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Geothermal Energy in Australia

Prepared for the

ARENA International Geothermal Energy Group

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Foreword

This report has been prepared for the Australian Renewable Energy Agency's (ARENA) International Geothermal Expert Group (IGEG) to provide an overview of geothermal energy development in Australia. This report describes the nature of Australia's geothermal energy resources and recent activities in the Australian geothermal energy sector. The report covers activities conducted by the private sector, the research sector, and government.

ARENA established the IGEG to investigate and report on the prospects for the commercial development of geothermal energy in Australia. This report's author, Cameron Huddlestone-Holmes was retained by ARENA to provide professional technical support to IGEG.

The terms of reference for the IGEG were:

1. Determine whether, over the periods to 2020 and 2030, there are plausible commercialisation pathways for either EGS or HSA geothermal energy to deliver cost competitive utility scale energy to Australia without long-term subsidy and to describe those pathways;
2. Critically evaluate:
    a. the performance of Australia's geothermal energy sector – how effectively has it used the private investment and public funding it has received to date?
    b. opportunities and threats to support a SWOT analysis of Australia's geothermal energy sector, including its size, structure, governance, skills, capabilities (technical and managerial) and finances;
3. Identify
    a. the main barriers facing pilot/demonstration projects, including technical, physical, economic, institutional and policy;
    b. the main barriers to commercialisation;
    c. the geothermal industry's capability gaps (including technical, managerial, engineering, scientific); and
    d. key gaps in data (including resource and technology specific performance data), information and knowledge.
4. Include site visits and face to face engagement with stakeholders in Australia; and
5. Prepare for the ARENA Board an analysis of risks and rewards for geothermal energy which will help inform the Board's consideration of how to allocate and prioritise funding for geothermal energy as part of its portfolio approach to supporting renewable energy in Australia.

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Executive summary

Geothermal energy is simply heat from the earth. Beneficial use of this heat is achieved by bringing the heat to the surface in a fluid (steam or water). This fluid may occur naturally in a subsurface reservoir or it may have to be introduced into the system. Temperatures increase with depth in almost all geological settings so geothermal energy could conceivably be used anywhere on the planet. However, to be considered economically viable, the cost of extracting and using this energy must be less than the value of that energy in the market it is being delivered to. It is useful to consider the technical ingredients of geothermal systems in relation to the costs of developing them, as these capital costs are one of the main drivers of the overall cost of generating energy from geothermal resources.

The amount of thermal energy available from a geothermal production well is governed by the flow rate and the goal is to find geothermal resources with high temperatures and flow rates. The optimal geothermal energy resource is one that finds the optimum combination of costs to develop the resource and the flow rate and resource temperature. These parameters are directly related to the geological setting of the resource. The majority of the geothermal resources currently exploited for power generation are convective hydrothermal systems (where the heat is carried upwards by fluids) that are found in geological settings that are in regions of active tectonics and volcanism along plate boundaries. These systems have high temperatures at shallow depths (<3,000 m), due to high heat flows caused by hot fluids moving upwards through rocks with high natural permeability.

Globally, there is growing activity in developing geothermal resources outside of these geological settings to increase the supply of geothermal energy. These geothermal resources are dominated by conductive heat flow. Conductive heat flow occurs when heat moves without the movement of the material or fluids within that material. These resources tend to have lower thermal gradients than convection dominated resources, requiring deeper drilling to reach high resource temperatures. The Australian continent lies entirely within the Indo-Australian tectonic plate and as a result of this tectonic setting Australia does not have the convective heat flow regimes that typify the majority of geothermal provinces worldwide. The Australian continent's thermal structure is dominated by conductive processes and the geothermal resources in Australia are generally considered to fall in the conductive category.

Geothermal resource types in Australia can be categorised as falling within three resource categories: *Shallow, direct use* resources that are typically in the 500 m to 1,500 m depth range targeting aquifers with high permeabilities at low to moderate temperatures for direct use applications; *Deep, natural reservoir* are resources that are typically greater than 1,500 m deep and targeting sedimentary or fractured aquifers with high natural permeabilities for direct use or electricity generation; and, *Enhanced Geothermal Systems* resources where the reservoir needs to have its permeability increased via stimulation of existing structures or the creation of new ones, for direct use or electricity generation.

Geothermal energy in Australia has significant potential to be a major resource. A compilation of geothermal resources as at December 2012 was 440,570 PJ_{TH} (recoverable heat), based on data reported by publicly listed geothermal companies. The size of the Australian geothermal resource is very uncertain because of the lack of data about temperature at depth. Geoscience Australia has estimated that the amount of heat in rocks less than 5 km deep but over 150 °C in temperature in the Australian continent is over 1.9×10^{10} PJ. These resource estimates suggest that the geothermal energy resource in Australia is practically limitless. However, unless these heat resources can be extracted economically, the estimates are somewhat meaningless.

Before the mid-90s, the limited geothermal energy activity in Australia was primarily focussed on direct use applications of hot groundwater. Early commercial geothermal energy systems accessed warm water from sedimentary aquifers, primarily for direct use applications. In Portland, Victoria, a district heating system was used to provide heat for building space and the municipal swimming pool from 1983 to 2004. A system

operated in the 1950s in Taralgon, Victoria, supplying 68 °C process water for paper manufacturing from two 600 m deep wells. The Great Artesian Basin that extends from Queensland to north-west New South Wales and northern South Australia has been exploited for water for drinking and agriculture for over 100 years. Thousands of bores have been drilled in to the basin with many extending past 1,000 m in depth with water temperatures of up to 110 °C. This hot water has been used for therapeutic baths and provided heat for Australia's first two geothermal power plants. The Mulka geothermal power plant was developed in 1986 in northern South Australia as a trial plant, funded by state and federal governments. The plant had a rating of 20 kWe and ran for three years. The Birdsville geothermal power plant in south-west Queensland, Australia's only operating geothermal power plant, was also built as an experimental plant funded by state and federal governments. The plant uses hot water from the town bore and has an output of 80 kWe net with a capacity factor of over 95%, supplying just under a third of Birdsville's electricity needs.

From the mid-90s, following a study commissioned by the Energy Research and Development Corporation (Somerville et al., 1994), geothermal energy received a significant boost in interest. This study looked at the potential for Hot Dry Rock (HDR) geothermal energy to make a large scale contribution to Australia's electricity supply, finding that Australia's HDR resource was 'extremely large'. Activity started to markedly increase when the New South Wales (in 1998) and South Australian (2000) Governments enacted legislation to allow for the exploration of geothermal energy resources. The first geothermal exploration lease granted was in the Hunter Valley region of NSW in 1999. The South Australia government awarded its first three geothermal energy leases to three separate consortia in 2001. Two of the leases were near Innamincka (GEL 97 and GEL 98), and the relevant consortia merged with Geodynamics Limited taking on these leases. Geodynamics Limited's Innamincka Deeps project is located on these leases and Australia's first well completed into to an EGS resource, Habanero 1, was drilled to a depth of 4,421 m on GEL 97 in 2003.

Following these early efforts, there was a rapid uptake in geothermal energy activity primarily driven by the private sector. By 2004, there were 24 geothermal exploration leases in South Australia and two in New South Wales. The peak of activity came in 2010, with 414 exploration licences or licence applications covering approximately 472,000 km^2 across all Australian states and the Northern Territory.

During the 2000s the industry was focussed on developing resources suitable for electricity generation, targeting reservoir temperatures over 150 °C, with only a few exceptions. There have been four projects that have drilled to reservoir depths in Australia: Geodynamics Limited's Innamincka Deeps Project; Petratherm's Paralana Project, Origin Energy Limited's Innamincka Shallows Project and Panax Limited's Penola Project. The first two are targeting EGS resources while the second two were targeting natural reservoirs. Only the Innamincka Deeps Project with six wells has progressed beyond a single well. In all cases, the temperatures found were close to expectations. The flow rates have been lower than expected, particularly for the natural reservoirs.

Geodynamics Limited then ran their 1 MWe pilot plant from April to October 2013 at their Innamincka Deeps Project. The system ran in standalone mode from June 2013, with availability exceeding 75%. The maximum well head temperature achieved was 215 °C with a flow rate of 19 kg/s. The flow rate was limited by the capacity of the injection well. The plant generated approximately 650 kWe gross which was able to supply all auxiliary loads. This was a significant achievement after more than a decade of activity around Innamincka. Two of the six wells at this site have been abandoned, including one after a catastrophic casing failure only days before hot commissioning of the pilot was due in early 2009, causing significant delays to the project.

Exploitation of geothermal resources for direct use application has continued. There are many examples of the hot artesian waters in the Great Artesian Basin being used for therapeutic baths, there are two fish farms that use warm groundwater for aquaculture in Victoria and South Australia and a meat processing plant in Victoria using warm groundwater for feedwater for sterilizationand hand washing water. There are 10 commercial direct use geothermal projects in Perth, producing geothermal fluid from the Yarragadee Aquifer to heat swimming pools.

Geoscience Australia and the various state and territory geological surveys have actively acquired pre-competitive data (the collection, collation and integration of basic geoscientific data, often strategically

focussed on national and state needs) for the geothermal sector. These data have proven to be critically important to the development of other earth resources by decreasing the risks and reducing costs of early stages of exploration. The two most significant activities have been Geoscience Australia's Onshore Energy Security Program and the Geological Survey of Queensland's Coastal Geothermal Energy Initiative.

The Australian geothermal energy research sector grew along with the industry with a peak of activity around 2010/2011. In August 2010, a group of university, CSIRO and Geoscience Australia researchers joined together to form the Geothermal Research Initiative (GRI) to foster collaboration on research and development for the geothermal energy sector. In 2011, the GRI's eight member institutions had an equivalent of 77 full time staff and over 40 post graduate students working on geothermal energy. The development of this geothermal energy research capability is quite recent, and is similar to the global research trends for the types of resources found in Australia. Nearly all of the researchers working in geothermal energy are transferring and adapting the knowledge they have gained in other fields.

As the geothermal sector grew through the 2000's, the sector matured with all six states and one territory (Northern Territory) enacting legislation to regulate geothermal energy development. An industry association was established and The Australian Geothermal Reporting Code was developed and released. There have been several government funded studies conducted for agencies of the Australian government to provide advice and guidance for the support of geothermal energy in Australia.

The total expenditure on geothermal energy in Australia from the late 1990's is approximately $900 million (nominal dollars). State and federal government funding allocated to support geothermal industry activity (excluding research and development and pre-competitive data programs) was $315 million as at the end of the 2013 calendar year. Of this amount, approximately $76 million has been spent and just over $100 million is still available to be spent. This means that just under a third of the value of government grants to the geothermal sector have been handed back, primarily as a result of project proponents being unable to secure the matching funds required as a grant condition. In addition to grants, $31 million in tax rebates have been received by the sector. The total amount spent by industry as at the end of 2013 is estimated to be approximately $828 million. The government contribution has been around 13% of the total expenditure by the Australian geothermal industry.

Funding to the research sector is somewhat more difficult to quantify. Major grants (for centres of excellence) for geothermal research total around $20 million to $25 million. The in-kind contributions of the research sector are expected to have at least matched that amount. Funding for pre-competitive data programs at Geoscience Australia and the state geological surveys has been around $30 million, although this is very difficult to quantify as some of this activity is conducted under recurrent funding.

Recent and continuing energy and emissions reduction policy changes at Federal level over the last seven years have created an uncertain environment for investment in renewable technologies. This policy uncertainty impacts the current and future market environment for the geothermal energy sector.

The Australian geothermal sector is currently stalled with very little activity in Australia. The lack of activity is due to the project proponents' difficulties in attracting funding.

Abbreviations

AERA	Australian Energy Resource Assessment
AETA	Australian Energy Technology Assessment
ARENA	Australian Renewable Energy Agency
bbls	Barrels, a measure of volume (159 Litres)
°C	Degrees Centigrade
cm/s	Centimetres per Second
CRI	Commercial Readiness Index
CRL	Commercial Readiness Level
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EGS	Enhanced or Engineered Geothermal System
EOR	Enhanced Oil Recovery
EPC	Engineering, Procurement and Construction
°F	Degrees Fahrenheit
FIT	Feed In Tariff
ft	Feet
GDP	Geothermal Drilling Program
GETEM	Geothermal Electricity Technology Evaluation Model
GJ	Gigajoule
GW	Gigawatt
GWh	Gigawatt hour
GRI	Geothermal Research Initiative
HSA	Hot Sedimentary Aquifer
HDR	Hot Dry Rock
IGEG	International Geothermal Expert Group
IRR	Internal Rate of Return
km	Kilometres
kg	Kilogram
kg/s	Kilograms per second
kW	Kilowatt
kWe	Kilowatt electric
kWh	Kilowatt-hour
LCOE	Levelised Cost of Energy

l/s	Litres per second
m	Metres
MPa	Megapascal
MT	Magnetotellurics
MW	Megawatt
MWe	Megawatt electric
MWh	Megawatt-hour
MW_{TH}	Megawatt thermal
NGDS	National Geothermal Data System (USA)
PJ	Petajoule
PJ_{TH}	Petajoule thermal
psi	Pounds per square inch
PTC	Production Tax Credit
REDP	Renewable Energy Demonstration Program
RET	Renewable Energy Target
SAM	System Advisory Model
SWOT	Strengths, Weaknesses, Opportunities and Threats analysis
TRL	Technology Readiness Level
TVD	Total Vertical Depth
WHP	Wellhead Pressure

Glossary

3D Seismic	Geophysical method that allows 3-dimensional images of the subsurface to be constructed by measuring the reflection of seismic energy (waves of elastic energy travelling through rock, comparable to sound waves in air). The seismic energy is created by a controlled seismic energy source (explosives or mechanical vibrations) and detected by an array of receivers.
Binary Cycle	The energy conversion system through which the hot geothermal fluid transfers its heat to a working fluid. The working fluid consists of a low boiling point fluid, such as a hydrocarbon that is used within the power plant.
Brine	Salty water. Most water found within the earth is salty.
Capacity Factor	The ratio of a power plants actual electrical generation to its maximum possible generation, usually expressed as a percentage.
Casing	Pipe that is lowered into a well and cemented in place to maintain the integrity of the well.
Cenozoic	The Cenozoic Era covers the period of geologic time from 65 million years ago to the present.
Conductive Geothermal System	A geothermal system where the movement of heat through the rock is dominated by conductive processes. Conduction is the movement of heat through a solid material.
Convective Geothermal System	A geothermal system where the movement of heat through the rock is dominated by convective processes. Convection is the movement of heat carried by the movement of fluid.
Darcy Flow	The process governing flow of fluid through a porous medium.
Diagenesis	The processes that affect sediment at or near the surface. These processes include compaction, where loose grains of sediments are squeezed together as they are buried, and cementation, where grains of sediments are held together by the deposition of secondary material.
Direct Use Geothermal	Geothermal energy utilised in the form of heat without the need to transform it into another type of energy. Direct use applications include space heating, food drying, and other industrial processes that use the heat.

Dispatchable — Dispatchable power is a form of power supply that is able to follow load.

Downhole — Denotes any equipment, measurements, or activities that are used or occur within a well.

Enhanced/Engineered Geothermal System — A geothermal reservoir that has been engineered to allow extraction of heat from geothermal resources with little permeability through to enhancement of geothermal resources that have marginal permeability.

Flow Rate — The rate at which geothermal fluid is produced from a reservoir through a well or a collection of wells.

Fracture Tortuosity — A measure of the geometric complexity of a fracture. Highly complex fracture geometries are likely to offer more resistance to flow than less complex geometries.

Heat Pump — A device that moves heat energy to or from a heat sink. A geothermal heat pump uses the earth as the heat sink (a body that can store heat).

Hot Dry Rock — A geothermal energy concept in which the reservoir is confined and fully engineered, including a ‘man-made reservoir’ in rocks that are essentially impermeable, and therefore ‘dry’.

Hot Sedimentary Aquifer — A geothermal reservoir within highly permeable layers of sedimentary rock.

Hydraulic Fracturing — A technique to enhance or create fracture paths for fluid flow within a rock mass by opening existing fractures or the creation of new fractures by the application of high-pressure fluid on the rock.

Hydrostatic Gradient — The change in pressure per unit depth inside the pore space of the earth due to gravity acting on water within that pore space. For freshwater at 20 °C and 100 kPa, this gradient is 9.79 kPa/m; for a brine with a composition similar to sea water, this gradient is 10.45 kPa/m.

Hydrostatic Pressure — The pressure inside the pore space of the earth due to gravity acting on water within that pore space at a given depth.

Injection — Delivery of fluid in to a reservoir via a well.

Levelized Cost of Energy — The minimum cost of energy at which a generator must sell the produced electricity in order to achieve its desired economic return.

Lithological Section — The sequence of rock types found in and above a resource.

Lithology — Description of the physical characteristics of a rock, including colour, texture, grain

	size, and composition.
Logging	The collection of data from a well using geophysical tools that are lowered into that well.
Magnetotellurics	Geophysical method that allows images of the subsurface to be constructed using measurements of variations of electrical and magnetic fields at the earth's surface.
Natural Deep Reservoir	A geothermal reservoir that has naturally high permeability that does not require any significant level of stimulation. This permeability may be within sedimentary layers or aquifers, or in fractures.
Overpressure	Pressures in rock formations that are abnormally high, exceeding the hydrostatic pressure at a given depth.
Packers	A device that can be placed in a well and expanded to seal off sections of the well. Packers may be removable or permanent.
Permeability	A measure of the ability of a rock to allow fluid to flow through it.
Petajoule	The heat energy content of about 37,000 tonnes of black coal or 29 million litres of petroleum.
Pleistocene	The Pleistocene Epoch covers the period of geologic time from about 2,588,000 years ago to 11,700 years ago.
Porosity	The open space within a rock, usually filled with fluid.
Precompetitive Data	Government provided information about the broad geology of a region, often strategically focussed on national and state needs, which is then used by private explorers to select areas for more intensive exploration. Pre-competitive information can be used by one explorer without preventing the use of the same information by another explorer.
Production	Extraction of fluid from a reservoir via a well.
Proppant	Fine-grained, round and permeable materials that are injected with fracturing fluids to hold fractures open (prop) after a hydraulic fracturing treatment.
Reserve	That portion of a Geothermal Resource which is deemed to be economically recoverable after the consideration of the geothermal resource parameters and modifying factors which directly affect the likelihood of commercial delivery (e.g. production, economic, marketing, legal, environmental, land access, social and governmental factors).

Reservoir A subsurface body of rock having sufficient porosity and permeability to store and transmit fluids. In the geothermal context, a reservoir also contains heat.

Resource In the geothermal context, a geothermal resource is a geothermal system that exists in such a form, quality and quantity that there are prospects for eventual economic extraction of heat.

Rig Release The completion of drilling a well, before the drill rig is demobilised.

Sand Back The method used to isolate parts of a well during hydraulic stimulation or other activities that involve injection of fluid in to the well. Sand is placed in the well, restricting the flow of fluid into the portion of the well that is filled with sand. The sand can subsequently be flushed from the well.

Shut In Closing or sealing a well after an injection or production period.

Skin Effect Damage to the wall of the well that either increases or decreases the ability of fluid to flow into or out of the well.

Snubbing A method for well intervention where the well is under pressure.

Spud The initiation of drilling a well, after the drill rig has been established on-site.

Stimulation Any of a range of techniques to increase the natural permeability of the rock. These techniques include hydraulic fracturing, chemical stimulation (including the injection of acids) or temperature cycling.

Tensile Failure Failure caused by tension (pulling apart or stretching).

Thermal Spallation The method of drilling that breaks the rock through thermal expansion caused by rapid heating.

Well Industry term for holes drilled into the earth for the purpose of gathering data or the injection or production of fluids.

1 Geothermal Energy in Australia

Geothermal energy has not been exploited at any significant scale in Australia. Interest in geothermal energy for large scale electricity generation in Australia started in the mid 90's with a study commissioned by the Energy Research and Development Corporation (Somerville et al., 1994). Prior to that, a limited number of small scale projects had been developed around Australia that exploited heat from aquifers at depths of less than a couple of kilometres.

There has been a substantial amount of interest in Australia's geothermal energy resources over the last fifteen years. This chapter describes the geology of Australia's geothermal energy resources, the activity in the geothermal energy sector over this time period and the current status of the sector.

1.1 Introduction to geothermal energy as a resource

Geothermal energy is simply heat from the earth. Beneficial use of this heat is achieved by bringing the heat to the surface in a fluid (steam or water). This fluid may occur naturally in the subsurface reservoir or it may have to be introduced into the system. Temperatures increase with depth in almost all geological settings so geothermal energy could conceivably be used anywhere on the planet. However, to be considered economically viable, the cost of extracting and using this energy must be less than the value of that energy in the market it is being delivered to. It is useful to consider the technical ingredients of geothermal systems in relation to the costs of developing them, as these capital costs are one of the main drivers of the overall cost of generating energy from geothermal resources.

The relationship between costs and the key technical parameters can be expressed as follows:

$$\frac{Cost}{MW} \cong \frac{C_{drill} + C_{BOP}}{c_p \times \dot{m} \times \Delta T \times \eta - \mathrm{P}}$$

where C_{drill} is the cost to construct production/injection wells, including engineering the reservoir; C_{BOP} is the cost of the balance of plant, including the surface power conversion equipment (electricity generation or direct use) and equipment required for pumping the working fluid into and out of the reservoir; c_p is the specific heat of the working fluid; $\dot{m}$ is the flow rate from the production well; ΔT is the sensible heat that can be extracted from the fluid ($T_{inlet} - T_{rejection}$,); η is the efficiency with which the heat energy can be used, and P are the parasitic losses.

