has been interpreted by politicians and media that geothermal cannot deliver on promises made to quickly ramp up supply of cost-effective base load renewable power. The reality is that there has been insufficient investment to adequately develop and demonstrate the technology to reach that conclusion.

As is the case elsewhere in the world, finance mechanisms are required to lower the high initial resource risk in a number of projects across Australia to increase investor confidence in the viability of geothermal resources and technology.

1. INTRODUCTION

In the twenty one years since the first hot dry rocks feasibility study in Australia was carried out by Somerville et al. (1994), a number of direct-use projects have become operational, two small-scale electricity projects have operated (one of which continues to do so at Birdsville, Queensland), but only one megawatt-scale electricity project has reached proof-of-concept. This is in spite of many early-stage exploration projects and approximately AUD900 M expenditure, of which more than half was expended on the Innamincka Deeps Joint Venture project by Geodynamics Ltd and Origin Energy Pty Ltd. Summaries of the development of geothermal energy in Australia are provided in Burns et al. (2000), Chopra (2005), and Beardsmore and Hill (2010).

This paper examines the period of peak activity and subsequent decline from 2008 until early 2014, and explains the rise and fall of geothermal development activities with the intention of understanding past support mechanisms in order to more effectively design and target future support mechanisms. The Australian Government's Geothermal Drilling Program (GDP), with which the authors had involvement in designing, assessing and administering, is used as the prism through which the sector is examined. The majority of the exploration and development work focussed on electricity generation, and this paper follows that focus.

2. BACKGROUND – GROWTH AND RETRACTION OF THE GEOTHERMAL INDUSTRY IN AUSTRALIA

The development of unconventional geothermal resources such as those in Australia is part of the continued global geothermal resource development pathway from very shallow resources (e.g. Lardarello, Italy) to deeper resources with few surface features (e.g. Salton Sea, US), to completely blind resources such as those primarily seen in Australia. Unconventional resources generally have conductive rather than convection heat regimes, and have lower heat flow.

With no active volcanoes on the Australian mainland, and few hot springs, it is not surprising that it has only been in the last 20 years that using geothermal energy has been seriously contemplated in Australia. Studies on geothermal potential began in the mid-1970's with compilations of heat flow determinations, hot spring occurrences and bore hole temperatures (Cull 1976, Cull 1978,

Cull and Denham 1979, Cull and Conley 1983). A case for a program to evaluate Australia's geothermal energy potential, including for 'hot rock systems', was put forward by Cull and Denham (1978), and an uncorrected geothermal map from bore hole gradients produced in 1980 (Nicholas et al. 1980). The first study on hot dry rocks feasibility was by Santos Ltd, a petroleum company, for power for a gas pipeline compressor station in the Cooper Basin of South Australia (Haines, 1984). A more significant study on hot dry rocks feasibility was completed for the Energy Research and Development Corporation in 1994 (Somerville et al. 1994).

A small geothermal power station has been operating at Birdsville, Queensland, utilising the town's artesian water supply bore with a relatively modest production temperature of 98°C (Ergon 2014). The plant was installed in 1992 and ran until 1994. It was recommissioned in 2001, and further modified in 2005. The geothermal resource is part of the Great Artesian Basin, and is considered to be a Hot Sedimentary Aquifer (HSA) resource. Power output is only ~80 kW net, but this amounts to one-third of the township's power demand and reduces the remote town's reliance on diesel fuel for power.

2.1 Basis of Sector in Australia

Legislation allowing, and regulations governing geothermal exploration were introduced in New South Wales in 1998, in South Australia in 2000, and subsequently in each other state and the Northern Territory. The first geothermal licence area was operated by Pacific Power Corporation, which conducted a seismic reflection survey and in 2001 drilled a 1946 m deep temperature logging well in the Hunter Valley, New South Wales. By 2004, Geodynamics Ltd had drilled Habanero-1 to 4421 m at Innamincka, South Australia.

The exploration and development activity that has occurred in Australia is distinct to EGS developments elsewhere in the world because the overwhelming expenditure has come from private, not government, funding. The relative ease of access to risk capital in Australia allowed tens of millions of dollars to be raised on the Australian Securities Exchange (ASX) for fundamental exploration and resource characterisation work (Beardsmore and Hill 2010).

A number of actions by Government have been very important to the early development of the sector. Firstly, legislation was passed in all jurisdictions to allow geothermal exploration and development. Secondly, in 2000 the Australian federal parliament passed the Renewable Energy (Electricity) Act and introduced the Mandatory Renewable Electricity Target (MRET) Scheme on 1 April 2001 (Chopra 2005). This provided a targeted amount of electricity to be sourced by generators from renewable sources, with tradeable Renewable Energy Certificates for each MWh produced. This incentive was important at the time for encouraging investment in renewable energy in Australia. In 2004, the Australian Government introduced the Low Emissions Technology Development Fund (LETDF) to provide AUD500 M for demonstrating new low emissions technologies with significant long term greenhouse gas abatement potential (Chopra 2005), and again this provided a strong signal of government support to renewable technologies investors. The LETDF was changed to become the Renewable Energy Demonstration Program (REDP), and two large grants were awarded to geothermal projects (see below).

Peak interest in the Australian geothermal sector occurred in 2009. The Australian Government had expressed strong support for the development of renewable technologies, including geothermal through the GDP, the Geothermal Industry Development Framework (GIDF; GIDF 2008) and Geothermal Industry Technology Roadmap (GITR; GITR 2008), the formation of the Australian Centre for Renewable Energy (ACRE), and the REDP. The Australian Geothermal Energy Association (AGEA), and some companies commissioned studies which indicated fast growth potential for generation from geothermal projects, including predictions of 2200 MW installed capacity by 2020 with a delivered power price of AUD90 per MW/h. The annual growth rate for electricity demand was approximately 3.5% in 2009, and had been steady for over a decade (AER 2013).

By the end of 2010, 57 companies had applied for 414 licence areas (covering 472,000 km^2) (Goldstein and Bendall, 2011). It is estimated that by early 2014 a total of approximately AUD900 M has been expended on geothermal projects and research in Australia, with approximately AUD107 M coming from various State and Federal government agencies. Nine deep geothermal wells have been drilled to test and characterize geothermal reservoirs (Figure 1, Table 1).