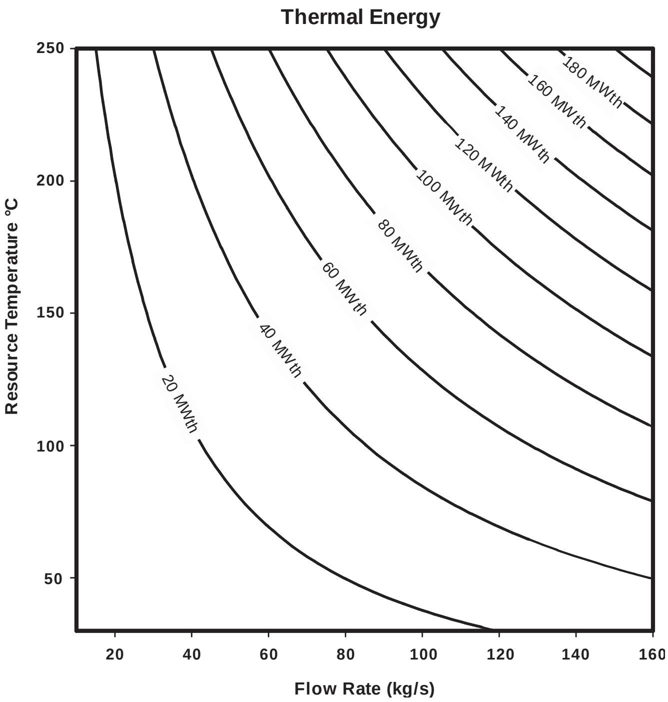
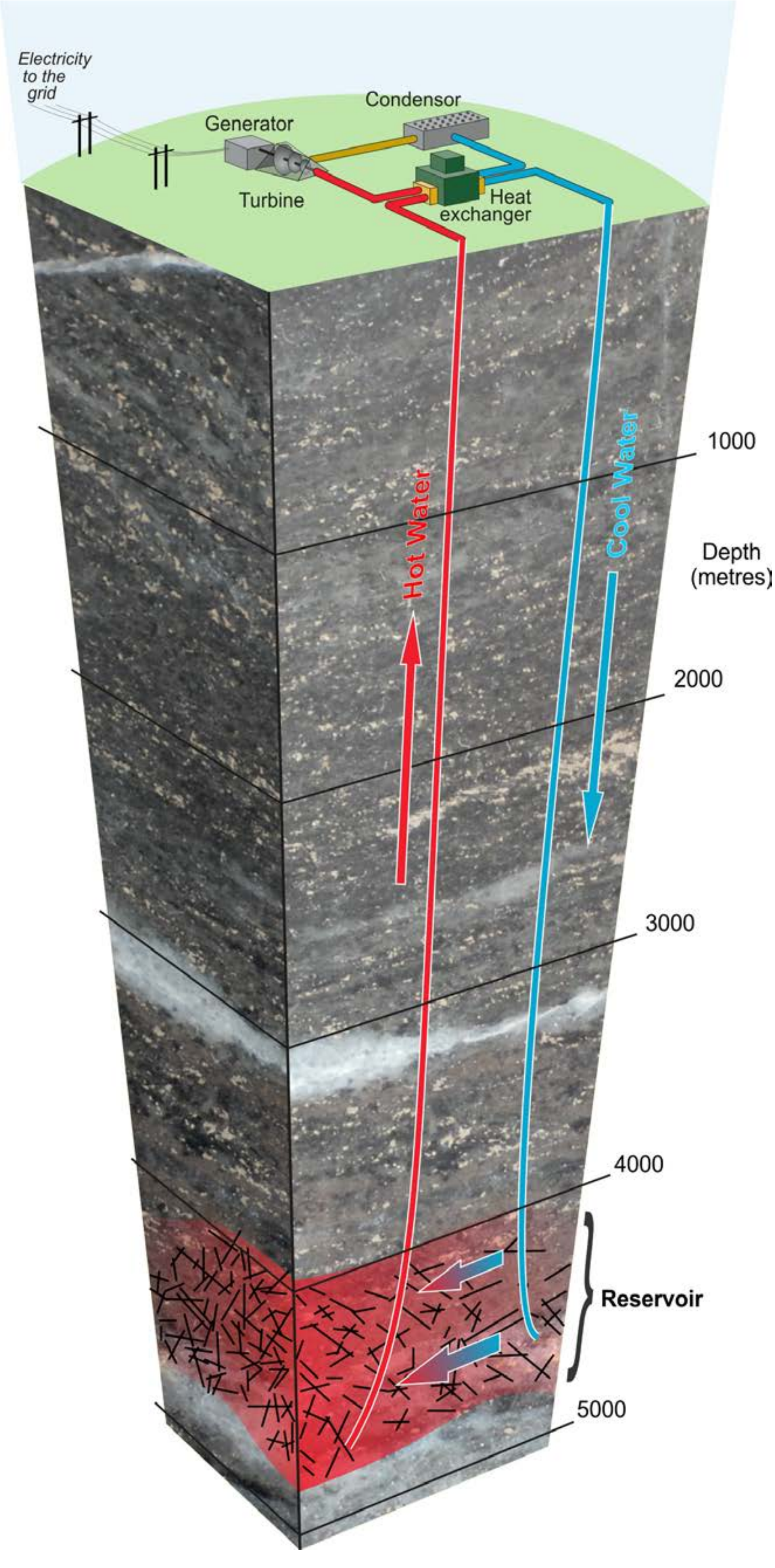


Figure 1 The amount of thermal energy (Megawatts thermal = MWth) produced by a geothermal well as a function of temperature and geothermal fluid flow rate (assuming an ambient temperature of 20 °C and pure water).

The amount of thermal energy available from a geothermal production well is governed by the flow rate (Figure 1 shows the relationship between available thermal energy, ΔT and $\dot{m}$). Clearly the goal is to find geothermal resources with high temperatures and flow rates. The rate at which temperature increases with depth in the earth varies according to the geology at a given location. The average thermal gradient for the continents is around 25 to 30 °C/km (G R Beardsmore & Cull, 2001), indicating that the average crustal temperature at 5,000 m depth will be around 150 °C. Higher temperatures could be found by drilling

Box 1 - Geothermal Energy Systems – Basic Components



While there is a good deal of variety in geothermal energy systems all have three basic components. The first is the geothermal resource (the heat), the second is the method with which this heat is accessed, and the third is the component that uses the heat.

The diagram on the left shows a geothermal system in a conductive geothermal resource that shows these three components.

The Geothermal Resource: The primary aspect of a geothermal resource is heat. In this case, the heat in the resource comes from deep within the earth and has been trapped by insulating rocks that overlie the resource. Another important characteristic of geothermal resources is the presence of fluid such as water or steam that can easily flow through the rock. In this case the fluid exists in fractures in the rock. These fractures could be naturally occurring or engineered through reservoir stimulation. The fluid may be naturally occurring or introduced to the system.

Heat Access: The heat energy in geothermal resources is accessed through wells drilled into the resource. The heat is then brought to the surface in a fluid (water or steam) through production wells. In the example shown here, the fluid is circulated in a closed loop comprising of a pair of wells. Cool water is injected into the resource through one well. This water travels through the reservoir where it is heated before it is produced from the resource through the second well.

Heat Utilisation: Once the heat has been brought to the surface in a hot fluid, the heat is then put to work. This can be through a power station, as shown in this example, or the heat can be used directly for district heating or other industrial processes.

deeper or by targeting areas with higher than average thermal gradients. The cost of drilling increases significantly with depth (Tester et al., 2006), so rather than drilling deeper, areas with anomalously high thermal gradients are usually targeted.

High flow rates require wells to either intersect formations that have high natural permeability (a measure of the ability of fluid to flow through the rock) or for the existing permeability to be increased. Permeability is usually higher at shallow depths however the temperatures are also lower (low ΔT). Deeper wells would reach higher temperatures but may require engineering activities to enhance permeability (improving $\dot{m}$). However these engineering costs add to the C_{drill} and deeper wells will usually require more energy to be used for pumping than shallow wells, increasing parasitic loads.

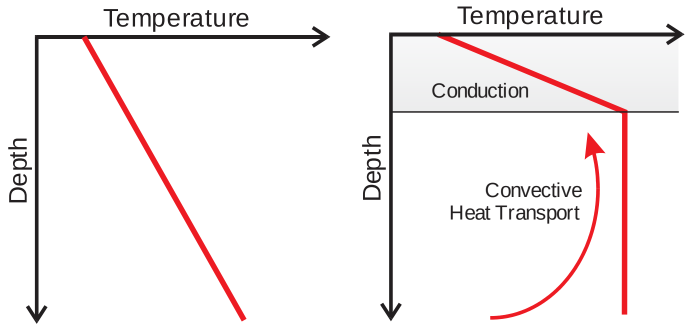


Figure 2: Temperature as a function of depth for a conduction dominated regime (left) and convection dominated regime on the right. After Sanyal and Butler (2010).

The optimal geothermal energy resource is one that provides the optimum combination of costs to develop the resource (C_{drill} and C_{BOP}) and the technical parameters of flow ($\dot{m}$) and resource temperature (ΔT). These parameters are directly related to the geological setting of the resource. The majority of the geothermal resources currently exploited for power generation are convective hydrothermal systems (where the heat is carried upwards by fluids) that are found in regions associated with tectonic plate boundaries and volcanic areas (e.g. west coast of the USA, New Zealand, Indonesia, Iceland, Italy and Japan), and extensional to transtentional tectonic settings (e.g. Basin and Range province, western USA). These systems have high temperatures at shallow depths (<3,000 m), due to high heat flows (Figure 2) caused by hot fluids moving upwards through rocks with high natural permeability. This permeability is usually within sub-vertical faults and fractures caused by active tectonic processes with flow concentrated in these fractured zones. These conventional, convection dominated, geothermal resources are restricted to geological settings that are in regions of active tectonics along plate boundaries (Figure 3).

Globally, there is growing activity in developing geothermal resources outside of these geological settings to increase the uptake of geothermal energy. These geothermal resources are dominated by conductive heat flow and have been termed ‘unconventional’ because of their differences to those geothermal resources that have been developed. Conductive heat flow occurs when heat moves without the movement of the material or fluids within that material (heat moving through a metal rod for example), and is less efficient than convective heat flow (Figure 2). As a result, these resources tend to have lower thermal gradients than convection dominated resources, requiring deeper drilling to reach high enough resource temperatures.

The range of geological settings that geothermal resources have been developed in and that are being targeted for geothermal developments is very broad. Moeck and Beardsmore (2014) recently proposed a classification scheme for geothermal resources based on the idea of ‘geothermal play types’. This approach is similar to that used in the petroleum sector for classifying petroleum resources. These geothermal play types are used to help to describe the geological factors that are important for geothermal energy resources. These factors include the geology of the reservoir (rock type and the existence of any fluids, permeability or structures), the geology of the material overlying the reservoir, and the source of the heat in the reservoir (conduction versus convection). Moeck and Beardsmore’s (2014) classification scheme is presented in Table 1.

The terms ‘conventional’ and ‘unconventional’ have been applied to geothermal resources recently. The distinction tends to be between the convective settings that dominate current electricity production from geothermal resources worldwide and conductive resources whose potential is currently being explored. The more descriptive terms convective and conductive have been preferred here.

Type			Geologic Setting	Heat Source	Dominant Heat Transport Mechanism	Storage Properties of Reservoir	Regional Topseal or Caprock	Examples
Convection Dominated	**CV-1:Magmatic**	**CV-1a:Extrusive**	Magmatic Arcs, Mid Oceanic Ridges, Hot Spots	Active Volcanism, Shallow Magma Chamber	Magmatic-hydrothermal Circulation	---	Extensive Low Permeability Clay-rich Layers	*Java*
		CV-1b:Intrusive	Magmatic Arcs, Mid Oceanic Ridges, Hot Spots	Active Volcanism, Shallow Magma Chamber	Magmatic-hydrothermal Circulation, Fault Controlled	---	---	*Taupo Volcanic Zone*
	CV-2:Plutonic	**CV-2a:Recent or Active Volcanism**	Convergent Margins with Recent Plutonism (< 3 Ma), Young Orogens, Post-orogenic Phase	Young Intrusion+Extension, Felsic Pluton	Magmatic-hydrothermal Circulation, Fault Controlled	---	---	*Larderello*
		CV-2b:Inactive Volcanism	Convergent Margins with Recent Plutonism (< 3 Ma), Young Orogens, Post-orogenic Phase	Young Intrusion+Extension, Felsic Pluton, Heat Producing Element in Rock	Hydrothermal Circulation, Fault Controlled	---	Low Permeability Caprock	*The Geysers*
	CV-3: Extensional Domain		Metamorphic Core Complexes, Back-arc Extension, Pull-apart Basins, Intracontinental Rifts	Thinned Crust+Elevated Heatflow, Recent Extensional Domains	Fault Controlled, Hydrothermal Circulation	---	---	*Basin and Range, Soultz-sous-Forêts*
Conduction Dominated	**CD-1: Intracratonic Basin**		Intracratonic/Rift Basins, Passive Margin Basins	Lithospheric Thinning and Subsidence	Conduction with insulating sediments. Litho/Biofacies Controlled	High Porosity/Low Permeability Sedimentary Aquifers	Insulating Caprock	*North German Basin, Otway Basin, Cooper Basin*
	CD-2: Orogenic Belt		Foreland Basins within Fold-and-thrust Belts	Crustal Loading and Subsidence Adjacent to Thickened Crust	Fault/Fracture Controlled, Litho/Biofacies Controlled	High Porosity/High Permeability or High Porosity/Low Permeability Sedimentary Aquifers	---	*Southern Canadian Cordillera, Molasse Basin*
	CD-3: Crystalline Rock - Basement		Intrusion in Flat Terrain	Heat Producing Element in Rock, Hot Intrusive Rock	Conduction often with insulating sediments. Radiogenic heat generation.	Low Porosity/Low Permeability Intrusive Rock (Granite)	Insulating Caprock	*Fenton Hill, Cooper Basin Basement*

Table 1: Geothermal play types. The play types found in Australia are highlighted in green (CD-1 and CD-2). Modified from Moeck and Beardsmore (2014). The comparative lack of detail in the conduction dominated geothermal play types is likely to be a reflection of the limited amount of understanding of these resources.

Thermal gradients (dT/dZ) in conductive regimes are related to crustal heat flow (Q) and thermal conductivity (λ) via the following equation:

$$\frac{dT}{dz} = -\frac{Q}{\lambda}$$

Anomalous thermal gradients in conductive thermal regimes are found where crustal heat flow (Q) is above average (due to mantle heat flow variations or heat production within the crust), thermal conductivity (λ) is below average, or a combination of these factors. Heat flow has two components, mantle derived heat flow and heat generated in the crust (the outer 25 to 70 km layer of the Earth). Mantle heat flow is relatively uniform although may it be higher in areas where the crust is thinner, above mantle hot spots, or where mantle degassing carries heat in to the lower crust. The primary mechanism of heat generation in the crust is through the decay of the radioactive isotopes of potassium, uranium and thorium. The heterogeneous distribution of these elements creates significant variations in the heat generated in the crust. These elements are often found in relatively high abundances in some granitic rocks and these rocks are often targeted for geothermal energy development.

The thermal conductivity of rock depends on its composition and structure (grain size, presence of pore space or fractures). Organic rich sedimentary rocks such as mudstone, shale and coal typically have lower than average thermal conductivities whereas rocks like granite, sandstone and gneiss have relatively high thermal conductivities. Areas that have high amounts of rock with low thermal conductivity (e.g. coal rich sedimentary basins) will tend to have high thermal gradients because of the insulating properties of these sediments.

These deeper resources often have low natural permeability and require enhancement by stimulation techniques.

Figure 3: The distribution of the world's conventional geothermal resources reflect their association with tectonic plate boundaries. Downloaded from http://geothermal.marin.org/GEOpresentation/sld015.htm.

1.2 Geological Context for Australia's geothermal energy resources

The Australian continent lies entirely within the Indo-Australian tectonic plate (Figure 4). As a result of this tectonic setting, the generally compressive stress regime in Australia (R. R. Hillis & Reynolds, 2000) and low levels of tectonic activity, Australia does not have the convective heat flow regimes that typify the majority of geothermal provinces worldwide. The Australian continent's thermal structure is dominated by conductive processes and the geothermal resources in Australia are generally considered to fall in the conductive category (see Table 1).

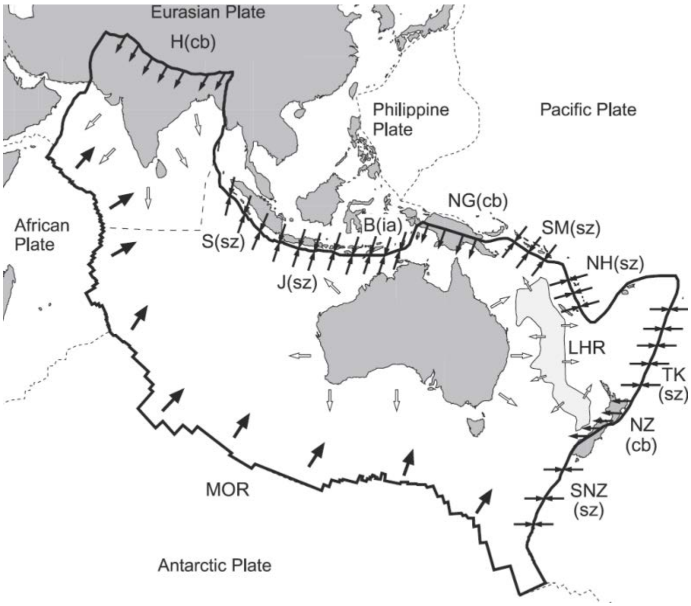


Figure 4: Tectonic setting of the Australian continent. Australia is part of the Indo-Australian Tectonic Plate. Australia has no convection based geothermal resources because of this tectonic setting. From (Reynolds, Coblentz, & Hillis, 2002)

Australia's geothermal resources have often been categorised as either Hot Sedimentary Aquifers (HSA) or Enhanced (or Engineered) Geothermal Systems (EGS). HSA resources could be considered as one end member in a continuum, representing resources that have high natural permeability. EGS resources then cover a broad spectrum with increasing amounts of reservoir enhancement required up to a point where reservoirs have no natural permeability (the original Hot Dry Rock concept first developed at Los Alamos National Laboratory, Brown, Duchane, Heiken, & Hriscu, 2012). This spectrum is shown in Figure 5, with a further subdivision for shallow direct use geothermal projects. The three resource categories shown in this figure provide useful distinctions for describing the fundamental aspects of different geothermal resource types in Australia.

A. *Shallow, direct use*: Typically in the 500 m to 1,500 m depth range targeting aquifers with high permeabilities at low to moderate temperatures for direct use applications. Geothermally heated swimming pools in Perth are an example. The geothermal resource that provides heat for the geothermal power station at Birdsville in Queensland also fits in to this category, even though it is not a direct use application.
B. *Deep, natural reservoir*: Typically greater than 1,500 m targeting aquifers with high permeabilities (no or minimal stimulation required) for direct use or electricity generation. These resources are in sedimentary aquifers (the fluid is stored within the space between sedimentary grains), fractured aquifers (the fluid is stored and flows within fractures in the rock) or some combination of the two. Examples include proposed deep HSA/direct use applications in Perth and the resources targeted by Salamander-1 and Celsius-1.
C. *Enhanced Geothermal Systems*: Geothermal resources where the reservoir needs to have its permeability increased via the stimulation of existing structures or the creation of new ones. Heat may be used for direct use or electricity generation, although electricity generation is the main target. Examples include Geodynamics Limited's Innamincka Deeps project in the Cooper Basin and Petratherm Limited's Paralana project.

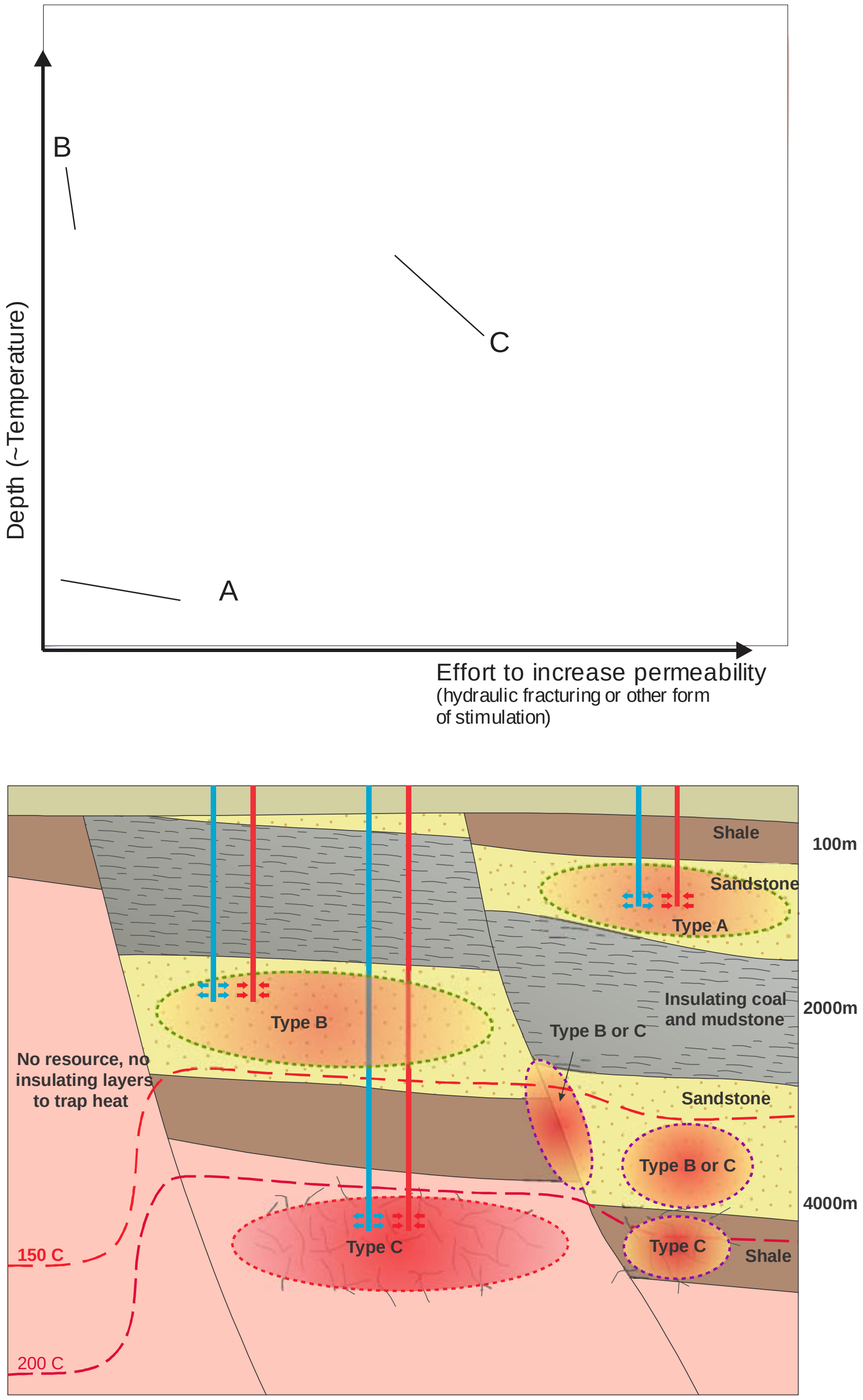


Figure 5: Categorisation of Australia's geothermal resource styles as a function of depth (approximates temperature) and the amount of enhancement required to produce the required flow rates. A) shallow, direct use; B) deep, natural reservoirs; and C) Enhanced Geothermal Systems and hypothetical geological settings for geothermal resources in Australia.

Figure 5 is a schematic showing the variety of geological settings for the three resource types described above. The primary difference between types A and B is the depth of the resource, with the shallower type A resources having lower temperatures, lower drilling costs and lower resource characterisation costs. The direct use applications that these shallow resources are used for (swimming pool heating, space heating) do not require very high temperatures but do require good flow rates.

A common factor of all of these resource types is the importance of sedimentary basins. Type A and B resources, in most cases, rely on the aquifers found within basins. All three resource types benefit from the fact that in many cases basins have rocks (coal, carbonaceous mudstones and shales) with low thermal conductivities that trap heat, increasing the thermal gradient. Over 60% of the Australian continent is covered by sedimentary basins (Figure 6).

When these basins are over basement rocks with average or above average heat flow, anomalously high thermal gradients result. For example, heat generated in the Big Lake Suite Granodiorite is trapped by the insulating carbonaceous mudstones, siltstones and coals of the overlying Cooper and Eromanga Basins at Geodynamics' geothermal development near Innamincka in South Australia. Anomalously high heat flows from lower in the crust may also contribute to this resource. Here, the thermal gradient exceeds 50 °C/km and the heat flow exceeds 100 mW/m^2, nearly double the average for continental crust (25–30 °C /km and 65 mW/m^2). High heat producing basement rocks are thought to be widespread within Australia (Geoscience Australia & ABARE, 2010). Recent studies have also suggested that mantle degassing may also contribute to crustal heat flow anomalies (e.g. Uysal et al. 2012).

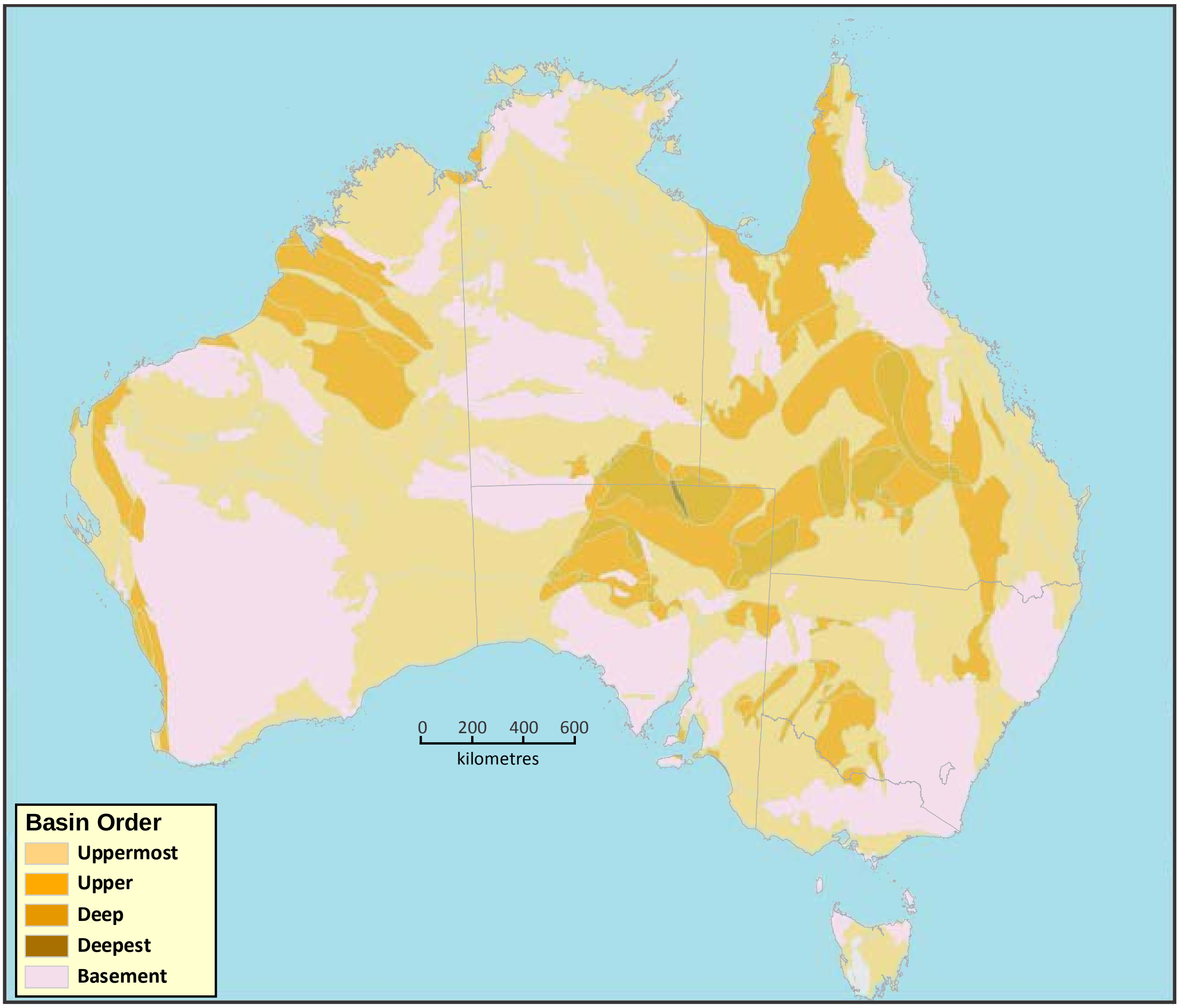


Figure 6: Australia's sedimentary basins (after Budd, 2007).

While Australia's geothermal resources are dominated by conductive heat flow, heat transport through fluid movement (convection and/or advection) may occur within thick and highly permeable aquifers. Sheldon et al. (2012) and Schilling et al. (2013) describe the potential for convection and advection in the Perth Basin, Western Australia, and the potential for thermal highs and lows because of these processes.

The stress conditions within continental Australia also have a significant impact on the characteristics of Australia's geothermal energy resources. The Indo-Australian plate is travelling north, colliding with the Eurasian plate along the Himalayas, and the Pacific plate in New Guinea. This setting has resulted in a stress state that is dominated by compressional tectonics with some regions of strike-slip (lateral displacement) tectonics (R. R. Hillis & Reynolds, 2000). There have been no areas identified with extensional/transtensional stress regimes more typically associated with convective geothermal settings. Active faulting within the Australian continent, while not completely absent, is much less frequent than in the active tectonic settings that host convective geothermal resources. This active faulting appears to be a critical component in providing fluid flow pathways for convective geothermal resources.

1.3 Australia’s Geothermal Energy Resource

The Australian Energy Resource Assessment (Geoscience Australia and BREE, 2014) describes geothermal energy as a major resource, with significant potential. However, the assessment also points out that the majority of Australia’s geothermal projects are still at proof-of-concept or early commercial demonstration stage. A compilation of geothermal resources presented in the AERA as at December 2012 was presented in the assessment with a total resource size of 440,570 PJ (recoverable geothermal energy). These resources were reported by geothermal energy companies listed on the Australian Stock Exchange in accordance with the second edition of the Australian Geothermal Reporting Code (Australian Geothermal Reporting Code Committee, 2010) These resource estimates are based on exploration activities that cover only a small portion of the Australian continent, by companies listed on the Australian Stock Exchange (unlisted companies have no obligation to report their resources or to follow the code if they do), and only three of these companies have drilled to reservoir depths.

By comparison, the Australian Energy Resource Assessment (Geoscience Australia and BREE, 2014) reports a recoverable black coal resource of just over 3,408,845 PJ. The black coal resource includes recoverable economic and sub-economic demonstrated resources and inferred resources. The size of the Australian geothermal resource is very uncertain because of the lack of data about temperature at depth. Geoscience

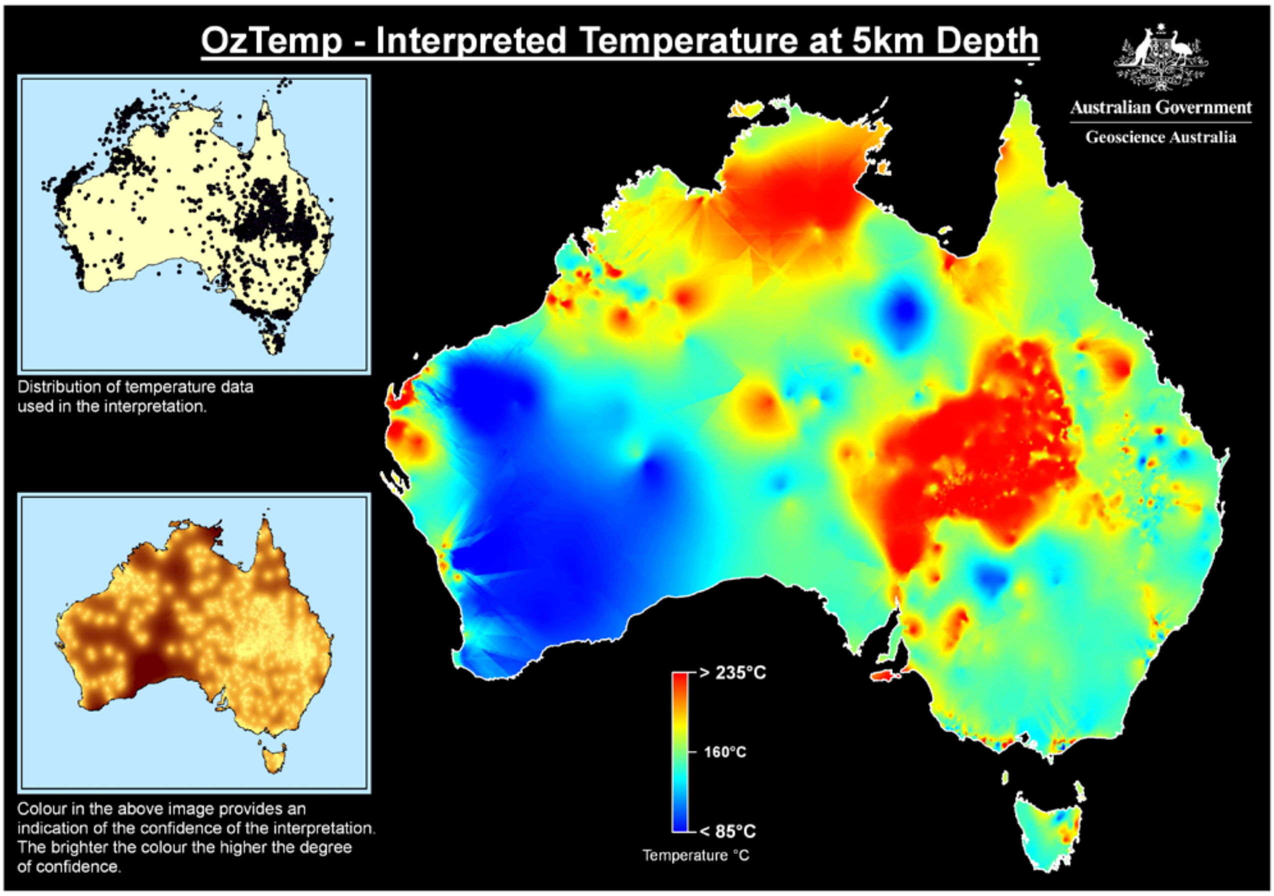


Figure 7: An interpretation of the crustal temperature at 5km depth, constructed using the OzTemp bottom-hole temperature database. The map is based on available data that has variable spatial coverageand it is likely additional areas of relatively high temperaturemay be identified in areas not yet depicted. Downloaded from: *http://www.ga.gov.au/energy/geothermal-energy-resources.html*

Australia has maintained a national well temperature database (Figure 7). Based on these data, the amount of heat in rocks less than 5km deep but over 150 °C in temperature in the Australian continent has been approximated by Budd et al (2008) at over 1.9 x 10^{10} PJ. Huddlestone-Holmes and Beardsmore (Huddlestone-Holmes & Beardsmore, 2012) calculated the amount of recoverable heat in Queensland, New South Wales, Victoria, Tasmania and South Australia as 142 x 10^6 PJ.

These various resource estimates all suggest that resource size for geothermal energy is very large. However, unless these heat resources can be extracted economically, the estimates are can only be considered as an indication of the potential contribution geothermal energy could make in Australia.

1.4 History of the Geothermal Energy Sector in Australia

This section provides an overview on the development of geothermal energy in Australia. There are two distinct phases in the development of the Australian geothermal sector. Before the mid-90s, there was limited activity primarily focussed on direct use applications of hot groundwater. From the mid-90s, following a study commissioned by the Energy Research and Development Corporation (Somerville et al., 1994), geothermal energy received a significant boost in interest through the first decade of the 2000s.

1.4.1 Early development's in geothermal energy in Australia (up to mid-1990s)

Prior to the 1990s, there had been several localities with limited tourist development around natural springs including Tallaroo and Innot (Queensland), Daley River (Northern Territory), Hastings (Tasmania), Tumut (New South Wales) and in Perth (Western Australia). Most of these resources are drawing on water circulating within normal geothermal gradients (Cull, 1985).

Figure 8: The extent of the Great Artesian Basin (beige) showing recharge areas (dark yellow), flow direction (green arrows) and clusters of springs (red dashed outline). Source: http://wetlandinfo.ehp.qld.gov.au/wetlands/ecology/aquatic-ecosystems-natural/groundwater-dependent/unweathered-sandstone/

Early commercial geothermal energy systems in Australia accessed warm water from sedimentary aquifers, primarily for direct use applications. In Portland, Victoria, a district heating system was used to provide heat to over 14,000 m^2 of building space and the municipal swimming pool. This system with an installed capacity of 104 MW_{TH} provided an estimated 8,857,014 MJ of energy savings per annum to the local council (Burns, Creelman, Buckingham, & Harrington, 1995; Burns, Weber, Perry, & Harrington, 2000). Operations commenced in 1983, with the system using heat from the 1,400 m deep Henty Park Bore that was part of a borefield used to supply drinking water. In 2004, water from the Henty Park Bore was no longer used for drinking purposes, instead being released in to the ocean via a canal once the heat had been extracted (Chopra, 2005). The system was decommissioned in 2006 as the surface release of ground water was no longer considered acceptable (Graeme R Beardsmore & Hill, 2010). A system operated in Taralgon, Victoria, supplying 68 °C process water for paper manufacturing from two 600 m deep wells in the 1950s before dewatering from brown coal mining caused massive dewatering in the region (Burns et al., 2000).

The Great Artesian Basin (Figure 8) that extends from Queensland to north-west New South Wales and northern South Australia has been exploited for water for drinking and agriculture for over 100 years. Thousands of bores have been drilled in to the basin with many extending past 1,000 m in depth with water temperatures of up to 110 °C and sustainable flow rates of up to 70 l/s (Cull, 1985). This heat is often seen

as a nuisance but has been utilised for therapeutic baths (e.g. Moree in northern New South Wales). Hot water from the Great Artesian Basin also provided heat for Australia's first two geothermal power plants.

The Mulka geothermal power plant was developed in 1986 in northern South Australia on a remote cattle station. The plant was a trial plant, funded by state and federal governments, and used water from a recently refurbished 80 year-old water bore that produced an artesian flow of 86 °C water. The water was not reinjected. The Organic Rankine Cycle power plant had a rating of 20 kWe and ran for three years before the system was decommissioned (Popovsky, 2013).

The Birdsville geothermal power plant in south-west Queensland was also built as an experimental plant funded by federal and state governments. The plant uses hot water from a bore that was drilled in the early 1960s to provide water for the town. The bore is 1280 m deep, has a 6 inch casing and produces 98 °C water with an unrestricted artesian flow of 40 l/s (Ergon Energy, 2013). The plant was designed and built by Enreco Pty. Limited (who also designed and built the Mulka power plant) with a design rating of 150 kWe gross using R114 as the working fluid. The plant was commissioned in 1992 for a four year trial, but was suspended in 1994 as the use of R114 was considered to be environmentally unacceptable (Burns et al., 2000). The plant was put back on line in 1999 with isopentane as the working fluid and several other modifications were made to improve the plant's performance. In 2004, the plant's output was 80 kWe net with a capacity factor of over 95%, supplying just under a third of Birdsville's electricity needs with the remainder coming from diesel and LPG-fired generators (Ergon Energy, 2013). Water flow from the bore is limited to 27 l/s. Some of the water produced is used to supply the town's drinking water while the remainder flows in to a wetland (Figure 9). None of the water is reinjected.

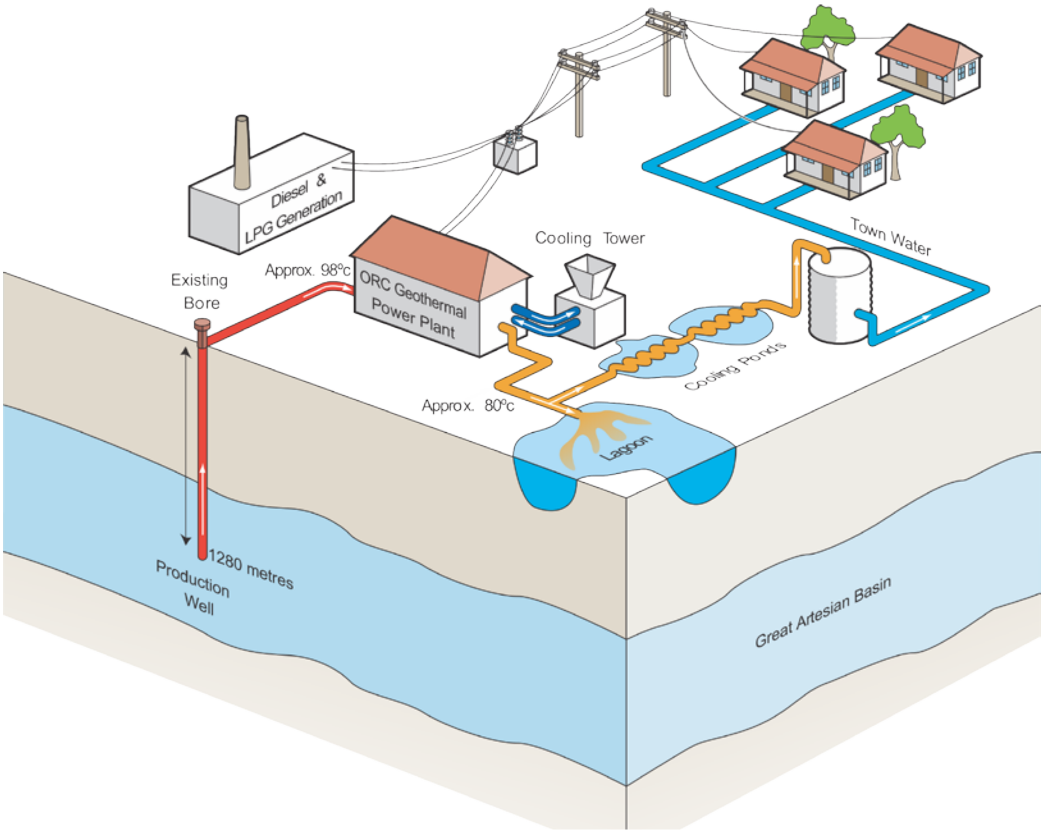


Figure 9 Schematic of the Birdsville Geothermal Power Station. Modified from Ergon Energy Birdsville Organic Rankine Cycle Geothermal Power Station fact sheet (Ergon Energy, 2013)

1.4.2 Australian Geothermal Energy's growth phase (mid 1990s to 2010).

1.4.2.1 The Hot Dry Rock Feasibility Study (pre-2000)

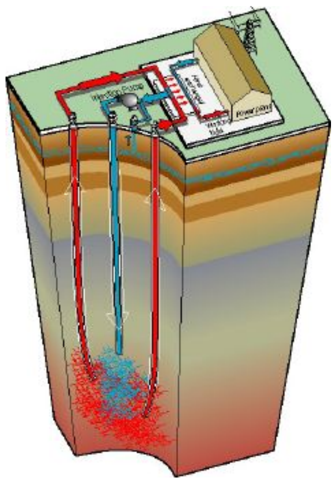
Although Hot Dry Rock geothermal potential had been considered in Australia from the mid 1980s (Burns et al., 2000), the real impetus for the establishment of the Australian geothermal energy sector appears to have come from the feasibility study commissioned by the Energy Research and Development Corporation (Somerville et al., 1994). This study looked at the potential for Hot Dry Rock (HDR) geothermal energy to make a large scale contribution to Australia's electricity supply. The study contained a comprehensive assessment of the available temperature data from over 4,000 petroleum and minerals wells and found that Australia's HDR resource was 'extremely large'. The study also found that the geology of Australia had potentially a unique combination of conditions that were favourable for developing a geothermal energy resource. These are:

- Areas with anomalously high crustal heat flow, particularly in the Great Artesian Basin area;
- Abundant coverage by thick sedimentary basins containing a high proportion of shales and coals with low thermal conductivities;
- The presence of large undeformed granitic bodies that contribute to heat generation and are ideally suited for geothermal reservoir creation; and,
- The dominant compressional tectonic setting that would result in the development of horizontal stimulation cells that are necessary for extracting an HDR resource.

The report also described the technologies required to extract a geothermal resource. The technologies (drilling, hydraulic stimulation, seismic monitoring and well logging) were all proven and mature. An economic study in the report found that HDR resources could be developed to produce electricity for less than $100/MWh with a 15% return on investment, which was comparable to power supply costs in remote areas using conventional technologies.

Box 2 - The Hot Dry Rock concept.

The Hot Dry Rock concept was originally established by researchers at the Fenton Hill site established by Los Alamos National Laboratory in the USA in the early 1970s (Brown et al., 2012). The concept is centred around the need to create a reservoir and assumes that the reservoir is confined. This requires fractures to be created and opened within the rock mass that the reservoir is being created in and these fractures are not open beyond the reservoir (fluid cannot move in to or out of the reservoir). Granite bodies are considered ideal for Hot Dry Rock systems as they are thought to be large, homogenous, contain some natural fractures (that assist in reservoir creation) and have high internal heat production. This concept could be considered an end member of Enhanced Geothermal Systems.



HDR Schematic from http://www.ees.lanl.gov/ees11/geophysics/other/hdr.shtml

The Sommerville et al. (1994) report recommended that Australia commence research into HDR technology through the drilling of a well and a reservoir stimulation program. Two candidate sites were nominated, one in South Australia, North East of Moomba (in the vicinity of Geodynamics Limited's current Innamincka Deeps project) and the other in the Hunter Valley, New South Wales.

1.4.2.2 Early Hot Dry Rock/EGS developments (2000-2004)

Activity immediately following the release of the HDR feasibility study consisted of further desktop studies of various potential localities for a demonstration site (Burns et al., 2000). It was not until the New South Wales (in 1998) and South Australian (2000) Governments enacted legislation to allow for the exploration of geothermal energy resources that activity started to markedly increase (Chopra, 2005).

The first geothermal exploration lease granted in Australia was over the target in the Hunter Valley region of NSW identified by Somerville et al. (1994). The grant was awarded in 1999 to Pacific Power Corporation, a state owned integrated power company that has since been broken up. Pacific Power conducted a series of heat flow wells with depths up to 920 m and one 1946 m deep well (Chopra, 2005). These activities were partly funded by a $790,000 Renewable Energy Commercialisation Program grant that involved researchers from the Australian National University (Australian Greenhouse Office, 2003). The wells found geothermal gradients of up to 65 °C/km. Geodynamics Limited acquired this lease from Pacific Power in 2002, along with an adjoining lease. Little activity has occurred on these leases since.

The South Australia government awarded its first three geothermal energy leases to three separate consortia in 2001. Two of the leases were near Innamincka (GEL 97 and GEL 98) and the relevant consortia merged with Geodynamics Limited taking on these leases. Geodynamics Limited was floated on the Australian Stock Exchange in 2002, raising $11.5 million in its initial public offering. Geodynamics Limited's Innamincka Deeps project is on these leases and Australia's first well in to an EGS resource, Habanero 1, was drilled to a depth of 4,421 m on GEL 97 in 2003. This project is discussed further in section 1.4.3.1.

GEL 99, which surrounds Moomba, was awarded to Scope Energy Proprietary Limited (SCOPE had strong links with the University of New South Wales **Sc**hool **o**f **P**etroleum **E**ngineering). The University of New South Wales was awarded a $1 million Renewable Energy Commercialisation Program grant to investigate the resources around the Big Lake 60 well within this lease (Australian Greenhouse Office, 2003). This lease was eventually acquired by Geodynamics Limited and it has seen limited activity.

1.4.2.3 A period of Rapid Growth and Decline (2004-2012)

Following these early efforts, there was a rapid uptake in geothermal energy activity primarily driven by the private sector. By 2004, there were 24 geothermal exploration leases in South Australia and 2 in New South Wales (Chopra, 2005) held by seven different entities. The peak of activity came in 2010, with 414 exploration licences or licence applications held by over 50 entities covering approximately 472,000 km^2 across all Australian states and the Northern Territory (Goldstein & Bendall, 2011).

Table 2 shows the annual change in exploration licences and licence applications, industry spending on field projects and Australian Stock Exchange listed companies established primarily to develop geothermal resource from the early 2000s to 2012. Over this time period, over $800 million has been spent on exploration activities on these licenses by the Australian geothermal industry. The majority of this expenditure has been in South Australia, with Geodynamics' Innamincka projects (see section 1.4.3.1) accounting for around half. All of the funding has been through direct equity investment or government grants. The majority of companies working in the geothermal energy sector are either small listed or private companies. Geothermal exploration lease applicants are required to submit a work plan as part of the application process. These work plans set out the minimum level of expenditure that the companies are required to make in order to comply with the conditions of their licences. At the end of the 2011 calendar year, a total of over $3 billion of work program investment was forecast for the period 2002 to 2015, with $733 million already spent (Goldstein & Bendall, 2012). This high level of expenditure reflects the optimistic approach the industry had, along with regulators used to the practices of the petroleum industry. It is unlikely that this investment will be realised with most companies in the sector seeking to suspend their licences or reduce their work program commitments to more realistic levels.