Table 1: Wells drilled in Australia to test deep reservoirs

Date Drilled	Name	Project	Operator	Depth	Max. Temperature	Target
2003	Habanero-1	Innamincka Deeps	Geodynamics	4421 m	243 °C	EGS - granite
2004	Habanero-2	Innamincka Deeps	Geodynamics	4459 m	244 ºC	EGS - granite
2008	Habanero-3	Innamincka Deeps	Geodynamics	4200 m	242 ºC	EGS - granite
2008	Jolokia-1	Innamincka Deeps	Geodynamics	4911 m	278 ºC	EGS - granite
2009	Savina-1	Innamincka Deeps	Geodynamics	3700 m	Well suspended	EGS - granite
2009	Paralana-2	Paralana	Petratherm	3725 m	176 °C	EGS – metasediment
2010	Salamander-1	Penola	Panax	4025 m	171 °C	HSA – sandstone
2011	Celsius-1	Innamincka Shallows	Origin	2417 m	160 °C	HSA - sandstone
2012	Habanero-4	Innamincka Deeps	Geodynamics	4204 m	242 ºC	EGS - granite

2.2 Sector Self-organisation

The Australian geothermal sector self-organised to a high degree, particularly through two bodies – the Australian Geothermal Energy Group (AGEG), and the Australian Geothermal Energy Association (AGEA).

The AGEG was formed in 2005 by Barry Goldstein working for the South Australian Mines and Energy department (now Department for Manufacturing, Innovation, Trade, Resources and Energy - DMITRE), which is Australia's Contracting Party to the International Energy Agency Geothermal Implementing Agreement (IEA GIA: http://iea-gia.org/). The AGEG functions somewhat

like a professional society, having the purpose of providing information to members. It also operated a number of Technical Interest Groups to undertake a number of pieces of work (see below). Membership comprised individuals and corporations across the sector, was free, and numbered more than 100 (individuals members were not counted if part of an organisation).

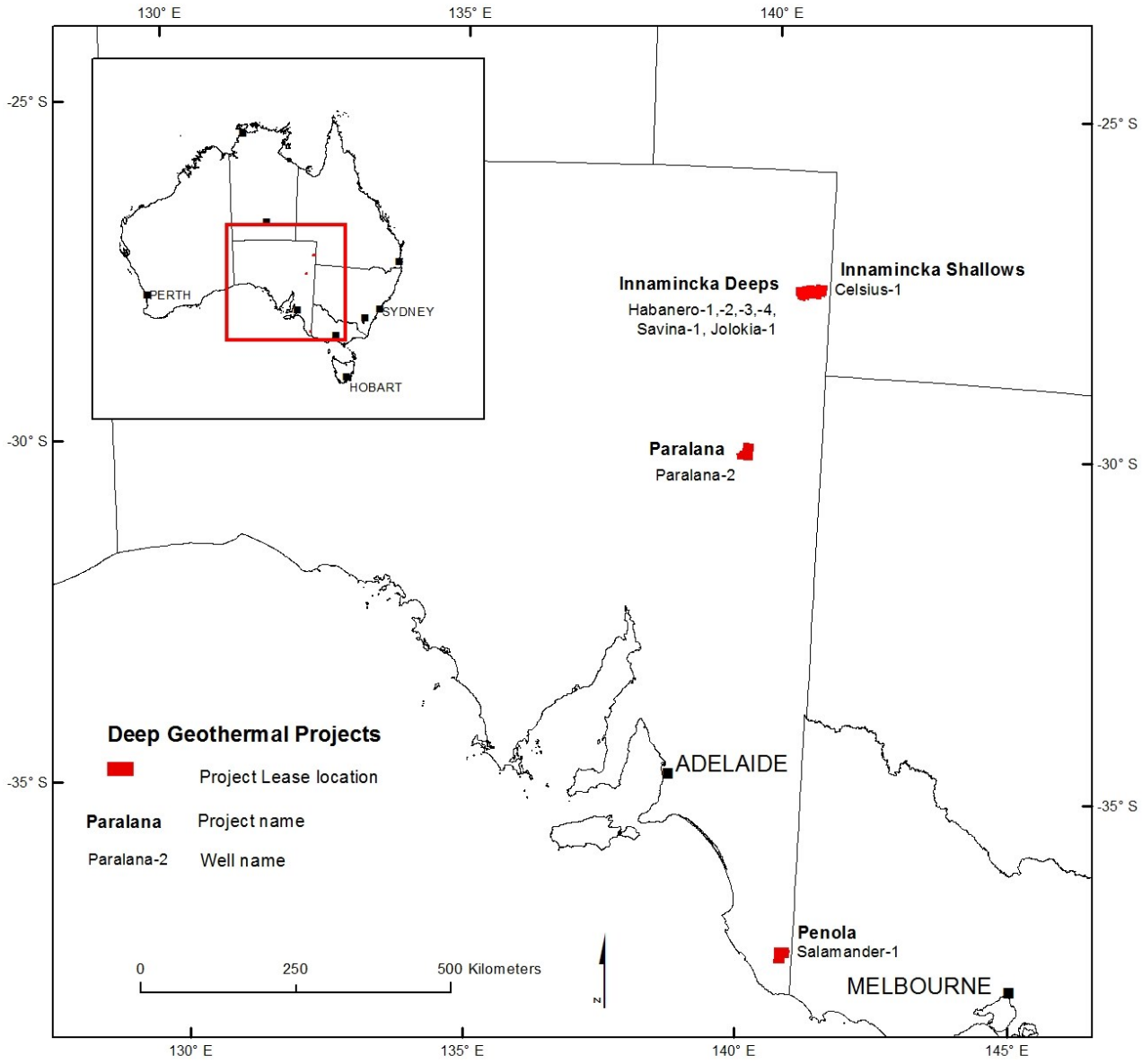

Figure 1: Location of deep geothermal wells drilled in Australia. Nine wells have been drilled to evaluate geothermal reservoirs.

The AGEA formed in 2007 from the Renewable Energy Generators Forum as a sufficient number of companies existed to support a sector-specific association. It had corporate and individual membership fees, and principally served as a lobby and advocacy group. Together with the AGEG, AGEA ran the annual Australian Geothermal Energy Conference (initiated in 2008), and most notably, developed the Australian Code for reporting of Exploration Results, Geothermal Resources and Geothermal Reserves (AGEA-AGEG 2009). DMITRE, with the AGEG and the IEA GIA developed the first protocol for induced seismicity (e.g. Morelli and Malavazos 2008).

Australia's leading research organisations established the Geothermal Research Initiative (GRI) in August 2010 (see Section 3.12).

3. SECTOR DEVELOPMENT 2007-2013

3.1 Geothermal Drilling Program and Associated Government Measures

The 2007 national election saw a transition from the centre-right Coalition to the centre-left Labor. The GDP was an election promise from Labor, and was launched in early 2008. Unfortunately the program fell far short of its promise, which has been held as a black mark against the industry, with only 1.7 grants being expended out of the seven committed. Many of the factors that affected the GDP were externalities, i.e. were not isolated to or caused directly by the actions of the industry. These factors and a timeline of events affecting the GDP are discussed below and summarised in Table 2.

On 16 September 2008, the Minister for Resources and Energy made a statement to Parliament regarding geothermal energy potential in Australia (Ferguson 2008). Minister Ferguson expressed strong support for the development of a geothermal industry, and included mention of Australia's joining as a foundation member of the International Partnership for Geothermal Technology.