The peak in activity came in 2010, with over $200 million spent on exploration activities and over 430,000 km^2 under geothermal exploration licences or licence applications (Figure 10 and Figure 11). The upward spike in expenditure in 2012 was due primarily to Geodynamics Limited's Habanero 4 well. The amount of expenditure for the 2013 calendar year is expected to be less than in 2011.

Year	Licences/ Licence Applications	Area (km^2)	Annual Spend (million)	Companies	ASX Listed Companies[2]	Market Cap (million)
2002	5	NA	$1	1	GDY	NA
2003	9	NA	$16	5	GDY	NA
2004	9	NA	$18	5	GDY	NA
2005	70	NA	$56	11	GDY, PTR, GRK	$172
2006	110	62,000	$62	16	GDY, PTR, GRK, GHT, EDE	$254
2007	277	285,149	$40	33	GDY, PTR, GRK, GHT, EDE, TEY, GER, KEN, HRL	$799
2008	385	356,263	$113	48	GDY, PTR, GRK, GHT, EDE, TEY, GER, KEN, HRL, PAX	NA
2009	403	360,624	$115	54	GDY, PTR, GRK, GHT, EDE, TEY, GER, KEN, HRL, PAX	NA
2010	414	472,565	$207	57	GDY, PTR, GRK, GHT, EDE, TEY, GER, KEN, HRL, PAX	$189[3]
2011	379	460,268	$80	56	GDY, PTR, GRK, GHT,EDE, TEY, GER, KEN, HRL, PAX	NA
2012	356	432,312	$106	52	GDY, PTR, GRK, TEY, GER, KEN, HRL, PAX	NA
2013[1]	238	306,362	NA	39	GDY, PTR, GRK, TEY, GER, KEN, HRL, RYG	$52[4]

[1] As at end of September 2013

[2] ASX listed companies focussed on geothermal energy. GDY:Geodynamics Ltd; PTR:Petratherm Ltd; GRK:Green Rock Energy Ltd; GHT:Geothermal Resources Ltd; EDE:Eden Energy Ltd; TEY:Torrens Energy Ltd; GER:Greenearth Energy Ltd; KEN:Kuth Energy Ltd; HRL:Hot Rock Ltd; PAX:Panax Ltd; RYG:Raya Group Ltd. KEN was acquired by Geodynamics at the end of 2013. TEY changed its name to High Peak Royalties in April 2014 and has shifted its focus to revenue from royalties.

[3] Does not include Geothermal Resources Ltd. or Eden Energy Ltd.

[4] As at 19 January 2014.

Table 2: Geothermal Activity up to end of the 2012 calendar year. Data compiled from various sources including Hillis et al (2004) Chopra (2005) and Australian IEA-GIA annual country updates from 2005 to 2012 (e.g. Bendall & Goldstein 2013) and from the South Australian Department for Manufacturing, Innovation, Trade, Resources and Energy. The data presented above is difficult to collect, particularly on expenditure. The values in the table should be treated as approximate. Companies holding licenses will include subsidiaries of parent companies in some cases.

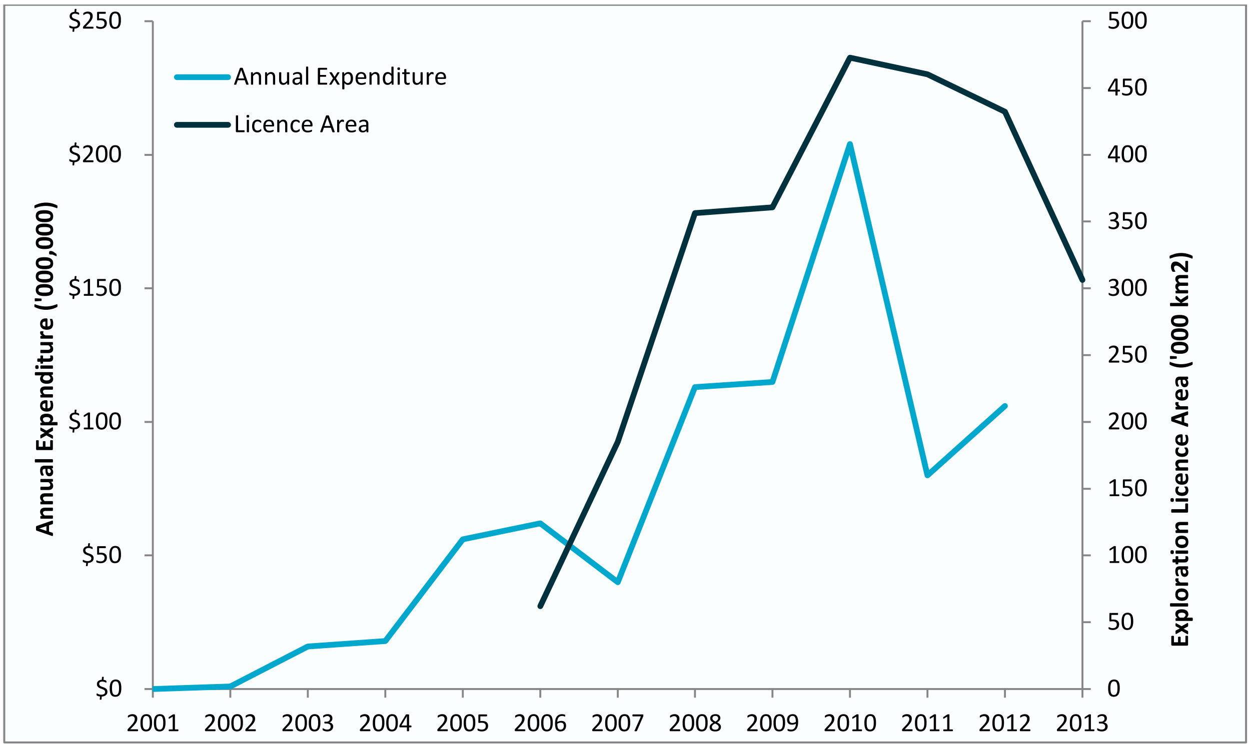


Figure 10: Annual expenditure on geothermal energy exploration in Australia and the area covered by geothermal exploration lease or lease application from 2001 to 2013. The peak of activity was in 2010. No data is available for expenditure in the 2013 calendar year, or for exploration licence area before 2006.

The activity throughout this period could broadly be considered in two categories; activities that don't include drilling to reservoir depths and those that do. The first category consists of preliminary reconnaissance activities that included desktop studies, geophysical surveys and shallow heat flow drilling (depths of a few hundred metres to around two kilometres). The purpose of the heat flow wells is to provide heat flow data that allow for the calculation of temperatures at depth. Other data, such as stress conditions, mechanical properties and thermal conductivity of overburden formations are also collected from these wells. The aim of these activities has been to reduce the uncertainty in the resource before deep drilling, with a focus on resource temperature. The second category involves drilling to reservoir depths, directly testing the targeted reservoir. There were four projects in this category – Geodynamics' Innamincka Deeps (6 wells), Origin/Geodynamics' Innamincka Shallows, Petratherm's Paralana and Panax's Penola Trough Projects. These projects are discussed in more detail in section 1.4.3.

The cost of the first category of activities ($100's of thousand to $1 – 2 million) is substantially less than the cost of drilling to reservoir depths (greater than $10 million) and is aimed at identifying suitable targets for deep drilling. Of the four projects that have drilled to reservoir depths all had data available from existing wells (known as offset wells in the industry), except for the Paralana project. Before drilling the deep well (Paralana 2) for this project, Petratherm drilled several heat flow wells including an 1,807 m deep well to provide thermal gradient and heat flow data.

There have been over 100 heat flow wells drilled by geothermal energy companies in Australia over the last decade. Some examples include:

- Kuth Energy Limited who have conducted a comprehensive 36 well, 20 km x 20 km, shallow (~250 m deep)drilling campaign on their tenements in Tasmania that identified to areas with greater than 100 mWm^{-2} surface heat flow (Holgate, Goh, Wheller, & Lewis, 2010);
- Geothermal Reosurces Limited (now a fully owned subsidiary of Havillah Resources Limited) conducted a detailed study at their Frome project in South Australia, drilling 13 wells including a 1761 m and 1809 m well with bottom hole temperatures of over 90 °C;
- Torrens Energy drilled 27 heat flow wells in their prospects along the Torrens Hinge Zone in South Australia, mostly with depths of 300-500 m with one well to 1,007 m and another to 1,807 m, finding heat flows of up to 120 mWm^{-2} at their Parachilna prospect;
- Petratherm Limited drilled a 487 m heat flow well, and then deepened it to 1,807 m after receiving favourable results, at their Paralana project in South Australia before progressing to their deep well (Paralana 2). A heat flow of 129 mWm^{-2} was measured in this well;

In many other cases the reconnaissance exploration has been limited to desktop studies using available data, collection of thermal gradient logs from existing wells, geophysical surveys (magnetics, gravity, magnetotellurics) and/or drilling of only one or two heat flow wells.

During the 2000s the industry was focussed on developing resources suitable for electricity generation, targeting reservoir temperatures over 150 °C, with only a few exceptions. The industry started to develop several different models for geothermal resources in Australia – Enhanced Geothermal Systems (EGS) and Hot Sedimentary Aquifers (HSA). The term Hot Dry Rock has all but disappeared from the Australian geothermal energy sector. Other geothermal resource concepts such as Heat Exchanger Within Insulator (HEWI), Fractures at Basin-Basement Interface (FABBI) and Secondary Enhancement of Sedimentary Aquifer Plays (SESAP) have also been used by the industry in an attempt to differentiate individual projects. These concepts are variations on the EGS model. Proponents of the HSA model claimed that HSA resources would cost less to develop because the permeability would not require enhancement, would be shallower, and could be accessed by conventional drilling methods as they are in similar geological settings to petroleum resources. However, HSA resources were not expected to be as hot as EGS resources and would therefore require higher flow rates (see Figure 1) to produce enough energy to have a reasonable cost.

1.4.3 Key Projects

1.4.3.1 Innamincka Deeps Project

This project is Australia's most advanced deep geothermal project. The project area is located near Innamincka (Figure 11), on one of the first three geothermal exploration leases awarded in South Australia in 2001. The area was known to have high temperatures at depth within a granitic basement subject to a compressive stress regime from petroleum exploration drilling. The target reservoir is within the Big Lake Suite Granodiorite (which is actually a granite) that is overlain in the Nappameri Trough of the Cooper and Eromanga Basins. The following summary of operations is based on well completion reports and Geodynamics Limited's annual reports.

The original conceptual model for the reservoir was very much along the Hot Dry Rock model pioneered at Fenton Hill. The stage 1 plan for development of this project was to demonstrate that heat could be economically extracted from the resource via a two-well circulation test. This test would be followed by stage 2, the construction of a 13 MWe demonstration plant including the addition of an extra production well.

The first well, Habanero 1, was drilled in 2003 to a depth of 4,421 m. The well intersected several sub horizontal fracture zones within the granite and found that this formation had high fluid overpressures (5,000 psi or 34 MPa). These overpressures were not anticipated and caused considerable well control problems during drilling of the granite section of the well. These problems, resulted in a significant overrun in drilling time and well costs (well costs were double those budgeted, Geodynamics Limited's 2003 Annual Report). Approximately 250 m^3 of drilling mud was lost in to the fracture system while bringing the overpressures under control. The discovery of overpressures in the granites, a pre-existing fracture network

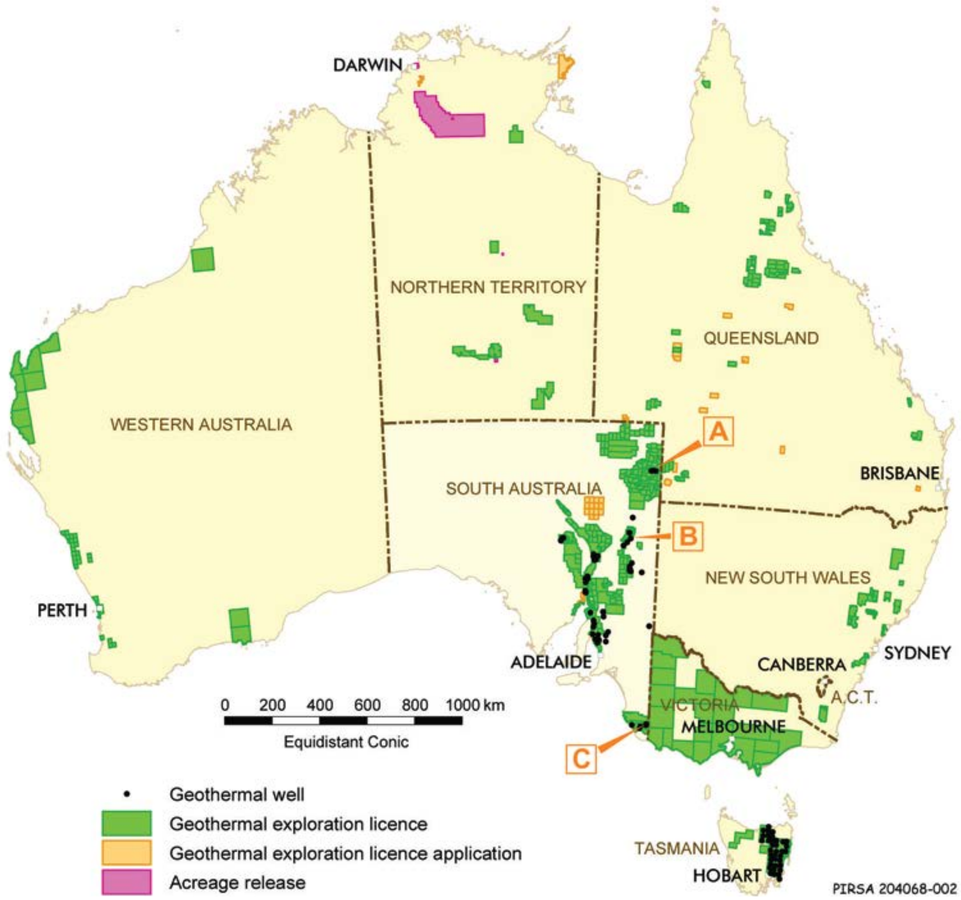


Figure 11: Geothermal licences, applications and gazettal areas as at 31 December 2010 (modified from Goldstein & Bendall 2011) Note that only 7 of the marked geothermal wells intersect reservoir depths. The rest of the wells are heat flow wells generally less than 1,000 m deep. Heat flow wells drilled in WA and NSW are not shown. The location of key projects are indicated by A (Geodynamics/Origin Energy's Innamincka Deeps and Innamincka Shallows); B (Petratherm's Paralana Project); and C (Panax's Penola Project).

and reservoir temperatures of over 248 °C were important discoveries from this well. Habanero 1 was designed as an injection well and could not be used for flow testing. The granite reservoir section was not cased.

Geodynamics completed a major stimulation of the Habanero 1 well in January 2004. Approximately 23 Ml of water was injected in to the reservoir stimulating a volume of 0.7 km^3, a significantly greater volume than anticipated. The 12,000 microseismic events that were recorded showed that the stimulated volume was sub-horizontal as expected in a compressive stress regime.

Following the successful stimulation of Habanero 1, Geodynamics proceeded to drill the Habanero 2 production well to allow the two well circulation test to be completed. The well was spudded (industry term for the start of drilling) in July 2004, approximately 500 m south-southeast of Habanero 1 and within the seismic cloud created by the stimulation of Habanero 1. Managed Pressure Drilling (MPD) methods were employed to manage the overpressures found in the granite section. Two high permeability fracture zones were encountered in the well. The drilling string was broken almost immediately after total depth was reached (4,342 m) leaving 245 m of drilling equipment in the well (known colloquially as a 'fish' in the drilling industry). This fish could not be recovered and a side track was drilled reaching a total depth of 4,358 m. The rig was released on the 31st of March 2005. At the completion of drilling a bridge plug, used to isolate the overpressures during construction of the well head, was lost in the hole at a depth of between 4,212 m and the bottom. The Habanero 2 well was then flow tested but flow rates only reached 15 kg/s. The connection with reservoir in Habanero 2 was considered to be poor due to obstructions near or within the well that Geodynamics attributed to either the dropped plug, drilling mud lost into the fractures during drilling, or a combination of these factors.

Geodynamics conducted a further stimulation of Habanero 1 in September 2005 while planning a well intervention program for Habanero 2. This stimulation increased the size of the stimulated zone by 50% and well injectivity by 30%. A snubbing unit was brought to site in March, 2006 to attempt to remediate the well. Initial attempts to remove the blockage in sidetrack 1 were unsuccessful. Three new sidetracks were attempted in Habanero 2 to reconnect to the reservoir. These sidetracks (sidetracks 2, 3 and 4) were drilled underbalanced (well pressures lower than formation pressures) using down hole turbines. Significant drilling problems were encountered and the well was abandoned after the drill string was lost due to well stability problems in sidetrack 4. These stability problems were later attributed to the formation overpressures and the underpressured drilling methods employed for these sidetracks. The snubbing unit was released in June 2006.

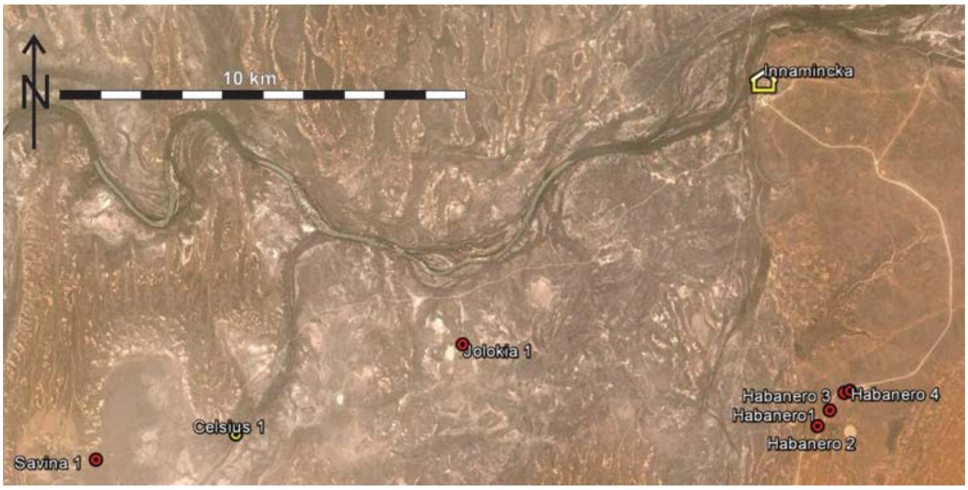


Figure 12: Geodynamics Ltd's Innamincka field site. Image source "Innamincka" 27°48'02.32" S and 140°41'04.72" E. **Google Earth**. Image Date 26 August 2011. Accessed 6 January 2014.

Geodynamics then re-scoped the project to a doublet (rather than 3 wells) and a 1 – 3 MWe demonstration plant. This re-scoping was done based in part on the lessons learned in drilling Habanero 1 and 2 and partly to meet the conditions of a Renewable Energy Demonstration Initiative Grant. Habanero 3 was drilled

approximately 550 m north-northeast of Habanero 1 between August 2007 and February 2008 using a drill rig that Geodynamics had purchased (Rig HP100). This rig was the most capable onshore drilling rig in Australia at the time. Habanero 3 was designed for production and injection. Managed Pressure Drilling methods were used in the granite section. While the well took longer to complete than anticipated (170 days instead of 90), primarily due to low penetration rates in the granite, no major problems were encountered. The upper fractures within the granite section were cased off to assist in managing overpressures. The well was completed with a 7-inch slotted liner in the granite reservoir section.

A local stimulation of Habanero 3 was conducted in April 2008. An open circulation test was then completed, producing brine from Habanero 3 into a cooling pond and then reinjecting the brine in Habanero 1. Habanero 3 had sustained flow rates of 20 kg/s at a surface pressure of 27.5 MPa and 27 kg/s at 15 MPa. The maximum flow rate recorded was 30 kg/s with no backpressure at the surface. Closed loop testing commenced in August 2008 but was halted due to a faulty injection pump seal. The closed loop test recommenced later in 2008 and was completed on the 25th of February, 2009, successfully circulating 60,000 tonnes of brine. The successful closed loop test was taken to be a demonstration of proof of concept (resource definition, drilling and well completion, reservoir enhancement, well productivity and injectivity, fluid circulation between wells, mitigation of identified operating constraints, no adverse environmental impacts).

A 1 MWe pilot power plant had been constructed as a demonstration of power generation from an EGS resource. The plant was only a few days away from hot commissioning using the Habanero 1 to Habanero 3 loop when a blow out occurred at Habanero 3 (24 April 2009) when casing near the surface failed. The well was brought under control 28 days later. Initial investigations into the cause of the casing failure suggested hydrogen embrittlement triggered by H_2S and CO_2 in the reservoir fluids. However subsequent investigations now point to caustic stress corrosion cracking caused by unset cement in the annulus between two casing strings combined with high temperature cycling during production testing as the most likely cause of the failure.

Immediately after completing Habanero 3, Geodynamics' rig HP100 went on to drill two more wells: Jolokia 1 and Savina 1 (Figure 12). These wells were drilled to prove the resources in the Cooper Basin for future expansion. Jolokia 1 was spudded approximately 9 km west of the Habanero site in March 2008 and drilled to a total depth of 4,911 m (including 1,209 m of granite) taking just over 180 days to drill. The granite reservoir section was not cased. Bottom hole temperatures in excess of 270 °C were recorded in this well, but no highly permeable fracture zones were detected. Savina 1 was spudded approximately 10 km west of Jolokia 1 in October 2008. The well was suspended after reaching a depth of 3,700 m due to the failure to recover stuck drill pipe. After plugging the well, the rig was released in early March 2009. Savina 1 intersected the top of the granite at 3,659 m and experienced high inflows, interpreted to be caused by the intersection of a high permeability fracture zone similar to those found in the Habanero wells.

Jolokia 1 was re-completed with a liner in October 2010 after some delays caused by regional surface flooding. This re-completion was done to mitigate the risks of a reoccurrence of the failure encountered in Habanero 3. The well was stimulated between October and November 2010. This stimulation failed to achieve high injection rates or a significant amount of seismic activity. The data indicated that only steeply dipping fractures were activated despite the compressive stress regime. Injection pressures were limited by the 10,000 psi rating of the well head, although these limits were partially overcome by using sodium bromide to increase the density of the injection fluid for part of the stimulation.

Geodynamics Limited then decided to prioritise their field activities in the Habanero area and to complete the demonstration of the 1 MWe pilot plant. This required the drilling of an additional well and Habanero 4 was spudded in March 2012 with drilling completed in September that year. The well was drilled approximately 140 m east of Habanero 3 to a depth of 4,204 m, targeting the main fracture zone encountered in the other Habanero wells. Habanero 4 cost just over $50 million to drill with a 'failure is not an option' approach. One of the technical innovations at Habanero 4 was the reverse cementing of the final casing string and the installation of a liner to reduce the risks of caustic stress corrosion cracking– the first well to be cemented this way in Australia. As well as implementing the novel well design, Geodynamics Limited also reported improvements in bit life and rate of penetration within the granite section, improved well bore stability, minimal fluid gains/losses when drilling through fractures and improved mud

management, reflecting the experience gained in drilling their other deep wells. The granite reservoir section was left open with no liner or casing installed.

Habanero 4 was stimulated and production tested in November 2012. A maximum injection rate of 53 kg/s was achieved during the stimulation, which involved the injection of 34 ML of water. This stimulation resulted in a further increase in the size of the stimulated zone at Habanero with over 27,000 microseismic events detected. Production testing prior to the major stimulation showed a maximum flow rate of 39 kg/s with a 21 MPa well head pressure.

Geodynamics Limited then ran their 1 MWe pilot plant from April to October 2013. Habanero 1 was used as the injection well (after some refurbishment) and Habanero 4 as the production well. The system ran in standalone mode from June 2013, with availability exceeding 75%. The maximum well head temperature achieved was 215 °C with a flow rate of 19 kg/s. The injectivity of Habanero 1 limited the flow rate, partly because of the 4½-inch tubing and partly because of a mud damage left in the reservoir during drilling. The plant generated approximately 650 kWe gross which was able to supply all auxiliary loads. There was no external load available to take any extra generation. The power plant trial exceeded expectations and demonstrated reservoir performance and closed brine loop stability; significant thermosiphon effect in the closed loop; and an effective chemical cleaning system to remove stibnite build up in heat exchanger (Mills & Humphreys, 2013).

Geodynamics Limited is currently evaluating the results of the pilot power plant trial and developing plans for further development of the Innamincka Deeps project. In addition to the potential for electricity generation, they are also looking at options for direct use of heat for gas processing.

1.4.3.1.1 Geodynamics Innamincka Deeps Funding

Geodynamics Limited's operations at Innamincka have cost in the order of $400 to $450 million to the end of the 2012/2013 financial year. The bulk of these costs have been funded through equity, with the company successfully raising approximately $350 million from investors since listing in 2002, including cornerstone investors Woodside Petroleum Limited (who no longer have a significant interest), Origin Energy Limited., Sunsuper/The Sentient Group, and Tata Power from India. The Renewable Energy Equity Fund was also a corner-stone investor contributing $1.8 million in equity in 2002, partially underwriting the IPO. This equity fund involves government and private funds and the government share was $1.2 million. Origin Energy Limited became a Joint Venture partner in the Innamincka project from the 19 December 2007, earning a 30% interest with a farm-in fee of $105.6 million and a continuing 30% share of costs. Origin exited the joint venture effective 30 June 2013.

Government grants totaling $102.3 million have also been awarded to Geodynamics Limited to assist in the development of the Innamincka resource. The grants are as follows (see also Appendix A.1):

- AusIndustry R&D Start Program grant for $5 million in 2002, for development of an HFR reservoir. A $1.5 million top up to this grant was provided in the 2003/2004 financial year. The grant is a co-contribution.
- AusIndustry Renewable Energy Development Initiative (REDI) Program grant for $5 million in 2005, for construction of the pilot power plant. Only $4.3 million spent. The grant is a co-contribution.
- South Australian Primary Industries and Resources Department (PIRSA) PACE grant for $100 thousand in the 2006/2007 financial year to bring in a high temperature image logging tool from Sandia National Labs in the USA to log Habanero 3. The grant is a co-contribution.
- A South Australian Government Regional Development Infrastructure Fund (RDIF) grant for $560 thousand in 2009, for 50% of the cost of the transmission line between the 1 MW Power Plant and the Innamincka township.
- A Renewable Energy Demonstration Program Grant for $90 million in November 2009, for the development of a 25 MW commercial demonstration plant in the Cooper Basin (including well field activities). The grant is a co-contribution, with total eligible expenditure for the project of $338.6 million. Geodynamics Limited and ARENA are in discussions about how this grant may proceed.

Geodynamics Limited has received two tax rebates totaling $30.7 million under the Federal Government's Research and Development Tax Incentive Scheme. Under the scheme, a cash refund of 45 cents per dollar

spent on eligible research and development is available to companies with an annual turnover of less than $20 million. Geodynamics' rebates relate to the costs incurred in the 2011/2012 and 2012/2013 financial years (including part of the costs of drilling and stimulating Habanero 4) for research and development conducted on the Cooper Basin Enhanced Geothermal Systems Project.

As at December 2013, Geodynamics Limited had drawn down $32.4 million of its REDP grant. The total government grant support Geodynamics Limited had received for their activities in the Cooper Basin is $43.9 million, with a further $57.6 million available under the REDP grant. Including the R&D Tax rebate and the early Renewable Energy Equity Fund investment, the total government contribution to the Innamincka Deeps Project is $74.6 million.

1.4.3.2 Innamincka Shallows Project

In 2010 Origin Energy Limited (50% and operator) and Geodynamics Limited (50%) announced the Innamincka Shallows Joint Venture to explore for shallow HSA resources in Geodynamics Limited's South Australian licence areas. Origin Energy drilled the Celsius 1 well approximately 15 km west of the Habanero site (Figure 12). The well was spudded on the 3rd of April 2011 and the rig released on the 19th of May 2011. The well's total depth was 2,417 m and the reservoir section was not cased. The well targeted the Hutton Sandstone at the base of the Eromanga Basin, which overlies the Cooper Basin. The Hutton has very good reservoir quality elsewhere in the basin and produces significant amounts of oil and gas (Alexander & Cotton, 2006). While temperatures achieved in this well met expectations (corrected bottom hole temperature of 160 °C), drill stem tests and log interpretations showed that the Hutton Sandstone had very low permeability.

Origin exited the Innamincka Shallows Joint Venture at the same time that it exited the Innamincka Deeps Joint Venture, effective 30 June 2013. No further drilling is planned for these HSA resources in Geodynamics Limited's licence areas.

Reservoir quality in the Hutton Sandstone is the subject of an ARENA Emerging Renewables Program Measure awarded to the South Australian Centre for Geothermal Energy Research at the University of Adelaide and CSIRO. Preliminary findings point to diagenesis (changes that occur in sedimentary rocks as they are buried) destroying any permeability within the formation (Dillinger, Huddlestone-Holmes, Ricard, Esteban, & Zwingmann, 2013).

1.4.3.2.1 Innamincka Shallows Funding

Funding for this project was supplied entirely by the joint venture partners with no government assistance. Total costs for the project are around $21 million, based on Geodynamics Limited's reporting of their contribution to the joint venture in their 2013 annual report.

1.4.3.3 Peteratherm's Paralana Project

Petratherm Limited's Paralana project was Australia's second EGS project to drill to reservoir depths. The Paralana project is located 600 km north of Adelaide in South Australia (Figure 11). The project is targeting fractured neo-proterozoic meta-sediments and meso-proterozoic basement rocks in a half graben immediately to the east of the Mount Painter Inlier, although the geology of the reservoir and thickness of units that would be encountered were unknown before drilling. The area was targeted because of the known high heat production of the Mount Painter Inlier, the Paralana Hot Spring with 62 °C water at the surface and the presence of insulating sediments. The Paralana 1B shallow heat flow well was drilled in September 2005 to a depth of 492 m. The measured temperature gradient was over 80 °C/km. The well was then deepened to 1,807 m in June 2006, recording a bottom hole temperature of 109 °C, and a calculated heat flow of 129 mW/m^2.

Based on the promising results of heat flow drilling, Petratherm Limited with their joint venture partner Beach Energy Limited (who ran the field operations) proceeded to drill the Paralana 2 well. This well was spudded in late June 2009 and the rig released in December 2009 after reaching a total depth of 4,012 m. Highly fractured ground in the lower part of the well resulted in a partial well collapse, with 7-inch casing cemented in the well to a depth of 3,725 m (it could not be advanced further). A temperature of 176 °C was

measured at a depth of 3,672 m. Overpressures of approximately 3,300 psi in geothermal brines were found at depths between 3,670 m and 3,864 m.

In January 2011, the well was perforated over the interval 3,679 m to 3,685 m and a diagnostic fracture injectivity test (DFIT) was run. After stimulation, the measured well head pressure was 3,940 psi indicating that the injectivity test had successfully connected with over-pressured reservoir fluids. A larger stimulation was conducted in July 2011. 3.1 ML of fluid were injected over a five day period. Initial injection rates were only 2 to 4 l/s (1-2 bpm) but increased to 20 l/s (10 bpm) after the injection of several acid stages. More than 10,000 microseismic events were recorded, with a complex distribution. The stimulated zone extends to the northeast and east of the Paralana 2 well by up to 900 m with depths between 3,500 m and 4,000 m.

In October 2011, a flow test of Paralana 2 was run over a period of seven days, relying on the well's ability to self flow. Flow rates of up to 6 l/s were recorded and a total of 1.3 ML of brine was produced.

1.4.3.3.1 Petratherm Limited's Paralana Project Funding

Petratherm Limited's operations at the Paralana Project have cost in the order of $25 million to $30 million to the end of the 2012/2013 financial year. The bulk of these costs have been funded through equity, with the company successful raising approximately $32 million from investors since listing in 2004, including cornerstone investor Minotaur Resources Investments Proprietary Limited (a wholly owned subsidiary of Minotaur Exploration Limited).

Beach Energy Limited, an Australian petroleum exploration and production company entered in to a joint venture for the Paralana Project in January 2007. Beach Energy Limited are the operator for field activities, lending their expertise gained in petroleum exploration. Beach may earn a 21% interest in the Paralana project through their contribution to the JV. TRUenergy Limited, an Australian integrated energy producer and retailer, farmed-in to the Paralana Project in August 2008. They left the JV in December 2011 having contributed to the cost of drilling and stimulating Paralana 2 without retaining any interest in the project.

A number of Government grants totaling $87 million have also been awarded Petratherm Limited to assist in the development of the Paralana resource. The grants are as follows (see also Appendix A.1):

- AusIndustry Renewable Energy Development Initiative (REDI) Program grant for $5 million in 2007, to test the Heat Exchanger Within Insulator model at the Paralana Geothermal Energy Project. The grant is a co-contribution.
- Plan for ACcelerating Exploration (PACE) grant for $100 thousand for a passive seismic array in 2008.
- Geothermal Drilling Program grant for $7 million in April 2009 to fund drilling of two deep wells at the Paralana Project. The grant is a co-contribution. $4.2 million was drawn down in the 2009/2010 financial year. The remaining $2.8 million was relinquished in 2013.
- An ARENA Emerging Renewables Program Project Grant for $13 million in June 2013 to assist in funding the drilling and stimulation of the Paralana 3 well. The grant is a co-contribution, with total eligible expenditure for the project of $27 million.
- A Renewable Energy Demonstration Program Grant for $62.76 million in November 2009, for the development of a 30 MW commercial demonstration plant at Paralana (including well field activities). The grant is a co-contribution, with total eligible expenditure for the project of $188.3 million. This grant was renegotiated in 2013, and is now $24.5 million for the development of a 7 MW plant to supply power to the nearby Beverley Uranium Mine.

Petratherm Limited. received a $443,112 tax rebate under the Federal Government's Research and Development Tax Incentive Scheme. Under the scheme, a cash refund of 45 cents per dollar spent on eligible research and development is available to companies with an annual turnover of less than $20 million. Petratherm's rebate relates to the costs incurred in the 2011/2012 financial year for research and development conducted on the Paralana Project (stimulation and flow testing).

The Emerging Renewables Program Project grant of $13 million by ARENA is conditional on Beach Energy Limited's ongoing involvement in the Paralana Project and on Petratherm Limited securing an additional $5 million in equity. As part of this grant, ARENA and Petratherm Limited also renegotiated the Geothermal

Drilling Program grant with Petratherm Limited relinquishing the remaining $2.8 million. The Renewable Energy Demonstration Project grant was also significantly re-scoped, downgrading the size of the planned demonstration plant down from 30 MW to 7 MW, which matches the needs of the nearby Beverley uranium mine.

As at October 2013, the total government grant support Petratherm Limited has received for their activities at the Paralana Project is $9.3 million, with a further $37.5 million available under the REDP and ERP grants. Including the R&D Tax rebate, the total government contribution to the Paralana Project is $9.7 million.

1.4.3.4 Panax Limited's Penola Project

Panax Limited's (now Raya Group Limited.) Penola Project is located in southeast South Australia, in the Penola Trough of the Otway Basin (Figure 11), targeting HSA resources hosted in fluvial sandstones in the Pretty Hill Formation. This location was targeted because the trough has been extensively explored for petroleum with more than 20 wells and extensive 3D seismic coverage (De Graaf, Palmer, & Reid, 2010). There is active gas production supplying a gas fired power station near Penola. The Pretty Hill Formation has a thickness of up to 1,000 m.

The project anticipated permeability thicknesses of 10 to 50 Darcy metres, high enough to sustain flow rates of 175 kg/s (without the need to enhance permeability) from a large diameter production well. Reservoir temperatures of 145 °C were predicted.

The Salamader 1 well was spudded on the 31st of January 2010 and the rig released on the 26th of March, 2010. The well was drilled to 4,025 m, with an 8 ½-inch production interval from 2,898 m to the bottom of hole, completed with a 7-inch perforated liner. An air lift string was placed to a depth of approximately 1,000 m to allow flow testing of the well. Drilling was unremarkable, with no major delays. Only six drill bits were used to drill the well. A maximum bottom hole temperature of 171.4 °C was recorded during well testing, although there is some doubt on the reliability of this value with other measurements indicating a bottom hole temperature of around 157 °C.

Well testing was conducted intermittently from April though to July, 2010. Flow tests were conducted by air lifting water from the well. During this testing the flow rates and permeability thickness are interpreted to have declined, the pay zone thickness reduced, and the skin effect[1] changed from positive to negative. After several flow tests, the well was acidized to try to improve connectivity to the formation. While this intervention further decreased skin effect, it was also interpreted to have reduced the payzone thickness. Flow testing achieved stable flow rates of between 10 and 15 l/s, indicating low permeability. An injection test was also trialled, achieving a maximum injection rate of 15 l/s at 92 barG (9.3 MPa, 1,330 psi) wellhead pressure. The permeabilities and flow rates encountered were much lower than anticipated. Panax Limited have indicated that the heavyweight drilling muds used in the well may have caused damage to the formation. The drilling mud used in the reservoir interval was a KCL/CaCO3/Polymer mud to 3,150 m and a more temperature tolerant KCl-KlaShield (polymer water-based drilling fluid system that uses polyamines) from 3,150 m with mud weights around 9.3 ppg. Losses of 8 to 10 bbls/hr were detected near the bottom of the well, but were managed with the use of additives.

Raya Group Limited have suspended activity on the Penola Project.

Reservoir quality in the Pretty Hill Formation is the subject of an ARENA Emerging Renewables Program Measure awarded to the South Australian Centre for Geothermal Energy Research at the University of Adelaide and CSIRO. Preliminary findings point to diagenesis (changes that occur in sedimentary rocks as they are buried) and fines migration destroying any permeability within the formation (Badalyan et al., 2013), although the study is still under way.

[1] Skin effect is the resistance to flow at the wall of the well, a positive skin effect means that there is resistance to flow, usually caused by damage to the formation. A negative skin effect means that there is no resistance and the permeabilities are higher in the immediate vicinity of the well than in the formation.

1.4.3.4.1 Panax Limited's Penola Project Funding

Panax Limited's operations at the Penola Project have cost in the order of $20 million to $25 million to the end of the 2012/2013 financial year. The bulk of these costs have been funded through equity, with the company successful raising approximately $43 million from investors since listing in 2007

Panax Limited received one grant from the federal government to assist in the development of the Penola resource, a Geothermal Drilling Program grant for $7 million in April 2009 to fund drilling of the Salamander 1 well at the Paralana Project. This grant was a co-investment and has been spent in full.

Panax Limited started as a uranium explorer, Uranoz Limited in 2007. It changed its name to Panax Limited in mid 2008, divesting all of its uranium assets to focus 100% on geothermal energy. Panax Limited has also developed interests internationally, most notably in Indonesia and changed its name to Raya Group Limited in May 2013 (Raya means 'great' in Indonesian). Raya Group Limited are now focussing their efforts on their projects in Indonesian that are targeting convective geothermal resources.

1.4.4 Direct Use Projects

As outlined in section 1.4.1, there has been a long history of the exploitation of geothermal resources for direct use application. This section provides a brief summary of the current direct use projects and facilities in operation around Australia. There are many examples of the hot artesian waters in the Great Artesian Basin being used for therapeutic baths. In nearly all cases, hot water found in bores drilled for drinking water are used, with varying levels of sophistication (Figure 13), with some municipalities and private operators setting up formal facilities. There are some localities where natural hot springs occur in the Great Artesian Basin (Dalhousie Hot Spring in South Australia for example), and these are popular tourist attractions. The other hot springs listed in section 1.4.1 are all still operating, although at small scale.

Figure 13: The "Hot Baths" at Comeroo Camel Station, near Bourke, NSW are an example of the many hot baths that use hot water from a bores in the Great Artesian Basin. In this case, the well produces water at 44 °C with flow rates of 4 l/s. Used with permission http://www.comeroo.com

There are two fish farms that use warm groundwater for aquaculture, producing barramundi, a tropical fish, in Victoria and South Australia. A meat processing plant in Victoria, owned by the Midfield Group, uses 42 °C groundwater from an 800 m deep bore as feedwater for sterilization (82 °C) and hand washing water (40 °C). The water is passed through a reverse osmosis plant to produce clean water before heating in a co-generation plant, which provides electricity and hot water from a boiler for the facility. Significant energy savings are achieved by using the groundwater, which is 30 °C hotter than the town water supply used previously, and also reduces the facilities need to purchase town water.

There are two geothermal spas in Victoria – Quality Suites Deep Blue (which includes a resort) in Warrnambool and Peninsula Hot Springs at Rye on the Mornington Peninsula. These two spas draw water from aquifers approximately 700 m deep at temperatures in around 43 °C (Graeme R Beardsmore & Hill, 2010).

Over the last decade, the aquifers of the Perth Basin in the Perth metropolitan area have seen a significant level of development for direct use applications. These projects are described in the following two sections. Green Rock Energy Limited attempted to scale up the use of these geothermal resources with a proposed project to provide campus wide cooling and heating for the University of Western Australia. The company received a Geothermal Drilling Program Grant of $7 million from the federal government and a $5.4 million Low Emissions Energy Development Fund grant from the Western Australian government September 2010. Unfortunately they were unable to raise enough funds to go ahead with the project.

1.4.4.1 Perth Swimming Pools

There are several commercial direct use geothermal projects in Perth, producing geothermal fluid from the Yarragadee Aquifer. This aquifer is a freshwater aquifer that supplies a significant portion of Perth's potable water. The Yarragadee Formation is a Jurassic non-marine fine to coarse-grained, poorly sorted feldspathic sandstone that has high permeabilities with a maximum thickness of 4,000 m. These direct use projects primarily use the geothermal energy to heat swimming pools and with the exception of the Bicton Geothermal Therapy Pool, all water is reinjected into the aquifer. Details of these systems are presented in Table 3. Data on funding for these projects is limited, but costs appear to be on the order of $1 million for a two well system. Some of these projects have been funded by state government grants, usually towards the redevelopment of a whole facility, although details are difficult to find.

Geothermal installation	Year Commissioned	Maximum Groundwater flow (l/s)	Production Depth (m)	Injection Depth (m)	Thermal Power (kW)	Produced groundwater temperature (°C)	Injected groundwater temperature (°C)
Bicton	1997	18	750	NA	400	40	NA
Christchurch Grammar School	2001	12	757	628	625	42	30
Challenge Stadium	2004	50	750	650	2000	43	35
Claremont Aquatic Centre	2004	14	864	608	775	43.5	31.5
Craigie Leisure Centre	2006	21	802	452	400	40*	34
St Hilda's Anglican School for Grils	2011	20.5	1,007	682	1275	49	34
Canning Leisure Centre	2012	26	1,165	588	975	47	38
Beatty Park Leisure Centre	2013	35	1156	799	1925	49	35
Hale School	2014	26	1,006	496	1725	45.5	30
Mandurah Aquatic Centre#	Under Construction (2015)	37	1100	700	1575	45.5	35.5

Table 3: Direct use facilities in Perth. # Proposed system parameters. Data from http://www.airah.org.au/imis15_prod/Content_Files/Divisionmeetingpresentations/WA/12-03-14-WA-Hale-School.pdf

1.4.4.2 CSIRO Sustainable Energy for the Square Kilometre Array.

The SESKA Geothermal Project is a component of the larger Sustainable Energy for the Square Kilometre Array (SESKA) project funded by the Australian Government through the Education Infrastructure Fund (EIF). The project received approximately $19.8 million from EIF.

The objective of the geothermal component of the project was to provide cooling for the Pawsey Centre Supercomputer using a sustainable geothermal solution. Supercomputers produce a large amount of heat and require around-the-clock cooling. The Pawsey Centre Supercomputer is one of the largest supercomputers in the Southern Hemisphere and is used to process large amounts of data transmitted from the Australian Square Kilometre Array Pathfinder (ASKAP). The supercomputer is also used for well geoscience and other high-end science applications.

The original project scope involved extracting 80 °C to 90 °C water from a pair of deep production wells drilled to a depth of approximately 3 km. This hot water was to be used to run an absorption chiller to produce a chilled water stream to cool the Pawsey Centre Supercomputer via a 16 °C water loop. The production wells were to be preceded by a deep exploration well that would confirm the deep geothermal resource and remain available as an enduring research/monitoring well.

A combination of factors surrounding the deep exploration well posed an unacceptable risk to CSIRO and resulted in the decision to discontinue this component of the project. These factors were, in particular, the failure to identify an appropriate drill rig supplier that could drill within the budgetary timeframe, technical and health, safety and environment (HSE) risks and ongoing uncertainty in the geothermal industry.

Further to this, the cooling requirements of the Pawsey Centre Supercomputer were significantly downgraded due to advances in technology during the project's inception. Modern chipsets may be cooled with ambient temperatures rather than requiring chilled water. This led CSIRO to re-scope the project to focus on the design and construction of a lower-cost heat rejection facility utilising a local shallow aquifer, and $13.7 million of the original grant was returned to government.

The CSIRO Groundwater Cooling (GWC) system is now constructed and has been successfully cooling the supercomputer since November 2013.

Cool water (<21 °C) is extracted via two production wells from the shallow Mullaloo Aquifer located under the Australian Resources Research Centre in Perth. The aquifer extends from approximately 35 to 120 m below ground-level (Poulet et al., 2013). This water is passed through an above-ground heat exchanger to cool the supercomputer. The heated groundwater (<30 °C) is then reinjected into the same aquifer through two warm water injection wells. The spacing between the warm water injection wells and production wells is approximately 340 m (Figure 14). An additional two injection wells (located between the production and warm water injection wells) inject cold water into the aquifer to help disperse heat. The additional cool water injection wells prevent the thermal plume migrating from the warm water injection wells towards the extraction wells.

There are nine monitoring wells located in the close proximity to the site monitoring temperature, pH, flow rate and other water quality data which are used to report on the regulatory licensing requirements of GWC and to further educational outcomes of the project.

Data from the system is publically available via the dedicated GWC website (www.groundwatercooling.csiro.au) and by free Smartphone apps (Apple and Android).

CSIRO estimates that using this system to cool the Pawsey Centre will save approximately 14.5 million litres of water in the first two years of operation compared with conventional cooling towers. The power required to run the groundwater cooling pumps will be offset by an array of solar panels on the roof of the Pawsey Centre.

Figure 14: Layout of the CSIRO Ground Water Cooling System in Perth. Wells MPB 01-13 and NPB 02-13 are the production wells, MIB 01-13 and MIB 02-13 are the warm water injection wells and MIB 01-11 and MIB 03-13 are the cool water injection wells.