The GIDF and companion GITR were launched by Minister Ferguson on 1 December 2008. Work on these documents was initiated at a Geothermal Industry Roundtable hosted by Resources Minister Ian Macfarlane and Environment and Water Resources Minister Malcolm Turnbull (of the previous Howard Coalition conservative government) on 27 March 2007. The work on the GITR was to be part of a State-Federal Government working group process on energy. The work was completed by a contractor for the Department of Resources, Energy and Tourism (DRET). Delays unfortunately meant that the GIDF and GITR were launched later than the GDP, although the GDP was designed to address many of the issues identified in consultation for the GIDF and GITR.

Consultation for the design of the GDP began in early 2008. Five options were initially discussed, being: support for drilling deep wells; access to drilling rigs (Government buys rig, operated by contractor); a well insurance scheme similar to that already operated by the World Bank; and support for shallow exploration drilling and associated testing to lower resource risk prior to expensive deep drilling. An option was put forward to set aside an amount (AUD10 M) for drilling-related support activities identified in the GIDF.

The GDP was opened for Expressions of Interest by the Minister for Resources and Energy Martin Ferguson on 8 August 2008. The main features of the Program were:

- a maximum of AUD7 M per project with a matching funding requirement (i.e. maximum Commonwealth Government contribution of 50%);
- eligible projects were to be for proof-of-concept (circulation between a pair of injection/production wells);
- the Program was competitive and to consist of a number of rounds;
- merit criteria were used to assess and rank applications. The criteria covered technical, managerial and financial aspects. Projects were expected to be able to meet the requirements of an Inferred Geothermal Resource by the terminology of the Australian Code for Reporting of Geothermal Exploration Results, Geothermal Resources and Geothermal Reserves (AGEA-AGEG 2009); and
- grant funding to be provided up-front instead of in arrears, with each grant having milestones and stage gates. Funding was to be made available as 60% on project commencement, 35% on demonstration of a suitable reservoir based on the results of the first well, and 5% upon agreed completion of the project including provision of geological data for the public record.

Applicants for Round 1 of the GDP provided an Expression of Interest in September 2008, and were then provided with feedback by the DRET for the purpose of improving full applications. Workshops to guide applicants through the full GDP application process were held in November 2008, and Round 1 closed in late December 2008. The full applications were assessed against the GDP merit criteria by financial and technical assessors, as well as being checked for eligibility by the DRET. The assessments were passed on to a specially-established Geothermal Expert Committee, which made recommendations to the DRET. Two Round 1 offers were made by Minister Ferguson on 20 April 2009, to the Paralana project of Petratherm Ltd and the Penola project of Panax Geothermal Ltd (now Raya Group).

Round 2 of the GDP opened on 9 June 2009, and on 6 November 2009 offers were made to the Koroit project of Hot Rock Ltd, the Hunter Valley project of Geodynamics Ltd, the Parachilna project of Torrens Energy Ltd, the Perth Metro project of Green Rock Ltd, and the Geelong project of Greenearth Energy Ltd. During this time, responsibility for the GDP was transferred from the DRET to the newly-created ACRE. However, there was a substantial delay until the execution of the grant deeds, with the deeds being executed between 17 August and 10 November 2010.

The first well to be drilled as part of the GDP was the Paralana-2 well, operated by Petratherm Ltd (Petratherm 2010, Petratherm 2011). Petratherm Ltd developed a new type of EGS concept, which they termed 'Heat Exchanger Within Insulator (HEWI)' (Petratherm 2007). The following paragraph is based on information from those three Annual Reports. The Paralana project is in the Arrowie/Poontana Basin adjacent to the northern Flinders Ranges approximately 600 km north of Adelaide. The chosen site is a small but deep graben in Mesoproterozoic basement infilled with Cambrian and younger sediments. The HEWI model postulates that deep sediments above high heat producing granites will be nearly as hot as the deeper granites, but will be easier to create permeable fracture networks within. Being shallower, the tradeoff of lower temperature is likely to be offset by cheaper drilling (Sanyal 2009) in addition to higher permeability. The well was spudded on 30 June 2009 and drilled to 4012 m, but obstructions meant that the well was fully cased with 7" casing to 3725 m. Rain caused delays during final cementing and casing, and partly contributed to an increased cost to the well of approximately AUD2 M (Petratherm Ltd has not stated what the full well cost was). The rig was released on 12 December 2009. Testing and hydrofracturing of the well occurred over the next 12 months, with delays caused by equipment unavailability and further rain and flooding restricting access. Excellent results were achieved in this well, with a temperature of 176 °C recorded at 3672 m, slight overpressures with inflows into the well via a number of fractures, and benign brines. An extensive seismic cloud was developed during a relatively small hydraulic stimulation event. Real-time seismic monitoring was employed during the hydraulic stimulation. Also, repeated magnetoteulluric surveys before and after injection suggest that stimulation occurred in an anisotropic heterogeneous complex fracture network (Peacock et al., 2013) rather than in a single fault plane. The identification of a complex fracture network should provide advantages for efficient fluid-rock heat exchange. The reservoir stimulation results were achieved through a single well perforation interval of six metres between 3679 and 3685 m. It could be expected that additional perforation intervals and stimulations could result in a high reservoir volume for use as a heat exchanger, with a higher fluid-rock surface area than those seen to date in other EGS reservoirs around the world. As of May 2014, Petratherm Ltd have been unable to raise sufficient funds for a second well, with a July 19 2014 deadline for securing the

funding shortfall (http://www.asx.com.au/asxpdf/20140506/pdf/42pg7zvy9wcqrb.pdf). Petratherm Ltd has negotiated a few changes to its grants with Australian Renewable Energy Agency (ARENA), including finalisation of the GDP grant in favour of an ERP grant, and a reduction with change of terms for its REDP grant (see below).

Petratherm Ltd formed a "rig club" to disburse the costs of rig mobilisation, and contracted Weatherford International to import the 2000 HP Le Tourneau "Lightning Rig" #828 from Dubai. This rig was also used to drill Salamander-1 (see below), but a third partner in the club withdrew leaving Petratherm Ltd to bear a large share of the rig mobilisation charges.