1.4.5 Pre-competitive data

Pre-competitive data acquisition (the collection, collation and integration of basic geoscientific data, often strategically focussed on national and state needs), occurs at federal level by Geoscience Australia and at state level by the various state and territory geological surveys. These data have proven to be critically important to the development of other earth resources (for example regional geophysical data for minerals and stratigraphic wells for oil and gas) as they decrease the risks and reduce costs of early stages of exploration and therefore increases exploration effectiveness. All jurisdictions have been active in compiling geothermal data based on existing datasets available for petroleum and minerals exploration, as well as some campaigns to collect temperature gradient data from existing wells. There have been two notable campaigns of data collection, one by Geoscience Australia through the Onshore Energy Security Program and the other through the Geological Survey of Queensland through their Coastal Geothermal Energy Initiative (CGEI).

Geoscience Australia's Onshore Energy Security Program was part of a broader set of energy exploration initiatives as part of the federal government's energy security initiative. Geoscience Australia received $58.9 million of new program funding from late 2006 to June 2011. The program covered onshore petroleum, uranium, thorium and geothermal energy resources. The Geothermal Energy Project received approximately $20 million of this funding, and aimed to 'improve the existing knowledge about the type and location of geothermal resources in Australia on a national scale' (Budd et al., 2010). In a submission to the International Geothermal Energy Group, Geoscience Australia lists the following contributions through their Geothermal Energy Project:

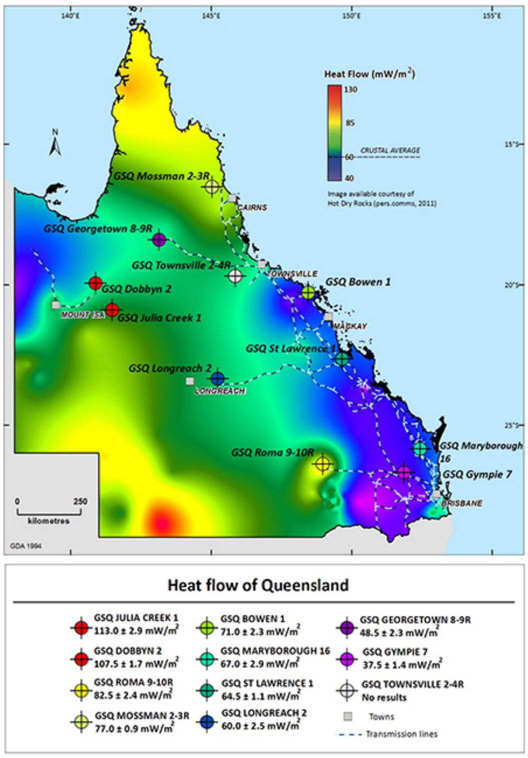


Figure 15: Heat flow measurements and heat flow model completed as part of the Queensland Coastal Geothermal Energy Initiative. Source: http://mines.industry.qld.gov.au/geoscience/coastal-geothermal.htm

- Continued development of the national well temperature database (originally started by Somerville et al. 1994, now OZTEMP) and produced a revised map of temperature predicted at 5 km depth for the whole of Australia (Figure 7);
- Collection of thermal gradient measurements and thermal conductivity measurements from core samples for heat flow determination in wells of opportunity across Australia, and publication of results;
- Helped to develop thermal modelling capability, including through sponsoring an Australian Geothermal Energy Group grant for development work by Intrepid Geophysics for Geomodeller, conducted code comparisons between different softwares;
- Developed the foundations of a Geothermal Play Systems framework, including a granite-sediment map, synthetic thermal modelling of geothermal geometries, and TherMAP, a new national-scale temperature map (Haynes, Gerner, Kirkby, Petkovic, & Budd, 2013);
- Conducted geothermal resources assessments in North Queensland, South Australia, Georgina Basin and Cooper Basin; and
- Active participant in the Geothermal Research Initiative, including their CRC application.

The Coastal Geothermal Energy Initiative (CGEI) aimed to investigate additional sources of hot rocks for geothermal energy close to existing transmission lines in Queensland. The initiative was funded by $5 million in direct funding by the Queensland Government and was implemented through the Geological Survey of Queensland. Through this initiative, 10 successful boreholes were drilled to depths between 320 m and 500 m. These boreholes were fully cored, allowing direct measurement of thermal conductivity. Temperature

logs were conducted several months after drilling to allow for thermal equilibration. These data were used to derive heat flow and to model temperatures at a depth of 5 km. The program found high heat flows (over 100 mW/m^2) in two boreholes drilled in the Millungera Basin in northwest Queensland (Talebi, Sargent, & O'Connor, 2014).

It is worth noting that the majority of work in collecting precompetitive data has been around temperature. There has been little work looking at other reservoir parameters. The level of activity focussed on geothermal resource data was much lower than for other commodities.

1.4.6 Australia's Geothermal Energy Research Sector

Research into the thermal structure of the Australian continent has a long history as applied in fields such as geodynamics and basin maturation. Interest in research in to Australia's geothermal energy resources and their exploitation was limited before the early 1990s (Cull, 1985; Somerville et al., 1994). The growth in activity started in the early 1990s, as outlined in section 1.4.2, with an international conference held in Canberra in 1993 (Wyborn, 1993) and the Somerville et al study (1994). The University of New South Wales, the Australian Geological Survey Organisation, the CSIRO and the Australian National University were early movers, receiving grant funding geothermal energy research (Burns et al., 1995, 2000).

The Australian geothermal energy research sector grew along with the industry with a peak of activity around 2010/2011. By this point in time three state based research centres were established, many universities were actively engaged in geothermal energy research and Geoscience Australia and CSIRO had established geothermal energy research programs.

The Queensland Geothermal Energy Centre of Excellence (QGECE) is based at the University of Queensland and was established with a grant of $15 million from the Queensland Government and a commitment for a minimum of $3.3 million from the university. The centre started operating in January 2009 with a five year research program. 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 centre funds the equivalent of 12 full time staff, drawn from the 16 academics and 18 postgraduate students. Government funding for this centre ends in mid-2014. While centre staff are seeking additional funding to maintain the centre, they are unlikely to be able to maintain the same level of activity in geothermal energy. The future of this centre remains uncertain.

The Western Australian Geothermal Centre of Excellence (WAGCOE) 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 a $2.3 million grant from the Western Australian government and substantial in-kind and cash contributions from the centre's members of just under $10 million over three years. The centre closed in March 2012 and while most of the staff working in the centre were redeployed within their home institutions, most are no longer focussed on geothermal energy research. The centre focussed on the development of the geothermal industry in Western Australia, concentrating on the Perth Basin, with a focus on HSA geothermal plays and direct use of the heat produced from these resources through three research programs:

- Perth Basin Assessment: Develop a rigorous scientific understanding of the geothermal resource in the Perth Basin;

- Above Ground Technologies: Identify and demonstrate innovative applications of HSA geothermal energy; and
- Deep Resources: Provide a scientific framework for the potential exploitation of deep geothermal resources.

The centre funded the equivalent of approximately 17 full time staff, with input from 34 academics and 11 postgraduate students.

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, with a grant of $1.6 million for a two year period starting in July 2009. The University of Adelaide contributed $400,000 over the same period. SACGER's operations have been extended through to 2014, bringing the total contribution from the South Australian state government ($3 million); Federal government grants and industry ($3 million) and the university ($4 million) to $10 million. The centre employs the equivalent of 5 full time staff, with input from 11 academics and 4 postgraduate students. The SACGER research program focus is on subsurface factors in hot rock and EGS resources such as reservoir characterisation and modelling.

In August 2010, a group of university, CSIRO and Geoscience Australia researchers joined together to form the Geothermal Research Initiative (GRI) through the signing of a Letter of Agreement. The aim of the GRI is to collaborate on the research and development of geothermal energy resources across a broad range of technologies and geographical locations in Australia with the aim of supporting the establishment of commercial and sustainable large scale geothermal power (electricity and heat) in Australia. GRI's initial members were the CSIRO, Geoscience Australia, QGECE, WAGCOE, SACGER, The Melbourne Energy Institute (University of Melbourne), The Priority Research Centre for Energy (University of Newcastle), and the Institute for Earth Sciences and Engineering (University of Auckland). In 2011, this group of institutions represented an effort equivalent to 77 full time staff and over 40 post graduate students working in geothermal energy. WAGCoE has been replaced by the University of Western Australia, and the University of New South Wales and Monash University have had strong links to the GRI which are in the process of being formalised. It is important to note that there is also geothermal energy research underway at some institutions outside of the GRI (for example Curtin University, Macquarie University, Australian National University).

During the 2011 - 2012 financial year the GRI worked with the geothermal sector on a bid for a Cooperative Research Centre (CRC)[2]. Through the bid process the GRI identified the key technical challenges, a high level research program (see appendix A.2) and the key research providers. However, the GRI did not proceed with the final submission as market conditions resulted in a lack of financial commitment from potential end users. The research program identified for the CRC is still considered important for the establishment of a successful geothermal sector in Australia, addressing the key risks around discovering and developing geothermal resources. The program and its four main themes were described in Huddlestone-Holmes et al, (2012) as follows:

- Optimising Resource Discovery. The aim of this program is to decrease exploration risks by developing the technologies and work flow required to discover geothermal resources, with an emphasis on finding best environments to achieve the necessary flow rates. The program will develop an understanding of the setting and key components of Australia's geothermal resource through a Geothermal Systems Analysis approach. Work on developing and improving methods (geophysical methods including seismic and EM/MT, geochemistry and algorithms) used for exploring and characterising geothermal resources in the Australian context will also be done.

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[2] The Cooperative Research Centres (CRC) program is an Australian Government Initiative that supports medium to long-term, end user driven research collaborations that focuses on major challenges facing Australia. A key component is collaboration with end-users with the aim of producing solutions that are innovative, of high impact and capable of being effectively deployed. A CRC typically runs for 5 to 10 years with budgets of $5 million to $10 million per year.

- Effective Reservoir Enhancement: This program aims to develop stimulation methods that allow the required flow rates to be achieved reliably. The basis of the program is the development of an understanding of the physics of the coupled thermo-hydro-mechanical-chemical (THMC) processes involved in reservoir stimulation at well to formation, well to well and reservoir scales. This understanding will be built on numerical modelling and the design and trialling of reservoir stimulation methods at laboratory and field scales. These stimulation methods include single and multiple zone stimulation of existing fracture permeability and the development of new fracture permeability. There will also be activities focussed on the development of improved stimulation monitoring methods (microseismic and magnetotellurics for example).
- Subsurface systems engineering. This program's aim is to improve reservoir stimulation efficacy through optimised well completions, decreased drilling costs due to prolonged well life and risk reduction through a better understanding of reservoir performance through time. As well as developing well completion technologies to enable long well life in conjunction with efficient stimulation activities, the program will also trial existing and develop new materials for temporary sealing of fractures during drilling, diverting agents during stimulation, and cements and cement replacements for casing. A smaller component of the program will be the development of reservoir models based on fully coupled THMC processes to predict the performance of reservoirs over their life. 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 programs aims to reduce the potential of the geothermal industry stalling due to non-technical issues 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 than technologies developed in isolation, and this program was designed to work with the researchers within the other programs to ensure these concerns were considered.

In addition to the research program outlined above, the GRI identified the importance of demonstration sites. Development of new technologies that can be effectively deployed requires close collaboration between researchers and the industry. Demonstration of new technologies, particularly in well completion and reservoir engineering will require access to deep wells drilled by the geothermal industry. The costs of drilling geothermal wells for experimental work are prohibitive for research organisations and the management of drilling programs is an unfamiliar task for academically focussed institutions. For these reasons, the GRI suggest that demonstration projects are necessary.

The GRI and its members are also actively seeking international collaboration on its research programs around geothermal energy, recognising that the development of viable conductive geothermal resources is a global challenge with the potential to have significant global impact.

The capabilities within the Australian research community cover the full range of disciplines that are required for geothermal energy development. However, the application of these research areas to geothermal energy is quite recent (research around the conductive types of geothermal resources found in Australia is an emerging field globally). Nearly all of the researchers working in geothermal energy are transferring and adapting the knowledge they have gained in other areas including minerals and petroleum resource exploration, petroleum field development and production and chemical and mechanical engineering. Australia has a strong track record in the science and energy of earth resource extraction, and this has been the area of geothermal energy that has received the most attention in Australia, which also matches the sectors stage of development. One of the goals of the research centres that have been established has been to build the skills, capabilities and experience in geothermal energy research. These efforts have been hampered by a lack of active field projects.

The research community in Australia has not been able to gain a lot of experience with field projects. There have been only four projects that have advanced to drilling in to the reservoir, and only one of these (Geodynamics Limited's Innamincka Deeps project) has drilled more than one well. In addition to this, geothermal companies in Australia have not had cash available to fund research at a significant level, despite indicating the need for this research. The industry is otherwise supportive of the research sector, offering access to data and engaging closely with the research community. The GRI's proposed CRC was well supported by industry in principle, however no cash commitments were made.

Recently there have been two research projects funded as Measures through the Emerging Renewables Program (ERP, see section 1.5 for a description). The first was to the Australia's Information Communications Technology (ICT) Research Centre of Excellence (NICTA) in 2011 when the ERP was managed by the Australian Centre for Renewable Energy (ACRE). The Data Fusion and Machine Learning for Geothermal Target Exploration and Characterisation project received $1.9 million from the ERP towards a total budget of $5 million. The project aims to improve resource targeting and exploration by developing software that will enable the geothermal sector to understand what makes a good geothermal site, drawing on NICTA's capabilities in data fusion and analysis of 'big data'. NICTA are collaborating with Geoscience Australia, the Australian National University and the University of Adelaide. The South Australian Department of Manufacturing, Innovation Trade Resources and Energy and several companies have supplied data to the project (Geodynamics Limited, Hot Rock Limited, Petratherm Limited). This project was completed in June 2014.

The second geothermal energy research ERP Measure was awarded to SACGER in 2012 and was the first grant awarded by ARENA through the ERP. This project is analysing the only two geothermal wells drilled in Hot Sedimentary Aquifer reservoirs in Australia to evaluate why the flow of fluid was significantly less than expected. The role of diagenesis on the destruction of permeability as well as the potential for formation damage during drilling and flow testing are being investigated. The ERP provided $1.25 million towards a total budget of $3.54 million for the two year duration of the project. CSIRO are a collaborator on the project, and the South Australian Department of Manufacturing, Industry, Trade, Resources and Energy (DMITRE), Geodynamics Limited, and Raya Group Limited are providing data and technical expertise. This project ends in September 2014.

As with the rest of the geothermal industry, geothermal energy research has experienced a rise and fall in activity. This trend is well demonstrated by the number of papers submitted to the Australian Geothermal Energy Conference, the major national conference for the sector. This annual conference was first held in 2008. Table 4 shows the number of papers and the number of registered attendees for the six conferences held to date.

	2008	2009	2010	2011	2012	2013
Papers	47	66	69	55	44	27
Attendees	322	431	263	180	88	69

Table 4: Number of papers and registered attendees at the Australian Geothermal Energy Conference since 2008. The decline in numbers since 2010 reflects a decline in the Australian geothermal sector and a decrease in international attendees at the conference.

1.4.6.1 Funding Sources for Geothermal Energy Research in Australia

There is no dedicated funding program for geothermal energy research in Australia. Instead, geothermal energy research has been funded through a variety of programs. The most important sources of funding for geothermal energy have been:

- Australian Research Council (ARC) Discovery Project Grants. These grants fund basic and applied research by individuals and teams, and are available across all fields of research other than medical research, which has its own scheme. Approximately $250 million was awarded in 2013 to 732 projects (out of 3,424 proposals, a 21.4% success rate). There has only been one discovery grant

awarded to a project focussed on geothermal energy ($300 thousand grant over three years for the development of stochastic models of natural fractures in reservoirs at the University of Adelaide).

- ARC Linkage Project Grants. These grants provide funding to support research and development projects which are collaborative between higher education researchers and other parts of the national innovation system. Each project must involve at least one partner organisation who must make a contribution in cash and/or in kind to the project that must at least match the total funding requested from the ARC. Just under $102 million was awarded in 2012 to 306 projects (out of 785 proposals, a 39% success rate). There have been at least four ARC Linkage projects with a geothermal focus: a combined desalination and power production system led by RMIT University; a geophysics project ked by the University of Tasmania; a geopolymer for well completion project at Swinburne University of Technology; and a geochemistry project led by Curtin University. The total grant funding for these three projects is over $900 thousand
- ARENA's Emerging Renewables Program (ERP) Measures. The ERP Measures fund provides funding of up to $3 million (not a hard limit) for activities that allow ARENA to deliver its strategic initiatives by removing or reducing roadblocks and to fill critical knowledge gaps within the industry (see section 1.5 for a more detailed description of the ERP). There have been two ERP Measures awarded for geothermal research as discussed above.
- ARENA Research and Development Program: This program aims to support research and development projects in priority renewable energy technologies that maintain or build on Australia's world class position in that area or that address conditions specific to Australia. The program also supports the growth of skills, capacity and knowledge in renewable technologies in Australia and aims to attract investment to improve the commercial readiness of priority renewable energy technologies. The first and current round of this program is restricted to solar technologies, with geothermal technologies expected to be eligible in a future round. ARENA has allocated up to $300 million over the period to 2022 to its R&D portfolio, with up to $20 million available in the first round. The maximum individual grant is $10 million.
- State Based Grants. The geothermal energy research centres in Queensland, Western Australia and South Australia have been funded from one off initiatives (Queensland), ongoing programs to establish research centres (Western Australia), or funds to assist renewable energy development (South Australia). In all cases, the funding mechanisms are usually short lived, with changes driven by the priorities of the government of the day. There have also been programs offering smaller grants in some states. South Australia has provided tied grants for research through the Department of Manufacturing, Innovation Trade Resources and Energy directly and through the PACE initiative (see appendix A.1). Victoria has offered research grants through the Energy Technology Innovation Strategy (ETIS) and the Sustainable Energy Research & Development Program (SERD 2). This includes funding for a project looking at electricity generation from low temperature resources (Driscoll & Beardsmore, 2011).

The total amount of funding that has been awarded for geothermal energy research in Australia is difficult to quantify. Some of the early grants for field projects could be classed as either research, industry support or a bit of both. Excluding the grants listed in appendix A.1, the total grant funding for research activities is somewhere in the order of $20 million to $25 million. This amount is expected to represent approximately half of the total research expenditure on activities focussed on geothermal energy over the last 15 to 20 years, with most of that expenditure occurring since 2009.

1.4.7 Supporting Framework

Geothermal energy exploitation is a new endeavour in Australia. Over the last decade or so there has been a range of activities undertaken to provide the supporting framework for this new industry. These activities are outlined below.

1.4.7.1 Legislation and Regulation

Under the Australian Constitution, Australia's earth resources are owned by the federal or state governments on behalf of the people (Geoscience Australia & ABARE, 2010). Exploration for and development of these resources is undertaken under licence or permit granted by government. Geothermal energy resources are owned and managed by the state and territory governments in Australia. Prior to 2000, none of these jurisdictions had laws in place to manage geothermal energy resources. By 2009, all six states and one territory (Northern Territory) had legislation in place. The applicable legislation is shown in Table 5.

While all seven of these jurisdictions have legislation and regulations in place, only South Australia has seen any deep drilling. The effectiveness of the management of geothermal resources is yet to be tested in any significant way, although the maturity of mineral and petroleum resource management in Australia suggests that there should not be any significant issues. The state authorities have shown flexibility in their acceptance of reduced work program commitments from licence holders due to the current state of the industry. There is some variation as to how the different jurisdictions have enacted geothermal resource legislation – some incorporating geothermal energy in to minerals and mining legislation, some in to petroleum legislation and some as stand-alone legislation. There is also variation in how shallow, direct use facilities are considered (those described in section 1.4.4). Some exclude projects from the relevant geothermal act or regulation if they are non-commercial (Western Australia), are below a prescribed amount of thermal power (Queensland), or are shallower than a cut-off depth or below a cut off temperature (Victoria) while some don't make any exemption. In all jurisdictions geothermal energy licences can overlap with licences for other resources.

Jurisdiction	Applicable Legislation	Description
South Australia	Petroleum and Geothermal Energy Act 2000	Geothermal energy incorporated into existing petroleum legislation, with significant amendments in 2009.
Victoria	Geothermal Energy Resources Act 2005	Regulates large-scale commercial and sustainable exploration and extraction of geothermal energy resources. Excludes resources less than 1 km deep and less than 70 °C.
New South Wales	Mining Act 1992	Included geothermal energy into existing mining legislation by including 'geothermal substances' in the definition of mineral (Group 8 - Geothermal Substances).
Queensland	Geothermal Energy Act 2010	Legislation covering exploration and production of large scale geothermal resources. Excludes 'non-commercial' uses and resources with less than 5 MW_{TH} combined for all wells. Superseded the Geothermal Energy Exploration Act 2004, an interim legislation to allow exploration activities.
Tasmania	Mineral Resources Development Act 1995	Included geothermal energy into existing mining legislation Geothermal energy is defined in the act as a Category 6 mineral.
Western Australia	Petroleum and Geothermal Energy Resources Act 1967	Geothermal energy incorporated into existing petroleum legislation. Does not cover 'non-commercial' uses or heat pumps.
Northern Territory	Geothermal Energy Act 2009	Legislation covering exploration and production of geothermal resources above 70 °C.

Table 5: Legislation that covers geothermal energy exploration and production in Australia (after Goldstein & Bendall, 2012).

1.4.7.2 Industry Associations

Australia has had two associations established to support the Australian geothermal energy sector, the Australian Geothermal Energy Group (AGEG) and the Australian Geothermal Energy Association (AGEA).

AGEG was established in 2006 and incorporated in 2009. The South Australian Department of Manufacturing, Industry, Trade, Resources and Energy (DMITRE, then PIRSA) was instrumental in the establishment of AGEG to support Australia's membership in the IEA's Geothermal Implementing

Agreement (GIA) and to facilitate interaction between all stakeholders in the Australian geothermal sector. AGEG's terms of reference are:

'Provide support for Australia's membership in the IEA's Geothermal Implementing Agreement (GIA) and facilitate engagement within the geothermal community.

Foster the commercialisation of Australia's geothermal energy resources. Collectively:

- *Cooperate in research and studies to advance geothermal exploration, proof-of-concept, demo and development projects*
- *Cooperate to develop, collect, improve and disseminate geothermal related information*
- *Identify opportunities to advance geothermal energy projects at maximum pace and minimum cost*
- *Disseminate information on geothermal energy for decision makers, financiers, researchers and the general public (Outreach).'*

(source http://www.pir.sa.gov.au/geothermal/ageg, accessed 13 Jan 2013).

Through its Technical Interest Groups (TIGs), AGEG facilitated many workshops on geothermal energy technologies as well as education environmental, social and economic issues. Activity within the TIGs has declined substantially since 2011. AGEG's operations have largely been funded by DMITRE and a share of the proceeds of the Australian Geothermal Energy Conference. AGEG is affiliated with the International Geothermal Association.

AGEA was established in 2007 as the national industry body representing the Australian Geothermal Industry. AGEA's Mission Statement is:

'To foster and accelerate the development and commercialisation of Australia's geothermal energy resources by:

- *Clearly and accurately articulating the advantages of geothermal energy and the progress of the industry;*
- *Cooperating across the industry to develop, collect, improve and disseminate information about geothermal energy; and*
- *Developing good and constructive relationships with government, the investment community and the broader Australian community.'*

(Source: http://www.agea.org.au/about-agea/about-us/ accessed 13 Jan 2013).

AGEA has seen a significant decline in membership over the last few years. AGEA's operations have been funded through annual membership fees and proceeds from the Australian Geothermal Energy Conference. In late 2013, AGEA's members decided that AGEA was no longer sustainable in its current form and that it needed to transition from a lobbying organisation to a professional organisation that has an advocacy role for the areas of expertise of its members. The management of AGEA and AGEG are discussing how the two organisations can best serve the Australian geothermal sector, with the possibility that a single entity incorporating the relevant activities of AGEG and AGEA will emerge in late 2014 or early 2015. These two organisations, along with the New Zealand Geothermal Association, are hosting the International Geothermal Associations World Geothermal Congress 2015 in Melbourne in April 2015. The Geothermal Reporting Code (see section 1.4.7.3) requires that a geothermal resource report be made by a competent person, being someone who is qualified and experienced in the type of resource being reported on. AGEG maintains a register of competent persons

1.4.7.3 Reporting Code

The Australian geothermal sector has recognised a need to have a mechanism that allowed for formal estimation and reporting of geothermal resources that would build confidence among investors. The Australian Geothermal Code Committee was established in 2007 as a joint initiative of AGEG and AGEA and the first edition of the code was released in 2008 (Australian Geothermal Reporting Code Committee, 2008), with an updated version released in 2010 (Australian Geothermal Reporting Code Committee, 2010).

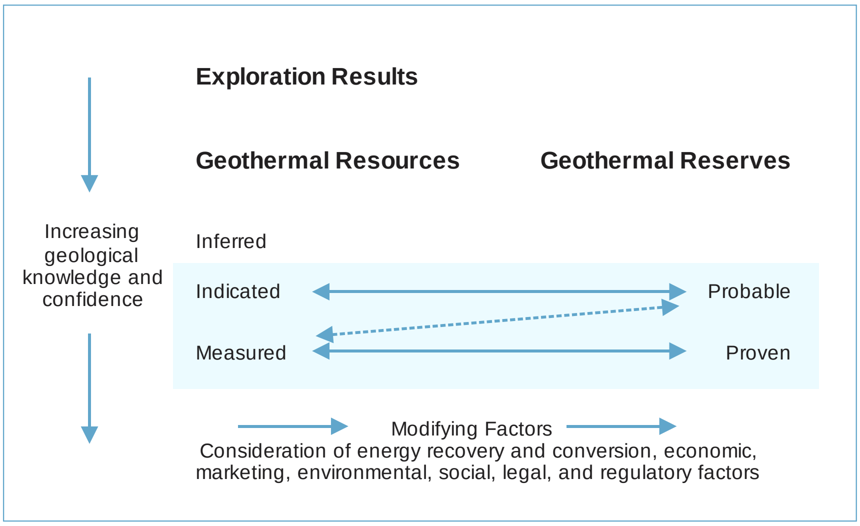

Figure 16: Key terminology in the Geothermal Reporting Code. Confidence in the resource estimate increases with increasing knowledge about the resource. Resources are those geothermal plays that have reasonable prospects for economic extraction. Geothermal reserves are the portion of the resource that can be considered to be economically recoverable based on the resource characteristics and the modifying factors (Australian Geothermal Reporting Code Committee, 2010)

The code is based on the Joint Ore Reserves Committee (JORC) Code used in the minerals sector that has been well accepted by industry, regulators and investors after more than 20 years of implementation, development and revision. An important feature of the Geothermal Reporting Code (and the JORC Code) is that while it sets requirements on how geothermal resources are reported, it does not mandate the method by which those resources are estimated (Ward et al., 2009). A key component of the Geothermal Reporting Code is the definition of the terminology used to report geothermal resources, and the minimum information that must be provided with the resource estimate (i.e. the data and assumptions on which the estimate is based). Good practice guidelines were developed for geothermal resource estimation as there were no existing accepted practices in Australia for these resources. These guidelines have been presented in the Geothermal Lexicon (Lawless, 2010) and a justification must be made if the method of resource estimation used for a resource report is substantially different from that recommended in the Lexicon. Another requirement of the Geothermal Reporting Code is that resource reporting must be made by a Competent Person. A competent person is someone who has the necessary qualifications and experience working on the type of resource being reported on. A competent person must also be on the Register of Practicing Geothermal Professionals, maintained by AGEG as a courtesy to the industry, as well as complying with the Code of Ethics of that register.

Unlike the JORC Code, adherence to the Geothermal Reporting Code is not yet mandated by the Australian Securities Exchange Limited or any other financial market regulators. AGEA does require its members to follow the requirements of the code.

1.4.7.4 Government Studies

There have been several government funded studies conducted for the Australian government or one of its agencies that have aimed to identify strategies to assist the establishment of geothermal energy in Australia.

1.4.7.4.1 Australian Geothermal Industry Technology Roadmap and Development Framework

In 2007, the Council of Australian Governments, the peak intergovernmental forum in Australia, commissioned the development of the Australian Geothermal Industry Technology Roadmap (Department of Resources Energy and Tourism, 2008b) as one of four technology roadmaps. This roadmap was developed through a series of workshops with the geothermal sector in late 2007. The technology roadmap focuses on the research and development needs of the geothermal industry in Australia. The capacity of the Australian and global research communities to address these needs, was also considered, and a timeline for geothermal development was prepared. The roadmap's high priority recommendations were:

- That a code for the reporting of geothermal resources be developed;
- That R&D into improved means of downhole pressure isolation for fracture stimulation be conducted;
- That a short and medium term forecast of geothermal and other competing drilling requirements and rig availability be compiled;
- That R&D into fracture stimulation mechanics and avoidance of unwanted seismic events be conducted;
- Establish a program of trials to build up a database of practical experience in drilling, well casing, well completions and fracture stimulation in a variety of geological settings;
- Establish proof of concept demonstrations of fluid circulation and energy extraction in several geological settings;
- Conduct R&D into improved methods of power plant cooling in hot arid environments that do not consume large amounts of water;
- Conduct R&D into the adaptation of existing geothermal power plant technologies to the high pressure and possibly corrosive nature of fluids encountered in Australian geothermal projects;
- Establish proof of concept demonstration power plants in several geological settings;
- That the existing capabilities of Geoscience Australia and the state and territory geological surveys be expanded for the acquisition, capture, manipulation, interpretation and dissemination of pre-competitive geoscience data; and
- Conduct R&D to assess and quantify potential environmental impacts of geothermal developments in Australia.

Following a roundtable with representatives of the geothermal industry, government agencies and research organisations in early 2007, the Department of Resources Energy and Tourism led the development the Australian Geothermal Industry Development Framework (Department of Resources Energy and Tourism, 2008a). This document is a companion document to the technology roadmap, focussing on the general framework required to develop a viable geothermal energy industry in Australia, identifying the following as key components:

- '*an attractive investment environment in which early stage ventures are able to mature to a level sufficient to attract private finance;*
- *accurate and reliable information on geothermal energy resources in Australia;*
- *networks that encourage sharing of information and experience between stakeholders including companies, researchers and governments in Australia and overseas;*
- *geothermal technologies suited to Australian conditions;*
- *a skilled geothermal workforce;*
- *community understanding and support of the economic, environmental and social benefits of geothermal energy;*
- *• a geothermal sector which understands and can contribute to the institutional environment within which it operates; and*
- *• a consistent, effective and efficient regulatory framework for geothermal energy'*

The framework sets out recommended strategies to achieve these goals.

1.4.7.4.2 Allen Consulting Group Report

In late 2010, the Australian Centre for Renewable Energy (ARENA's predecessor) commission Allen Consulting to provide information that would assist ACRE in identifying barriers to the development of a geothermal industry in Australia and how ACRE may be able to assist in removing those barriers. The report (Allen Consulting Group, 2011) was released in March 2011. The report found that geothermal energy could make a significant contribution to Australia's base load energy needs. For this to occur, the geothermal sector would need to attract additional government and private sector support. Further development in Australia would require either additional government support or a change in market returns as companies are only able to raise a small portion of the required capital on the market. The report also noted that geothermal energy was therefore unlikely to make any contribution to the Renewable Energy Target (the original expectation was that geothermal energy would contribute up to 40%). The opportunity presented by off-grid demand was noted, as was the potential for direct use applications.

Of the 50 to 70 companies with a direct interest in geothermal energy exploration, a large number had only a speculative interest according to the report. Of the companies that were committed to geothermal energy development, very few if any had the ability to raise the necessary capital to make further progress (with around $40 million required for a two well program). The expected returns from geothermal energy projects are too low or uncertain for the perceived risk to attract investors. Grants under the Geothermal Drilling Program have also failed to reduce the capital raising requirements to allow projects to proceed. The report found that the technology for extraction of heat from the earth and the conversion of that energy to electricity is generally well understood, although there is significant uncertainty in the quality of geothermal resources. The main area of concern is the ability to produce adequate flows. The technical expertise available to the sector was found to be very capable, although the capacity was limited.

The report suggested that a range of policies would be needed to assist geothermal energy development that fall within three categories: market incentives through mandated targets or price support; Hot Sedimentary Aquifer development through the funding of several demonstration plants; and, cost subsidies including subsidies for drilling, low cost finance and tax incentives. The report also found that in terms of pre-competitive data and R&D support, solving engineering challenges were more important than geological data at the point in time that the report was written. The report also recommended support for direct use geothermal energy with inclusion in the existing Renewable Energy Target as the most effective option.

In terms of ACRE's role in facilitating and supporting the geothermal sector, the report made several recommendations. ACRE should support research in to the key barriers that are preventing industry progress. These barriers are likely to be in resource characterisation and drilling costs.

The report found that *'Large-scale deployment of geothermal will occur when the sector can demonstrate commercial and technical viability in Australia.'* To achieve commercial viability, the gap between expected market returns and expected costs of electricity production must be removed. Technical viability will only be proved when the sector demonstrates that resources are available that can sustain substantial flows over a long period of time, requiring full-scale demonstration projects. Table 6 is from the report and provides a summary of the report's recommendations.

Recommendation	Time Frame	Details
Build Investor Confidence in HSA	Immediate	The Government should encourage the development of HSA on a small scale (around 10 MW), on-grid to reduce investor uncertainty. A focus on HSA is recommended as it is likely to provide a lower cost and lower risk pathway for development, and together with a carbon price this could initiate a positive change in investor sentiment. This support would complement the existing REDP projects. The development of 2-4 successful electricity plants in Australia would provide sufficient data and information to improve investor confidence. ACRE should be the delivery agency for such a program.
Improve market signals: Geothermal price gap scheme	Longer Term	The Government should introduce a price gap scheme to accelerate the development of the geothermal electricity sector. The Government has announced that it will introduce a carbon price from July 2012. Depending on the price targeted initially there may still be a price gap for viable supply of geothermal electricity until the carbon price is sufficiently high. A price gap scheme would be an interim measure until a long-term carbon price is established in Australia.
Improve market signals: Market based incentives for geothermal energy	Longer Term	The Government should move as soon as possible to introduce either a feed-in tariff or a flexible price mechanism for all types of geothermal energy. In particular, direct-use applications of geothermal energy should qualify for assistance under the SRES. ACRE should encourage consideration of this initiative.
Lower costs: Revised drilling program	Longer Term	Any new drilling assistance should be provided on a 50:50 cost-share basis. A revised program would recognise the increased drilling services in Australia. ACRE should be the delivery agency for the revised program.
Industry Development Policy: Monitoring role for Ministerial Council on Energy Resources	Longer Term	The Standing Council on Energy and Resources (SCER) should take on an ongoing monitoring role of the geothermal industry to ensure any impediments are dealt with in a timely fashion. There are a number of important regulatory and policy issues, although not critical, which could inhibit the development of the geothermal industry. These include approval processes for exploration and development, harmonisation across jurisdictions, grid connections, training and skill development and precompetitive resource assessments. ACRE would be an important source of advice to the SCER.
Research and Development	Longer Term	Research and development activity should be better coordinated. Research priority setting should involve the research community and industry. There are opportunities for strengthening international linkages. ACRE could play a key role in facilitating coordination of the research sector and strengthening Government support, Australian and State/Territory, through advice to the SCER.

Table 6: Recommendations from the Allen Consulting Group Report (table ES 1.2 in Allen Consulting Group, 2011)

1.4.7.4.3 ACRE Expert Group

The ACRE Geothermal Expert Group was established in 2010 to guide the Allen Consulting Group's Report and to advise ACRE on the outcomes of that report (ACRE Geothermal Expert Group, 2011). The Geothermal Expert Group largely endorsed the findings of the Allen Consulting Group's Report, finding that while a substantial government, private and research organisation investment in geothermal energy would be required, the dividends would be substantial. The key market gap preventing private investment in geothermal energy was reiterated by the Geothermal Expert Group as high technology and resource risks that cannot be justified by the size of the reward.

The Geothermal Expert Group recommended that a market incentive would be required for the first 3,500 GWh of geothermal energy in Australia. To justify the investment that would entail, the technical viability would need to be demonstrated through the development of 50 MW capacity. A graded co-investment strategy was recommended, consisting of an early stage with the amount of direct government support decreasing as projects progressed through various stages of development (Figure 17). Finally, a recommendation to provide support for direct use projects was also made.

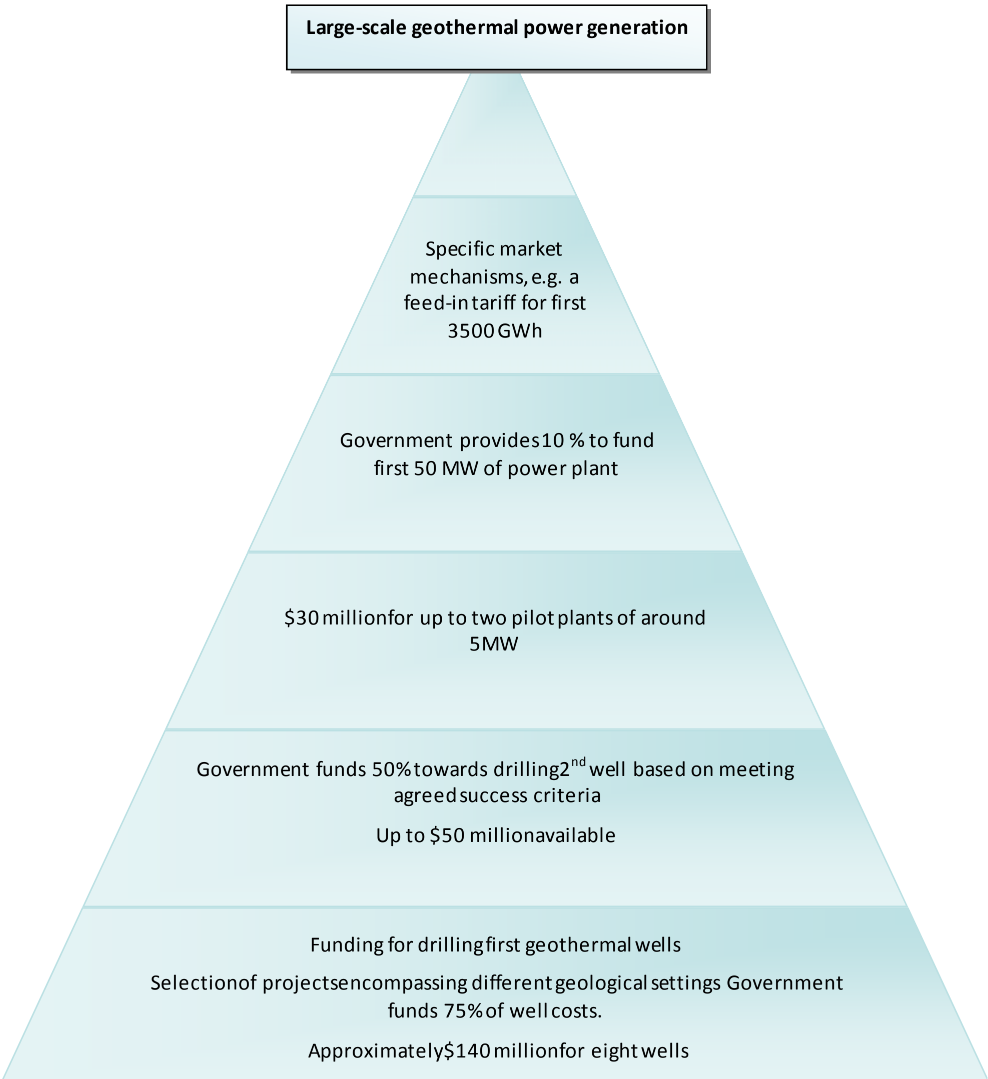

Figure 17: Summary of the graded co-investment model for geothermal power (ACRE Geothermal Expert Group, 2011).

1.4.7.4.4 ACRE Geothermal Directions Paper

ACRE produced a directions paper for geothermal energy in 2011. A summary of the strategy is presented in Table 7. ACRE noted that major geothermal research and development projects fall outside of the ACRE Board's area of the responsibility.

Category	Strategy
Emerging Renewables Program	Future funds directed to the geothermal industry should generally be incorporated in the Emerging Renewables program. This would allow the assessment and management of projects to be streamlined and would use existing and established processes. The Emerging Renewables program will provide a flexible and integrated approach to funding renewable energy technology including geothermal.
Investment Attractiveness	New ACRE geothermal funding under Emerging Renewables should be targeted at the gaps that remain in the Geothermal Expert Group's graded co-investment model. A staged or gateway approach, in which ACRE funded projects that have successful outcomes can apply for subsequent funding towards demonstration, is supported. Projects that do not achieve their stated outcomes and perform poorly may have their funding suspended or terminated.
Drilling	Projects that can reduce the costs of drilling geothermal wells and improve the success rates of drilled wells will be eligible for support under the Emerging Renewables program.
Market incentive	The need for potential market incentives could be explored by the ACRE Board to see how they could assist in overcoming the first mover disadvantage problem for early developers of geothermal, and also other clean energy technologies,
Pre-competitive data	A pre-competitive data program should be developed for the geothermal industry to be funded through ACRE. Any program should leverage off and coordinate with other relevant Commonwealth and state programs. ACRE funded geothermal projects will be required to disseminate their project learnings and their geological data,
Direct-use Geothermal	ACRE funding could assist further development of expertise in direct-use geothermal and improve understanding of the technology.
Collaboration	Collaboration where there are synergies will be encouraged and supported through the Emerging Renewables program, including the Measures component.
International Collaboration	Under the Emerging Renewables program an ACRE measure could fund activities that provide avenues to improve collaboration and knowledge dissemination in the geothermal sector.
Engagement with state and territories	Through the Ministerial Standing Council on Energy and Resources (SCER), geothermal development issues could be progressed with jurisdictions, ACRE and geothermal peak bodies. This would fall under the SCER priority area of clean energy development. Using SCER mechanisms, ACRE should facilitate the development of a draft national geothermal plan with a particular focus on achieving strategic collaboration on pre-commercial resource identification, for consultation with industry and submission to SCER for approval.

Table 7: Key strategies in ACRE's Geothermal Directions Paper (source: http://www.innovation.gov.au/Energy/CleanEnergy/AustralianCentreRenewableEnergy/Pages/StudiesResearch.aspx)

1.5 Funding to the Australian Geothermal Sector

Data on grants and expenditure in the geothermal sector is difficult to compile quantitatively due to varying reporting obligations for listed and unlisted companies, variation in state regulations and so on. The following information should be considered as approximate.

The total amount of state and federal government funding given to support geothermal industry activity (excluding research and development and pre-competitive data programs) was $315 million as at the end of the 2013 calendar year (Appendix A.1). Of this amount, approximately $76 million has been spent and just over $100 million is still available to be spent. This means that just under a third of the value of government grants to the geothermal sector have been handed back, primarily as a result of project proponents being unable to secure the matching funds required as a grant condition. Of the $76 million spent to date, Geodynamics Limited has been responsible for around $44 million ($102 million in grants awarded, with $57.6 million still available). An additional $31 million in tax rebates have been received by the sector. The total amount spent by industry as at the end of 2013 is estimated to be $828 (data sourced from DMITRE and Bendall & Goldstein, 2013). In summary, the government contribution has been around 15% of the total expenditure by the Australian geothermal industry.

Funding to the research sector is somewhat more difficult to quantify. Major grants (for centres of excellence) for geothermal research total around $20 million to $25 million. The in-kind contributions of the research sector are expected to have at least matched that amount. Funding for pre-competitive data programs at Geoscience Australia and the state geological surveys has been around $30 million, although this is very difficult to quantify as some of this activity is conducted under recurrent funding to the relevant departments.

The total funding to the Australian Geothermal Energy sector has been around $900 million (nominal). Most of this expenditure has been in the last decade, with governments contributing around 18% of the total (Table 8).

Category	Government Funding (million)	Private/In-kind (million)	Total (million)
Industry	$107*	$721	$828
Research	$25	$25	$50
Pre-competitive	$30	-	$30
Totals	**$162**	**$746**	**≈$900**

* Includes $31 million in R&D tax rebates

Table 8: Summary of expenditure on geothermal energy in Australia to the end of 2013. Data is approximate.

1.5.1 Currently Available Grants and Grant Schemes for Geothermal Energy

The following section outlines the grant schemes from which active grants have been awarded to the geothermal sector and grant schemes that remain open for applications. ARENA has a range of other initiatives currently open, however the Emerging Renewables Program described below appears to be the only scheme that is applicable to the majority of the geothermal sector.

1.5.1.1 Renewable Energy Demonstration Program (REDP)

The Renewable Energy Demonstration Program (REDP). The REDP was launched in February 2009 and was administered by the Department of Resources, Energy and Tourism, then the Australian Centre for Renewable Energy, and now ARENA. The program had $435 million in available funds aimed at supporting the commercialisation and deployment of renewable energy in Australia. The program was designed to fill the gap between post-research and commercial take up of new technologies. The REDP was a competitive, merit-based grants program to demonstrate the viability of technologies that had been proven at pilot plant scale, but had not progressed to full commercial operation. Funding was provided on the basis of the applicant providing at least two dollars for every dollar of grant funding. The renewable energy technologies eligible for this grant were solar, geothermal, wind, biomass, hydro, ocean energy or a combination of these technologies. Geodynamics Limited and Petratherm Limited were two of six

successful applicants awarded grants under this scheme in November 2009. The program only had a single funding round.

Geodynamics Limited was awarded $90 million for the development of a 25 MW commercial demonstration plant in the Cooper Basin, at the Innamincka Deeps project (including well field activities). The total eligible expenditure for the project was $338.6 million. As at December 2013, Geodynamics Limited had drawn down $32.4 million of its REDP grant. Geodynamics Limited and ARENA are in discussions about how this grant may proceed.

Petratherm Limited was awarded $62.76 million for the development of a 30 MW commercial demonstration plant at Paralana (including well field activities). The total eligible expenditure for the project was $188.3 million. A condition precedent in the agreement required Petratherm Limited to achieve proof of concept (a closed flow loop) before the REDP funds could be accessed. Petratherm Limited were unable to fund the drilling of the second deep well (Paralana 3) to demonstrate proof of concept. Subsequently, Petratherm Limited applied for and was awarded an Emerging Renewables Program Project grant in 2013 for $13 million to fund half of the costs of the drilling of Paralana 3. This second deep well will allow the closed flow loop to be completed and proof of concept to be demonstrated. As part of the negotiations for the ERP grant, the scope of the REDP grant was renegotiated. The revised scope is now for a 7 MW plant to supply power to the nearby Beverley Uranium Mine, with the grant funding reduced to $24.5 million. The REDP funds can only be accessed once the closed flow loop has been demonstrated.

1.5.1.2 Emerging Renewables Program (ERP)

The ERP was first established by ACRE and has since been expanded by ARENA. The aim of this program is to funds activities to support the development, demonstration and early stage deployment of renewable energy technologies with the potential to lower the cost, and thereby increase the supply, of renewable energy in Australia (source: http://arena.gov.au/initiatives-and-programs/emerging-renewables-program/). The ERP has two components:

- ERP Measures are for smaller projects with up $3 million dollars in grant funding that address roadblocks to the delivery of ARENA's strategic initiatives, that develop renewable energy technologies, or that fill critical knowledge gaps within the industry; and
- ERP Projects that support the development, demonstration and early stage deployment of renewable energy technologies, providing grants between $2 million and $30 million.