The second well drilled as part of the GDP was the Salamander-1 well, operated by Panax Geothermal Ltd (now Raya Group). Salamander-1 was drilled in the Penola Trough in the westernmost Otway Basin, South Australia, and was targeting an HSA play within the Cretaceous Pretty Hill Formation. Relatively good quality geological data was available in the area, including deep offset petroleum wells, seismic surveys and rock property data. At the target depth of 3500-4000 m the coarser sandstones of the Pretty Hill Formation were estimated to have porosity of 15% ± 2% (Panax 2008). The spud date was 31 January 2010, and the well was drilled to 4025 m in 44 days, and the bottom 1125 m 8½" section was cased with slotted liner (Panax 2010a). Steam was produced from the well, with a maximum temperature of 171.4 °C recorded at 4000 m (Panax 2010b). Well clean-up operations saw a decrease in flow rates. A study by the University of Adelaide's South Australian Centre for Geothermal Energy Research found it likely that fines migration had compromised permeability (Badalyan et al. 2013). Although the GDP guidelines were for two-well projects, Panax Geothermal Ltd negotiated with the DRET that all of the AUD7 M grant funding could be used for the Salamander-1 well. As of early 2014, there are no public plans to assess the possibility of any permeability stimulation or flow impedance remedial processes, and Raya Group is focussing on Indonesian geothermal prospects and projects.

On 8 August 2011 Green Rock Ltd, Torrens Energy Ltd, Greenearth Energy Ltd and Hot Rock Ltd jointly announced the relinquishment of their GDP grants. None of the companies were able to meet the Commonwealth's matching funding requirements. On that day the Minister for Resources Martin Ferguson announced that the Emerging Renewables Program (ERP) was open, and that AUD26 M returned from the GDP would be added to the AUD100 M previously set aside for the ERP.

In December 2012, Geodynamics Ltd relinquished its GDP grant for its Hunter Valley EGS project. In June 2013, Petratherm Ltd relinquished its unspent GDP grant (approximately AUD2.8 M) and reduced its REDP grant (from AUD68.2 M for a 30 MW plant to AUD24.5 M for a 7 MW plant) in favour of a AUD13 M ERP grant. This change was made to make more grant funding available earlier in an attempt to enable the drilling of a second deep well–Paralana-3.

Of the AUD50 M committed to the GDP, only AUD11.2 M was expended. Of the 14 wells that were planned, only two were completed, and no proof-of-concept was demonstrated by the GDP.

The Geodynamics Ltd Innamincka Deeps JV project did not receive GDP funds, but was awarded an AUD90 M grant from the REDP (Geodynamics 2010). This has been the flagship geothermal project in Australia, and while it has suffered a number of setbacks (discussed throughout this paper), it has also had considerable success. In particular, a 1 MW pilot plant was successfully operated for 160 days (Geodynamics 2013). Prior to closure of the trial, the plant was operating at 19 kg/s and 215 °C brine produced at the well-head. The operation of the pilot plant will enable Geodynamics Ltd to complete studies on the financial viability of further development.

Table 2: Timeline of main events affecting the Australian geothermal sector with particular relation to the Geothermal Drilling Program.

Year	Period	Event
2007	27 March	Geothermal Industry Roundtable, Parliament House, Canberra
	24 November	Federal election, change of government
2008	Early	Consultation on design of Geothermal Drilling Program (GDP)
	16 September	Minister Ferguson statement to Parliament on geothermal energy
	August – September	Expressions of Interest for GDP Round 1 lodged
	November	Workshops on applications for GDP Round 1
	1 December	Minister Ferguson launches Geothermal Industry Development Framework (GIDF), Geothermal Industry Technology Roadmap (GITR)
	15 December	Carbon Pollution Reduction Scheme White Paper released
	Late December	Round 1 GDP applications close
2009	Early	Deliberations on GDP Round 1
	February	Flooding of the Cooper Creek
	20 April	Minister Ferguson announces Round 1 GDP offers to Petratherm Ltd and Panax Geothermal Ltd
	29 April	Habanero-3 well control incident
	9 June	GDP Round 2 opens for applications
	30 June – 12 Dec	Drilling of Paralana-2 by Petratherm Ltd. Testing and stimulation over next 12 months
	15 September	Major Wall St stock devaluation marks onset of Global Financial Crisis (GFC)
	October	Australian Centre for Renewable Energy (ACRE) takes responsibility for GDP
	6 November	Round 2 GDP offers made to Hot Rock Ltd, Geodynamics Ltd, Torrens Energy Ltd, Green Rock Ltd and Greenearth Energy Ltd
2010	31 Jan – 23 Mar	Drilling of Salamander-1 by Panax Geothermal Ltd. Testing over next two months

Year	Period	Event
	19 February	Termination of Home Insulation Program
	Mid – late	Heavy rainfall and flooding affects Paralana and Innamincka projects
	August	Formation of Geothermal Research Initiative
	17 Aug – 11 Nov	Signing of Round 2 GDP grant deeds
2011	Early	Heavy rainfall and flooding affects Paralana and Innamincka projects
	May – April	Drilling of Celsius-1 by Innamincka Shallows JV
	8 August	Green Rock Ltd, Torrens Energy Ltd, Greenearth Energy Ltd and Hot Rock Ltd relinquish GDP grants
	8 August	Minster Ferguson announces opening of Emerging Renewables Program (ERP) incorporating AUD26 M in unspent funds from GDP
	September	Clean Energy Act legislated
2012	1 July	Australian Renewable Energy Agency (ARENA) replaces ACRE, taking responsibility for ERP and Renewable Energy Demonstration Program (REDP)
	December	Geodynamics Ltd relinquishes GDP grant
2013	20 June	Petratherm Ltd relinquishes remainder of GDP grant, reduces REDP grant, and gains ERP grant

3.2 Government Programs Dealing with Geothermal

The GDP was initially part of the Renewable Energy Fund administered directly by the DRET. In October 2009, the GDP became the responsibility of the newly-formed Australian Centre for Renewable Energy (ACRE), which had a Board and a degree of autonomy from the DRET, but was ultimately still responsible to that portfolio's Minister. On 8 August 2011, the unexpended GDP funds were made available to the ERP.

On 1 July 2012, ARENA came into force, and replaced ACRE which included taking responsibility for the ERP and REDP; the GDP had ceased by this date. ARENA was created through legislation (Australian Renewable Energy Agency Act 2011), and is largely autonomous, although its budget is still controlled by Government. The transitions to ACRE and ARENA have been disruptive to the geothermal industry. At both times, new Boards were formed and new staff employed with little experience or familiarity with geothermal issues. Both new agencies have conducted reviews in order to educate themselves about the needs of the sector. Geothermal, as a geological resource, is very different to other renewable energies, and more difficult, expensive and risky to understand, discover and characterise. Effectively managing programs and setting policy demands a high level of technical knowledge and years of experience. The separation of functions for technical knowledge, program delivery, and policy development within the government has created barriers.

3.3 Carbon Pollution Reduction Scheme

The Carbon Pollution Reduction Scheme White Paper was released on 15 December 2008 (CPRS 2008), signalling an intent by the Labor Government of the day to encourage the deployment of new renewable energy technologies. The Bill was introduced to Parliament three times, each time passing the House of Representatives but each time being rejected by the Senate. A form of carbon tax was legislated in 2011 (the Clean Energy Act 2011). Uncertainties in this area of government policy caused hesitation by investors in all renewable technologies in Australia, as very few of the technologies can become commercialised without some form of government support.

3.4 Flooding

In February 2009, a decade-long drought broke in the Cooper Basin and Flinders Ranges project areas causing extensive equipment movement delays as unsealed roads became impassable. This did not directly affect any GDP projects (they started later than this), but did delay the Geodynamics Ltd Habanero project. Further significant rain and flooding events in these areas also occurred in mid- and late-2010 and early 2011 which did cause delays to the Paralana project.

3.5 Technical Failures/low flow rates/high costs

Only two wells were completed as part of the GDP; however Geodynamics Ltd and Joint Venture partner Origin Energy Ltd did drill a number of wells during the same period which included funding from the REDP. Unfortunately, many of these wells encountered difficulties during drilling or low resultant flow rates, or were very expensive. The low success rate, and very high cost of some wells, has been widely perceived as demonstrating that geothermal resources in Australia are too risky and too costly to discover, characterise and exploit.

Geodynamics Ltd built a 1 MW pilot power plant and surface infrastructure to circulate geothermal brine between the Habanero-1 and Habanero-3 wells, and was due to commission the circulation loop and power plant in late April 2009, following the successful circulation of geothermal brine between the wells in March, marking proof-of-concept. On 24 April 2009, the Habanero-3 well control incident occurred. Uncontrolled flow from Habanero-3 was stopped 28 days after the original incident date. Initial investigation concluded that the casing material had cracked due to hydrogen embrittlement, which was caused by dissolved gases in the geothermal brine (Geodynamics Ltd 2011). A more in-depth, two-year long investigation found that the combination of highly caustic fluids on the outside annulus of the casing combined with high temperatures during production testing caused stress corrosion cracking. The highly caustic fluids were remnant in the annulus between production and intermediate casings due to difficulties encountered while mixing slurry for cementation (Geodynamics Ltd 2011). The Innamincka Deeps Joint Venture received a AUD14.8 M payout from well insurance for the loss of the Habanero-3 well.

As part of a strategy to prove a large resource area and therefore gain investor confidence, Geodynamics Ltd drilled two wells at approximately 10 and 20 km distance from the Habanero site, into the same granite body (Geodynamics 2009). Jolokia-1 spudded on 18 May 2008 and drilled to 4911 m, becoming Australia's deepest onshore well. A temperature of 278 °C was recorded at the base of the hole following completion on 24 September 2008 (Geodynamics 2009). No drilling or completion difficulties were encountered other than low rates of penetration. The findings of the Habanero-3 well control incident reviews caused Jolokia-1 to be re-lined in July 2010 prior to hydraulic stimulation, however hydraulic stimulation did not return good results. Geodynamics Ltd concluded that the steeply dipping fractures encountered in the well were not optimally oriented for hydro shearing, a very different result to that found at Habanero. Logging the deep part of the well was difficult because of the high temperatures and pressures (Geodynamics 2011).

Also drilled in the Innamincka Deeps project, Savina-1 was spudded on 23 October 2009, and reached a maximum depth of 3700 m. Drilling had been conducted with managed pressure (underbalanced) drilling, with a relatively low mud weight. An overpressured conductive fracture caused the drill string to become differentially stuck, and the well was secured with a plug at 2640 m (Geodynamics 2009). The fracture is similarly overpressured and productive as the Habanero Main Fracture. No temperature measurement has been reported by Geodynamics Ltd, but it states that a nearby well indicates temperatures higher than at Habanero.

In 2012 Habanero-4 was designed to address all of the issues encountered by previous drilling at Habanero, Savina and Jolokia. It was drilled according to prognosis, with the exception of part of the final reverse cementing job requiring remediation by a squeeze job (Geodynamics 2012a). The well cost approximately AUD51.5 M, including a high well-design cost.

In May-April 2011 Celsius-1 was drilled to a depth of 2416 m in what has become known as the Innamincka Shallows Joint Venture, operated by Origin Energy. Celsius-1 was designed to test the potential of using the Hutton Sandstone as a permeable aquifer, in the shallow sedimentary sequence above the Habanero granite. Temperatures in excess of 145 °C were recorded, but poor flow rates were found (Geodynamics 2011).

As discussed previously, the part-GDP funded Salamander-1 well was drilled quickly with no difficulties on the Limestone Coast, South Australia, gave a good indication of good temperature at 4000 m, but returned low flow rates (Panax 2010c).

There are a number of positive results that are often overlooked in the face of the incidents above. Regarding cost, Habanero-1 and -2 were drilled for relatively low cost at approximately AUD16 M each, and the shallower Celsius-1, Salamander-1 and Paralana-2 wells were drilled for similar costs. Regarding flow rates, no deep geothermal well and reservoir has yet been shown to be adequately productive, however some reservoirs have not been adequately tested. For example, there were limitations on the hydraulic stimulation in the Jolokia-1 well – a higher pressure of water injection, thermal stimulation or some form of fracture initiation method may have developed higher injection rates. At Paralana-2, good self-flow rates were seen, hydraulic stimulation showed a well-developed three dimensional fracture cloud from a single perforation interval, and time-series magnetotelluric data during the stimulation showed a dramatic increase in conductivity that could be explained by the formation of an interconnected fracture network. This reservoir needs to be tested by a second deep well to demonstrate proof-of-concept flow between the two wells through the reservoir. At Salamander-1, acidification was attempted to lower near-well bore impedance, but to the authors' knowledge, no evaluation has been made of the possible remediation by hydraulic stimulation for either near-well bore flow, or reservoir-scale flow path development.

Some further positives for the geothermal industry in Australia include the deep drilling experience available. Some 11,000 deep bores have been drilled for petroleum in Australia, so deep drilling is not unusual, and the temperatures and pressures of the geothermal projects outside the Innamincka Deeps project are not outside the range of experience of petroleum drilling. There are also play types that have not been tested in Australia, which may provide new opportunities for easy-to-access, high-flow reservoirs. The yet-to-be drilled Mid West Geothermal (Green Rock Energy Ltd) and Koroit (Hot Rock Ltd) projects are based on exploration/reservoir models not yet tested in Australia, but are similar to the Rhine Graben projects in Germany, particularly the Landau development. This play type targets fracture systems within sedimentary sequences, as this secondary permeability is higher than matrix permeability alone.

3.6 Global Financial Crisis

The start of the Global Financial Crisis (GFC) was marked by a major stock market devaluation on Wall Street on 15 September 2009. The strength of the geothermal industry in Australia, and the reason for the rapid progress made early on, was that exploration and development were funded by markets that were accustomed to funding resource projects with high risks. Progress had been more rapid than elsewhere in the world (mostly in exploration and identification of potential resources) where funding was provided dominantly by Government for R&D. While this more privately funded investment model enabled rapid initial progress, the effect of the GFC on geothermal investment in Australia was dramatic. At the time the GFC occurred, the five GDP Round 2 recipients were trying to raise the required matching funding for their projects, and all failed to do so in the post-GFC risk-adverse investment environment. As a result, none of the grants were able to be taken up. With the exception of Geodynamics Ltd, no significant capital raisings have been able to be undertaken by geothermal companies since the GFC.

Although the decline in the Australian geothermal industry is a result of all of the factors discussed in this paper – many of them are inter-related – the GFC is considered by the authors to be the dominant cause.

3.7 Induced Seismicity & Government Sensitivity to Program Risk

Concerns around hydraulic fracturing have become widely publicised in Australia over the past two years, mostly around coal seam gas developments. The perceived risk is primarily related to possible effects on water tables e.g. potable aquifer contamination, rather than induced seismicity. A distinction is not made by the media or the public about the difference between hydraulic fracturing operations in geothermal and petroleum developments. Hydraulic fracturing in deep EGS geothermal projects does cause

earthquakes up to magnitude 4, but do not interfere with potable water aquifers which is the principal cause of concern in shale and coal seam gas operations.

The earthquakes caused by the Basel hydraulic fracturing in 2006–2007 did have an effect in Australia during the GDP. In the Geelong area in the Otway Basin, Victoria, a GDP applicant inadvertently created the impression that it intended to use hydraulic stimulation. In spite of the fact that hydraulic fracturing was not in fact part of the project plan, a local resident raised objections resulting in a delay to the signing of the grant deed (Greenearth 2010).

In other parts of Government, adverse events in the Home (or Homeowners) Insulation Program (Garrett 2009, ANAO 2010) caused Government to review its risk profile across all Programs. The risk of induced seismicity required further changes to the GDP grants, even for projects not expecting to use hydraulic fracturing, causing further delays in the granting of Round 2 funds.

3.8 Availability and Cost of Drilling

The GDP was designed with an expected cost of drilling of less than AUD15 M per well. Drilling costs during the period the GDP was active increased significantly from this figure, driven by international demand for rigs for oil and gas drilling, particularly US shale gas. The availability of rigs in Australia also decreased because of the higher international demand.

For the GDP, Petratherm Ltd formed a 'rig club' to contract Weatherfords to bring Rig #828 into Australia (see above).

Anticipated difficulty in accessing drilling rigs drove Geodynamics Ltd to buy two rigs. Rig 100 was a 2000 HP Le Tourneau Lightning Rig, and was used to drill Habanero-3, Habanero-4, Jolokia-1, Savina-1 and Celsius-1. Rig 100 was purchased in February 2007 for AUD32 M, and Geodynamics Ltd partnered with Westpac Bank to defray AUD19 M of costs. Rig 200 was a custom-built National Oilwell Varco rig and was not used by Geodynamics in drilling. Rig 100 was sold to Weatherford for AUD16.8 M (Geodynamics 2012b), and Rig 200 to Pangaea Big Foot Pty Ltd, in June 2012 for AUD21 M (Geodynamics 2012c). At the time of sale, Geodynamics Ltd had a 70% interest in both rigs. Both rigs were sold for considerably less than purchase price.

In order to produce power at low cost, it is estimated that well costs need to be less than ~AUD9.5 M for a 4500 m deep well (MMA 2008). Lowering the drilling cost component of geothermal developments in Australia will require a combination of improved technologies to reduce material, labour and time costs, well designs that achieve higher flow rates, and a more competitive drilling market.

3.9 Size of Grants

At the time that the GDP was designed, geothermal companies thought that wells would cost approximately AUD10–15M each to drill, depending on depth, location and other attributes. The investment market was buoyant, with resource stocks being particularly so. The AGEA lobbied for a grant amount of AUD7 M per successful project application – this figure was thought to be a big enough grant to help cover costs and attract investors, and support enough projects to properly demonstrate geothermal technology in a broad range of environments. It was hoped that the proof-of-concept projects would provide enough of a demonstration that future projects would have little difficulty in attracting investors.

The GFC struck while the Round 2 applications were being assessed. As discussed previously, the effects of the GFC removed any possibility of comparatively high-risk resource projects securing additional capital. Ultimately none of the applicants were able to raise sufficient capital to proceed with the projects. As mentioned above, the effects of increased drilling costs and diminished rig availability were occurring at the very time that companies' ability to secure funds were diminished. Without proof-of-concept and demonstration projects, there is no way to lower resource and return risks.

In response to this increasingly negative operating climate, an attempt was made by the DRET to facilitate the combination of several of the grants to adequately support at least one proof-of-concept project, but no agreement could be reached.

3.10 Reduction in Demand for Power, Transmission Costs

Even under some form of carbon pricing, electricity demand was forecast to continue moderate to strong growth between 2010 and 2050 (e.g. ROAM Consulting, 2011). However, since the GFC a net decrease in the demand for electricity in Australia has been observed (Figure 2). A number of factors contributed to decreasing electricity demand in most parts of Australia in the post-GFC period. These include (AER 2013):

- Energy efficiency measures including those significantly funded and/or supported by Government;
- a boom in installed domestic rooftop solar capacity due to generous Federal and State rebates and feed-in tariffs;
- a drop in household consumption as a response to increasing power prices; and
- a decrease in industrial demand due to high overall operating costs making many operations and, in particular, manufacturing, unprofitable internationally.

The decreasing electricity market trend is continuing in 2013-2014, with projected electricity demand set to decrease (Sandiford 2014). Whereas the geothermal projects planned in 2008 were expecting to provide new supply to meet an increasing demand, from 2009 onwards they have been in a position of competing in an oversupplied market with decreasing returns. This situation has contributed to the lack of investor willingness to invest in geothermal companies.

The Geodynamics Ltd Origin Energy Pty Ltd Joint Venture Habanero project in the Cooper Basin has been the first, largest and therefore most visible geothermal power project in Australia. It is frequently criticised for being too remote and requiring a long, expensive electricity transmission line for connection to the eastern Australian power grid, adding significantly to project

development costs. There is very limited local demand, therefore network connection is necessary for scaling up beyond the 10s MWe scale. Despite most other proposed projects being significantly closer to, if not beneath, the existing transmission network, the perception of high transmission costs stuck and negatively affected investor sentiment of the sector.

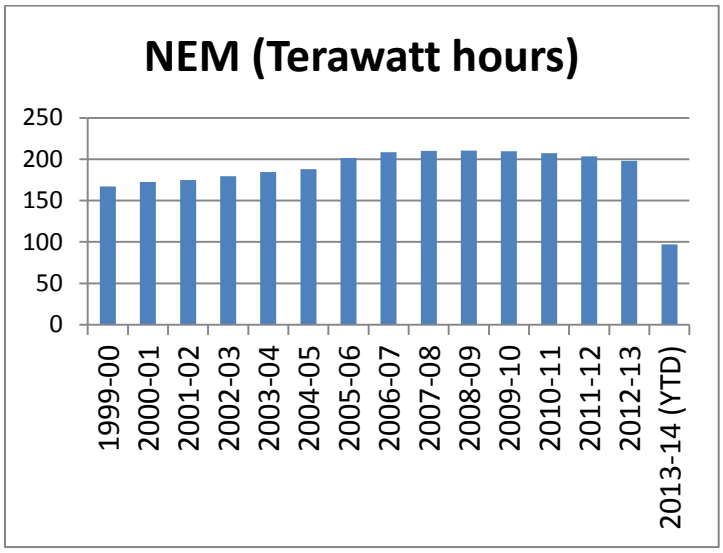

Figure 2: National Electricity Market electricity consumption, Terawatt hours by Australian financial year (July-June). Electricity consumption within the NEM increased by approximately 3 per cent per annum until 2008-09, from which time it has decreased by an annual average of 1.1 per cent (data from Australian Energy Regulator website (see AER 2013)).

3.11 Negative Sentiments

The geothermal industry had to draw attention to itself in order to attract market capital and government support. The industry promoted itself as low risk, clean and green, and set ambitious targets regarding timing and scale of power generation (e.g. MMA 2008). Amongst the claims promoted by the Australian Geothermal Energy Association were:

- The emerging Australian Geothermal Energy Industry can be expected to provide at least 1000 MW and potentially up to 2200 MW of base-load capacity by 2020 into the National Electricity Market;
- That capacity potentially represents up to 40% of the Federal Government's 2020 Renewable Energy target of 45,000 GWh – the equivalent of the output of up to 6000 MW of wind farms;
- An estimated AUD12 B would be invested to develop 2200 MW of installed capacity;
- The cost of generating electricity from geothermal resources is expected to move rapidly down the cost curve through to 2020 – through learning, experience and economies of scale outcomes commencing at around AUD120/MWh at small scale (10 MW to 50 MW projects) and decreasing to around AUD80/MWh at large scale (300 MW or greater projects) by 2020; and
- That price is expected to be lowest cost of any form of renewable energy.

As outlined in this paper, the industry has not developed as AGEA forecast, and those targets and other interim targets have not, and will not be met. These 'broken promises' have alienated the sector to investors, politicians and policy makers, to the extent that there is scepticism that geothermal can be made to work at all in Australia, let alone be economically viable. This sentiment has become an additional impediment on top of all of the others listed in this paper.

The geological complexity of geothermal systems in Australia has been underestimated, and this has contributed to the results of low flow rates in drilling to date. In hindsight, the claims of the companies were overly simplistic about the geological complexity of geothermal systems in Australia. More drilling and research and development is needed in order to develop the geological and engineering knowledge necessary to have a robust 'geothermal systems' understanding. Other resource industries, especially oil and gas, have demonstrated and subsequently accepted that deep resources require a significant commitment to characterise the resource or reservoir. Geothermal has not yet been demonstrated to have not worked in Australia, rather it has been demonstrated that more information is required before a success/failure assessment can be made. But from the initial results over the last five years, investors have been unwilling to commit to the additional activities and associated risks required in order to achieve either a commercial demonstration of the technology, or prove that the industry is not viable in Australia.

3.12 Growth and Decline of R&D Lags Industry

In contrast to EGS projects in other countries, early EGS projects in Australia were undertaken solely by the private sector and not as government-funded research and development projects. Between 2003–2008 this approach was productive with a lot of pre-drill exploration work being undertaken, and a few deep wells drilled. In response to the rapid growth of the geothermal industry the

academic sector and government technical agencies established policy and research capabilities. The Western Australian Geothermal Centre of Excellence (WAGCOE, https://www.geothermal.org.au/) was established in 2009 by the State government. The Queensland Geothermal Energy Centre of Excellence was also established by the State government in 2009 (QGECE, http://www.geothermal.uq.edu.au/about). The South Australian Centre for Geothermal Energy Research was established in mid-2010 by the University of Adelaide (SACGER, http://www.adelaide.edu.au/geothermal/). The University of Newcastle Priority Research Centre for Energy (UNPRCE, http://www.newcastle.edu.au/research-and-innovation/centre/energy/research/renewable-energy-systems) and the Melbourne Energy Institute (MEI, http://www.energy.unimelb.edu.au/) both had some geothermal research within their programs. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) had a Geothermal Energy Stream (http://www.csiro.au/en/Organisation-Structure/Divisions/Earth-Science--Resource-Engineering/Geothermal.aspx), and Geoscience Australia had a Geothermal Energy Section (http://www.ga.gov.au/energy/geothermal-energy-resources.html).

The GRI was formed in August 2010, with the aim of performing research to support the development of commercial and sustainable large scale geothermal power generation (electricity and heat) in Australia. The members of the GRI have been the CSIRO, GA, WAGCOE, QGECE, SACGER, MEI, UNPRCE, and also included the Institute of Earth Science and Engineering of the University of Auckland, NZ.

All of these capabilities have been either completely or largely wound-up since 2012 in response to the decline in the geothermal industry, with the exception of the QGECE which finishes in 2015. Many studies, including student research, have been recently, or will be completed at a time when there is very little uptake of the results. For example, the Australian Renewable Energy Agency provided grant funding to two R&D projects, both of which finish in mid-2014. They are the Enhanced Data for Geothermal Exploration project by NICTA, and the Reservoir Quality in Sedimentary Geothermal Resources project by SACGER (http://arena.gov.au/projects/geothermal-energy/).

4. DISCUSSION

Difficulty in attracting investment into geothermal developments is common world-wide. It is now widely recognised that geothermal developments have high levels of resource, technical and financial risk in their early stages, at the same time that costs are high, and this is a significant barrier to investors (ESMAP 2012). The Geothermal Risk Mitigation Facility for Eastern Africa (www.grmf-eastafrica.org/) and the Utility Scale Renewable Energy Program by the Clean Technology Fund (CTF) of the Climate Investment Funds (CIF) (http://www.worldbank.org/en/news/feature/2013/12/18/new-funding-to-boost-international-support-for-geothermal-energy) have both been established with the aim of supporting exploration and early stage drilling activities.

A variety of other funding mechanisms have been used world-wide, and are summarised by ESMAP (2012) and EGEC (2013). In Australia, the Mandatory Renewable Energy Target (MRET,http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/Browse_by_Topic/ClimateChange/Governance/Domestic/national/Mandatory) has been the largest incentive scheme that has encouraged investment in renewable energy developments, but as yet no geothermal projects have reached the production stage necessary to earn Renewable Energy Certificates.

The GDP had a number of design elements similar to the abovementioned multilateral programs. Funding was provided at the early drilling stage, aiming to mitigate resource risk, firstly by lessening contributions required from investors, and secondly by providing up to seven demonstrations of the technology and all of the learnings that would have come with that. The GDP had a competitive merit based application process, with applications being assessed against managerial, financial and technical/geological criteria. The grants were broken into milestones with stage gates to be assessed during the project. Two features not commonly used in international programs were that funding for each milestone was provided upfront, and that the final milestone was the provision of all resultant data to the Commonwealth for dissemination to other interested parties. With valuable hindsight, it is the authors' opinion that the only design flaw of the GDP was that the grants were too thinly spread, and that fewer projects should have been supported with more funding per project.

In spite of the less successful than anticipated uptake of the GDP grants, there are lessons that have been learned from the developments supported by the GDP as well as those outside the GDP. It is generally accepted within the sector that no technology breakthroughs are needed to commercialise geothermal power production. Improvements in understanding about the resources that will lower risks and lower expected costs for developments are required. Methods to reduce the costs associated with commercialising geothermal resources are expected to include: more robust exploration methods and models and better geoscience data allowing the best reservoirs to be quickly identified and characterised; improvements in drilling, particularly through 'learning-by-doing' within each project; and improvements in energy conversion efficiency.

None of the above three development needs can be attained without substantial investment. Geothermal energy in Australia has the potential to be one of the cheapest, cleanest and most reliable power sources, and a variety of different support programs and actions are required to facilitate development. Fortunately, Australia can benefit from international experience both directly and indirectly, through technology development and financial approaches. Work conducted to date in Australia can also be of use to other countries developing EGS technologies. Australia is a member of the International Partnership for Geothermal Technologies, and the International Energy Agency Geothermal Implementing Agreement to facilitate this international sharing of knowledge. Many of the required technology developments will come from other sectors, including in drilling, logging and energy conversion.

Improvements in technical aspects of geothermal developments in Australia cannot happen within a breakthrough in the financing of projects. Novel applications or development routes for geothermal must be investigated to open up alternate investment pathways. This could include co-production from high-water-cut oil or gas production, huff-and-puff from depleted petroleum reservoirs, as an adjunct to enhanced oil recovery operations, or large-scale direct-use applications in places like the Perth Basin (for example, cooling of the Pawsey Centre supercomputer (CSIRO 2014)).

5. CONCLUSION

After a period of rapid growth between 2000 and 2008, the geothermal industry in Australia has declined due to a confluence of factors. The effects of this decline can be observed within the Geothermal Drilling Program (GDP), an AUD50 M program of the Australian Government aimed at developing a number of proof-of-concept projects. Unfortunately, the decline of the industry is widely perceived as a failing of the technology and resources, or of the companies themselves, and this has deterred both private investment and government support. Understanding the underlying causes of the decline in the Australian geothermal sector is important when considering any future industry development, and is relevant to other countries utilising similar resources.

The single largest contributor to the decline was the Global Financial Crisis (GFC) which reduced the availability of risk capital. Alongside this, an increase in drilling costs meant that project costs increased, but the companies' ability to fund those increases did not increase, nor did the grant amounts from the GDP. A decrease in power demand throughout much of Australia meant that a new entrant would have to under-price the existing generators, which new geothermal projects were unable to do. Numerous delays occurred during this time, which exacerbated the above factors, and these delays combined with a number of apparent failures meant that confidence in the viability of the technology in Australia diminished. The lack of investor support is starkly demonstrated by Petratherm Ltd's Paralana project, which demonstrated world-leading stimulation of an unconventional geothermal reservoir in a location with an off-grid (and therefore high-return) market, but has been unable to raise sufficient capital to date to match Government grants to progress the project.

Despite the drilling of nine deep wells, only one circulation test has been conducted. This is widely perceived to indicate that drilling is too difficult, and that geothermal reservoirs will be unproductive in Australia. The reality is that neither the technical nor commercial viability of geothermal energy for power generation in Australia has been tested sufficiently to make this conclusion. Geodynamics Ltd has drilled six deep wells into granite, and has learnt much about drilling and completing wells safely, and about fracturing in this environment. Two wells have been drilled to test alternative, and potentially more cost effective, shallow Hot Sedimentary Aquifer plays, neither of which produced significant flows. For both of these projects, insufficient work has been completed to assess the viability of hydraulic stimulation, or the spatial variability of permeability within the reservoir.

In all cases of deep geothermal drilling in Australia to date, the prognosed temperature targets were reached, but there is an information gap regarding the geological nature of permeable or permeability-susceptible EGS and HSA reservoirs. This knowledge gap can only be filled by a number of projects exploiting a variety of geological environments and testing a number of drilling and permeability enhancement methods. Bridging this knowledge gap is necessary to reduce reservoir and technical risk for investors.

Companies are demonstrating their ability to adapt to the poor operating environment by evaluating less traditional approaches. For example, in addition to producing power, Geodynamics Ltd has investigated the feasibility of supplying process heat to potential shale gas developments in the Innamincka vicinity. Several companies have taken up conventional geothermal project in other countries, or have taken up petroleum projects, or moved into other forms of renewable energy.

Potential investors must have confidence that projects can be commercially successful. Reducing costs, as well as proving resources, is necessary. Showing that costs can be reduced and proving of resources can only be achieved through small- to medium-scale demonstration projects, which by themselves may be uneconomic on a purely commercial basis.

The development of unconventional geothermal resources such as those in Australia is part of the continued global geothermal resource development pathway from very shallow resources, to deeper resources with few surface features, to completely blind resources. Unconventional resources generally have conductive rather than convection heat regimes, and have lower heat flow. This is directly analogous to the development of the petroleum industry which has developed conventional resources, and is now exploiting tight oil and gas reservoirs. In Australia, this process of testing and developing geothermal resources was started, but not completed. A wide range of factors, mostly beyond the control of geothermal developers, has stymied this development process. The lack of progress has largely been perceived as a failure of the technology and of the developers, but this conclusion is not justifiable in the face of the available evidence. The development of a geothermal industry in Australia will be dependent on achieving proof-of-concept in a number of projects with favourable economics, which will require significant investment. This investment will not be supported by private or corporate investors alone, and co-investment is necessary from Government or from large energy companies, in particular oil and gas developers who are familiar with deep resource development.

The GDP provided an estimated 50% of drilling costs upfront for the first two wells in a project to demonstrate proof-of-concept. More recent assistance programs elsewhere in the world are based on a similar approach – supporting early wells to decrease resource risk. The GDP ultimately failed to meet its objectives because of a range of factors including rising costs, decreasing electricity demand and unavailability of capital because of the GFC. Large-scale geothermal technology has not been adequately tested in Australia to validate its commercial viability. The needs for development of geothermal in Australia are very similar to those in other countries having conductive heat regimes requiring deep EGS projects.

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