The total amount of funding allocated to the program has recently been increased to $215 million. The funding amounts per grant given above are not mandated, but are considered to be firm guidelines. In terms of funding ratios, ERP grants do not generally fund the majority of project costs, with the grant recipients expected to cover a higher proportion of grant funding for more mature technologies. The application process for measures is a one step process, while applications for projects involve an expression of interest followed by a full application. The ERP is open for applications on a continuing basis and applications are assessed on their own merits.

There have been three ERP grants awarded to geothermal energy projects. Two of these are ERP measures that are addressing roadblocks or generating knowledge for the geothermal sector. These are the grants awarded to NICTA and SACGER described in section 1.4.6. There has been one ERP Project grant awarded to Petratherm Limited. This $13 million grant is for half the costs of the drilling and stimulation of the Paralana 3 production well to complete the closed loop with the Paralana 2 injection well. As discussed above, the successful completion of the closed loop is a condition precedent for the renegotiated REDP grant. The ERP Project grant itself has condition precedents, including the continued involvement of Beach Energy Limited in the Paralana Joint Venture and that Petratherm Limited raise the remaining $5 million required to complete the project.

1.5.1.3 Tax incentive – R&D

The Australian Federal Government has a Research and Development Tax Incentive Scheme aimed at supporting innovation within small companies. Under the scheme, a cash refund of 45 cents per dollar spent on eligible research and development is available to companies with an annual turnover of less than

$20 million. While exploratory drilling to characterize resources is exempt from the scheme, activities that are experimental by nature (the development of a sub-surface heat exchanger for example) or preparatory works to allow that experiment to be conducted (drilling a well to reservoir depth) are considered to be eligible expenditure. Both Geodynamics Limited ($22.2 million) and Petratherm Limited ($440 thousand) have successfully claimed this rebate.

1.5.1.4 Geothermal Drilling Program (GDP)

The Geothermal Drilling Program (GDP) was launched in August 2008 as a result of a commitment made during the 2007 federal election campaign. This program has been the only funding scheme explicitly aimed at geothermal energy development. The program was originally administered by the Department of Resources, Energy and Tourism, then the Australian Centre for Renewable Energy. The program had $50,000,000 in available funds aimed at assisting the geothermal industry in overcoming the short-term barrier posed by high drilling costs to demonstration of proof-of-concept. Proof of concept was considered to be a closed loop (circulation between an injection and production well). The GDP was designed in close consultation with the geothermal industry and was a competitive, merit-based grants program. Funding was capped at $7 million per project and grantees were required to fund at least 50% of the project costs from their own sources. There were two rounds of funding, with two grants awarded in the first round and a further 5 in the second round (Round 1 in 2008/2009 and Round 2 in mid to late 2009). Only the two projects from the first round drew on the grant funding.

Panax Limited drilled the Salamander 1 well and received the full grant amount, having made the case that for their HSA resource flow tests from a single well would constitute proof of concept (see section 1.4.3.4. for more information on this project).

Petratherm Limited drilled the Paralana 2 well as the injection well for a doublet at their Paralana project, drawing on $4.2 million of their grant. Petratherm Limited were unable to raise the required funding to drill the Paralana 3 production well and relinquished their claim on the unspent grant money as part of their negotiations for their ERP Project Grant (see section 1.4.3.3 for more information on this project). Higher than anticipated costs for drilling Paralana 2 reduced the amount of capital Petratherm had available for drilling Paralana 3. These high costs included high mobilisation fees for the drill rig, slow drilling rates, and delays caused by flooding. The drilling rig used for Paralana 2 and Salamander 1 was brought in to Australia with the expectation that the mobilisation costs were to be shared by several operators across multiple wells. However these other operators did not drill and the rig only drilled two wells before leaving Australia, leaving the costs of mobilisation into and out of Australia to be borne by Petratherm Limited and Panax Limited.

The five grant recipients from the second round of the GDP all failed to go ahead. Four of the projects were unable to demonstrate that they could raise the necessary funding required to complete the projects. The other grant was to Geodynamics Limited for their Hunter Valley Project. Geodynamics Limited relinquished this grant on commercial grounds combined with community sensitivity around hydraulic fracturing in New South Wales.

When the GDP was devised in late 2007 – early 2008, the $7 million per grant cap was expected to cover close to 50% of a two well program, and the investment community were expected to be tolerant of the risks for these projects. By the time grants were awarded, drilling costs had risen substantially (or had been underestimated) requiring the grant recipients to raise considerably more than half of the project costs. Events such as the well failure at Habanero 3 in early 2009 and poor flow test results from Salamander 1 increased the perceived risk of geothermal projects in Australia. These high risk levels were unacceptable to the investor community, particularly following the global financial crisis of late 2008 that had decreased the amount of money available for high risk investments.

1.5.1.5 Geothermal Exploration Tax Deduction

From 1 July 2012 geothermal energy explorers have been able to claim an immediate tax deduction for expenses incurred while prospecting for geothermal energy resources. This tax deduction was put in to place by amending existing tax laws that allowed mineral and petroleum companies to claim a deduction

for their exploration activities. As a tax deduction, a company would need to be profitable and paying tax to be of any value. Allowing companies to claim an immediate tax deduction for their resource exploration expenditure provides an incentive for companies to invest in exploration. The new federal government, elected in October 2013, may remove geothermal resources from these provisions as it intends to repeal the broader package of legislation that introduced it.

1.6 General Policy Environment

The Australian geothermal energy sector has operated within a policy and regulatory framework that has been continually evolving over the last two decades, with changes driven primarily to address climate change and energy security. Australia is a Federal parliamentary democracy with three levels of government: Federal; State; and local. Each level of government has different jurisdiction although there is some overlap between them. The geothermal energy sector is directly impacted by policies relating to electricity generation, greenhouse gas emissions reductions and resource exploitation.

The legislative and regulatory arrangements discussed in section 1.4.7.1 cover the resource exploitation policy aspects, which fall within the jurisdiction of State governments. These arrangements have allowed for geothermal energy exploration to occur throughout Australia. While the small number of projects that have advanced to deep drilling means that these arrangements have not been tested in depth, the maturity of the State regulators in managing resources in Australia would suggest that there should be no significant issues in this area. The only caveat is in relation to hydraulic fracturing activities. There has been some public concern about hydraulic fracturing as a result of coal seam gas developments in the eastern states Australia. This has led to moratoriums on this technology in New South Wales and Victoria. If substantial geothermal development was to occur the Australian population may similarly identify (real or perceived) issues of concern as they become more aware of the technology (Carr-Cornish & Romanach, 2014). Such concerns may lead to policy and regulatory issues for the geothermal sector.

Energy and emissions reduction policies exist at all three levels of government, although they are primarily the jurisdiction of Federal and State levels. Australian governments have legislated policies aimed at reducing greenhouse gas emissions for over two decades (Climate Change Authority, 2014). There are a range of policy instruments that can be applied to this task (Table 9) and many of these approaches have been implemented in Australia. In a 2011 research report on carbon emission policies in key economies, the Productivity Commission identified around 230 policies relevant to emissions reductions in Australia (Productivity Commission, 2011). This complex policy framework is the result of Australia's government structure, along with the relevant constitutional responsibilities, intergovernmental agreements and market arrangements (Byrnes, Brown, Foster, & Wagner, 2013).

The Australian government has made a commitment to reduce greenhouse gas emissions by 5% (unconditional) to 25% of 2000 levels by 2020 through the United Nations Framework Convention on Climate Change Copenhagen Accord and the Kyoto Protocol (Climate Change Authority, 2014). Australia's emissions reduction policies are aimed at achieving these commitments. These policies include those that are aimed at reducing the emissions intensity of energy supply; increasing the contribution of renewable energy; increasing energy efficiency; and, reducing emissions from agriculture, fossil fuel extraction and distribution, waste, LULUCF (land use, land use change and forestry), and industrial processes.

There have been significant contributions to emissions reductions from LULUCF (85% reduction from 1990 levels by 2012) and flattening demand for electricity (Climate Change Authority, 2014). This flattening of demand for electricity is attributed to subdued economic growth and structural changes in the economy away from electricity intensive industries, the response of electricity consumers to higher electricity prices, improvements in energy efficiency and increased rooftop solar photovoltaic generation (which reduces demand for electricity from the grid) (Australian Energy Regulator, 2013; Climate Change Authority, 2014). The net effect of these emissions reductions is that they reduce the need to meet Australia's current emissions reductions targets through other means, such as increasing the supply of renewable energy.

Explicit carbon prices	Regulatory instruments
Emissions trading scheme — cap-and-trade	Renewable energy target
Emissions trading scheme — baseline and credit	Renewable energy certificate scheme
	Electricity supply or pricing regulation
Emissions trading scheme — voluntary	Technology standard
Carbon tax	Fuel content mandate
Subsidies and (other) taxes	Energy efficiency regulation
Capital subsidy	Mandatory assessment, audit or investment
Feed-in tariff	Synthetic greenhouse gas regulation
Tax rebate or credit	Urban or transport planning regulation
Tax exemption	Other regulation
Preferential, low-interest or guaranteed loan	***Support for research and development (R&D)***
Other subsidy or grant	R&D — general and demonstration
Fuel or resource tax	R&D — deployment and diffusion
Other tax	***Other***
Direct government expenditure	Information provision or benchmarking
Government procurement — general	Labelling scheme
Government procurement — carbon offsets	Advertising or educational scheme
Government investment — infrastructure	Broad target or intergovernmental framework
Government investment — environment	Voluntary agreement

Table 9: A taxonomy of emissions reduction policies. From Productivity Commission Research Report on Carbon Emission Policies in Key Economies (Productivity Commission, 2011).

Policies that directly support the development of renewable energy generation capacity in Australia have been in the form of mandatory renewable energy targets, feed in tariffs, and capital subsidies. Australia introduced the Renewable Energy Target (RET, originally called the Mandatory Renewable Energy Target) in 2001 with a target of an additional 9,500 TWh of additional renewable electricity to be generated by 2010 (equivalent to an additional 2% of total electricity generation). The RET was expanded in 2009 with a target of an additional 45,000 TWh (or an expected 20%) by 2020 (Climate Change Authority, 2012). South Australia, Victoria and New South Wales all set about implementing their own renewable energy targets in the mid 2000s. The Victorian and New South Wales schemes were abandoned when the expanded RET was implemented in 2009. The South Australian target remains and reached its 20% target in 2011. It has since been expanded to 33% renewable electricity generation by 2020 (Climate Change Authority, 2014). The RET has contributed to the increase of non-hydro renewable generation from 0.6% in 2000 to 3.9% in 2012 (BREE, 2013).

While geothermal energy is eligible under the RET, it has so far made no contribution to the target. The RET has tended to favour established technology such as wind (Byrnes et al., 2013). Wind energy makes the largest single contribution, with an increase from 58 GWh in 1999/2000 to over 6,000 GWh in 2011/2012. Generation from solar PV increased from 44 GWh to just under 1,500 GWh over the same period (BREE, 2013). State based feed in tariffs for small scale (< 100 kW) solar PV were a significant contributor to the growth in electricity supply from this technology (Climate Change Authority, 2014). The unexpectedly rapid growth in small scale solar PV as well as other small scale technologies, such as solar hot water systems, that were eligible under the RET resulted in the RET being separated into two parts: the Large Scale Renewable Energy Target (LRET) with a target of 41,000 TWh; and, The Small Scale Renewable Energy Scheme (SRES), which is uncapped but expected to deliver the remaining 4,000 TWh of the original total renewable target set in 2009.

Throughout the 2000s a range of grant schemes were established to assist development of low emission or renewable technologies at Federal and State levels. These grant schemes generally provided capital subsidies and were mostly technology agnostic (see appendix A.1 for a list of grants awarded to geothermal companies). There were some targeted schemes such as the $1.5 billion Solar Flagship Program and $1.7 billion CCS Flagship Program. Both of these programs have been subsequently reduced in size. For geothermal energy, the $50 million Geothermal Drilling Program (see section 1.5.1.4 for more detail) was

established in 2008. The GDP has been the only grant scheme specifically targeting geothermal energy so far in Australia.

The climate change, emissions reduction and energy policy areas have been hotly contested at a Federal level since the 2007 Federal election. At this election, the Kevin Rudd led Labor Government was elected with a policy platform that included an emissions trading scheme. The first act of this government was to ratify the Kyoto Protocol. This government also implemented the expansion of the RET discussed above. However, the government was unable to pass its emissions trading scheme legislation through the Senate and deferred this policy. Action on climate change was again a significant issue at the 2010 Federal election. Labor was able to form a minority government under the leadership of Julia Gillard with support from several independents and a member of the Greens party. In 2011, this government established the Clean Energy Future policy framework and related legislation successfully passed through Parliament in 2011 with the support of the Greens in the Senate. The key features of this policy were:

- A national carbon price with a fixed (indexed) price for the first three years before moving to a cap and trade scheme linked to the European Emissions Trading Scheme;
- A range of support schemes for industry and households, including income tax cuts, to offset the anticipated cost of electricity increases as a result of the carbon price;
- Establishment of ARENA (Australian Renewable Energy Agency), an independent government agency whose objective is to improve the competitiveness of renewable energy technologies, and to increase the supply of renewable energy in Australia. ARENA's initial funding was for $3.2 billion;
- Establishment of CEFC (Clean Energy Finance Corporation) - a government owned organisation that has been established to use a commercial approach to overcome market barriers and mobilise investment in renewable energy and lower emissions technologies. The government is providing the CEFC with a total of $10 billion over a five-year period;
- A range of schemes to support farmers and land managers to reduce emissions and capture carbon including the Carbon Farming Initiative; and,
- Continuation of the Renewable Energy Target.

At the 2013 Federal election (7 September 2013), the Government was elected with a policy platform that included rescinding the carbon price put in by the previous government. The government has a Direct Action policy on climate change that will include the introduction of an Emissions Reduction Fund. This fund is intended to provide a pool of capital to purchase the lowest cost abatement through a reverse auction. The details of this scheme are yet to be finalised. The Government has also indicated that they intend to close the CEFC, and either close ARENA or reduce or re-profile funding to ARENA in conjunction with the repeal of the carbon price.

The government has also commissioned review of the RET. The RET is reviewed every two years with last review being conducted in 2012 by the Climate Change Authority (Climate Change Authority, 2012). This authority was established by the previous government to provide independent advice on the operation of Australia's carbon price, emissions reduction targets and other government climate change initiatives. However, the current government has established a separate review panel for the 2014 RET review consistent with its intent to close the Climate Change Authority at the same time that it repeals the carbon price policy.

The government has committed to developing an Energy White Paper in 2014. This white paper will set out the government's energy policies covering energy resources (for domestic consumption and export), transport fuels, the electricity sector, and emissions reductions through energy efficiency and renewable and alternative energy. The previous government published an Energy White Paper in 2012, the first Energy White Paper since 2004.

Recent and continuing energy and emissions reduction policy changes at Federal level over the last seven years have created an uncertain environment for investment in renewable technologies (Byrnes et al., 2013). This policy uncertainty impacts the current and future market environment for the geothermal energy sector.

1.7 Current Activity in the Australian Geothermal Sector

The Australian geothermal sector is currently stalled with very little activity happening in Australia. The primary reason for the lack of activity is the lack of funding. Table 10 shows the current financial position of the geothermal energy companies listed on the Australian Stock Exchange. With the exception of Geodynamics Limited, none of these companies has enough funding to allow for any significant field activities.

Company	Market Capitalisation ($ million)	Cash on Hand ($ '000)
Geodynamics Limited	20.7	39,450
Hot Rock Limited	2.07	1,808
Petratherm Limited	1.94	636
Green Rock Energy Limited	5.72	1,325
Greenearth Energy Limited	7.13	478
Raya Group Limited (Panax)	5.48	884
High Peak Royalties Limited (Torrens)[2]	3.31	6,000

[1]Greenearth Energy Limited has suspended works on their geothermal permits and are currently active in other renewable energy and energy efficiency activities.

[2]Torrens Energy Limited merged with Phoenix Oil and Gas Limited and changed its name to High Peak Royalties Limited at the end of April 2014, shifting its focus to revenue from royalties. The company is maintaining its geothermal energy tenements. Cash on hand as reported to investors on 27 June 2014.

Table 10: Financial position of Australia's listed geothermal energy companies. Market capitalisation as at 11 July 2014, cash on hand as reported at the end of the March 2014 quarter.

Geodynamics Limited is currently developing options for further development of their Innamincka Deeps project. Identifying a market for the energy produced will be important for further development. The company is looking at potential opportunities provided by recent activity in unconventional gas development in the area around Innamincka, including the possible direct use of geothermal heat in gas processing. Geodynamics Limited recently announced that that they had signed an exclusivity agreement with Beach Energy Limited, providing Beach with an exclusive right to negotiate a farm-in agreement to Geodynamics' geothermal exploration licences at Innamincka. The agreement includes a co-funded research program to investigate the use of geothermal energy in gas developments in the area. Geodynamics Limited is also starting to look at geothermal projects outside of Australia that are targeting convective geothermal resources and plan to commence exploratory drilling at either Savo in the Solomon's or Etafe in Vanuatu in the second half of 2014.

Petratherm Limited is seeking the additional $5 million they need to as a condition precedent for the ERP Project grant for their Paralana project. Until this funding is in place, no further activity is expected. The deadline for securing this funding was originally in December 2013, however ARENA has granted Petratherm Limited an extension to the 19th of July 2014.

Green Rock Energy Limited have announced that they are currently reviewing their Mid-West Geothermal Energy Project following the decision of their JV partner, AWE Limited, to withdraw from the project. This project is in the north Perth Basin, Western Australia and AWE Limited is exploring for petroleum resources in the same area. The joint venture partners aimed to use the synergies present in exploring for geothermal energy and petroleum resources in overlapping tenements. At the time of the announcement, Green Rock

Energy Limited had been negotiating terms and conditions with the Western Australian Government in respect to an existing grant from the Low Emissions Energy Development Fund (LEED) and ARENA in respect to an ERP grant to assist in financing the project. Greenrock Energy Limited has also moved into petroleum exploration to diversify their activities.

No other geothermal companies have publicly announced plans for field activity in Australia in the foreseeable future.

There is some activity in the geothermal energy research and pre-competitive data communities, primarily through the two remaining centres of excellence (QGECE and SACGER) and the ERP Measures funded project at SACGER (finishing in September 2014).

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A.1 Government Grants

Renewable Energy Equity Fund (REEF). The Renewable Energy Equity Fund is a venture capital fund established to increase Australian private investment in renewable energy and enabling technologies through the provision of equity finance. Approximately A$18 million of the available funding was provided via the Australian Greenhouse Office's REEF licence and approximately A$9 million is from private sources. The fund was announced in 2007 and established by AusIndustry in 2000. CVC REEF Ltd., part of The CVC Group, is licenced to manage the fund.

Renewable Energy Commercialisation Program (RECP). Administered by the Australian Greenhouse Office. The Renewable Energy Commercialisation Program (RECP) was launched in 1999 with $54 million in funding. The RECP was a five-year competitive grants program that sort to provide support for strategically important renewable energy technology initiatives that have strong commercial potential. Individual grants were usually between $100,000 and $1 million and grantees were required to fund at least 50% of the project costs from their own sources.

Strategic Assistance for Research and Development (R&D Start) Program. Administered by AusIndustry The R&D Start program was introduced in 1996 by the Federal government to assist Australian industry to undertake research and development and commercialisation. The program merged in to the Commercial Ready program in 2004. $1.3 bilion in industry grants were awarded during this time. Grants of up to $15 million were available and grantees were required to fund at least 50% of the project costs from their own sources.

Renewable Energy Development Initiative (REDI). Administered by AusIndustry, provided grants with matching funding from $50 000 up to a limit of $5 m for eligible renewable energy technology projects of up to three years in duration. The grant scheme was competitive and merit-based and aimed to support the development of new renewable energy technology products, processes or services that have strong early stage commercialisation and greenhouse gas emissions reduction potential. Project applications were invited from the solar, wind, geothermal, biomass, and hydro sectors and ocean energy harnessing technologies. The program ran from 2005 to 2008. Grantees were required to fund at least 50% of the project costs from their own sources

Greenhouse Gas Abatement Program GGAP. Administered by the Australian Greenhouse Office. GGAP was introduced in 1999 and ran until 2009. $400 million was allocated to the program, although the program was underspent. The program aimed at helping Australia meet its commitments under the Kyoto Protocol by funding the most cost-effective abatement opportunities across the economy as they arise.

The Plan for ACcelerating Exploration (**PACE).** Administered by the South Australian Department for Manufacturing, Innovation, Trade, Resources and Energy (DMITRE, previously PIRSA). The initiative was launched in April 2004 by the South Australian government and includes funding for collaborative exploration programs that will address critical uncertainties in mineral, petroleum and geothermal exploration, promoting South Australia as a premier destination for mineral and energy investment. Grantees were required to fund at least 50% of the project costs from their own sources Funding of $30.9 million from 2004 to 2011. **PACE 2020** is a $10.2 million expansion of the PACE initiative.

NSW Climate Change Fund Renewable Energy Development Program (CCFERD). Established by the New South Wales government, CCFERD supports renewable energy projects which will generate electricity or displace grid electricity use in NSW for stationary energy purposes.

Geothermal Drilling Program (GDP). The GDP was launched in August 2008 as a result of a commitment made during the 2007 federal election campaign. The program was administered by the Department of Resources, Energy and Tourism, then the Australian Centre for Renewable Energy, and now ARENA. The program

had $50,000,000 in available funds aimed at assisting the geothermal industry in overcoming the short-term barrier posed by high drilling costs to demonstration of proof-of-concept. The GDP was a competitive, merit-based grants program. Funding is capped at $7 million per proof-of-concept project and grantees were required to fund at least 50% of the project costs from their own sources. There were two rounds of funding (Round 1 in 2008/2009 and Round 2 in mid to late 2009).

South Australian Regional Development Infrastructure Fund (RDIF). RDIF makes available up to $3 million per year in grants to infrastructure projects in regional areas. The grants are awarded through a competitive merit-based application process.

Renewable Energy Demonstration Program (REDP). The REDP was launched in February 2009 and was administered by the Department of Resources, Energy and Tourism, then the Australian Centre for Renewable Energy, and now ARENA. The program had $435,000,000 in available funds aimed at supporting the commercialisation and deployment of renewable energy in Australia. The REDP was a competitive, merit-based grants program, with funding provided on the basis of the applicant providing at least two dollars for every dollar of grant funding.

Queensland Collaborative Drilling Initiative (CDI). The CDI is designed to stimulate exploration investment in under-explored parts of Queensland. The program co-funds the drilling costs of innovative exploration programs through grant rounds.

Education Investment Fund (EIF). EIF was announced in the 2008-09 Budget. The role of the EIF is to build a modern, productive, internationally competitive Australian economy by supporting world-leading, strategically-focused infrastructure investments that will transform Australian tertiary education and research. EIF had a sustainability round with applications accepted in September 2009.

Energy Technology Innovation Strategy (ETIS). Established by the Victorian Government, ETIS aims to accelerate a variety of pre-commercial energy technologies through research, development, demonstration and deployment stages, so that they are ready for market-uptake.

Low Energy Emissions Development (LEED) Fund. Established by the Western Australian Government and administered by the WA Department of Environment and Conservation. LEED provides financial support for the demonstration and commercialisation of innovative low greenhouse emissions energy technologies in Western Australia. LEED funding support of around $30 million has been invested in a range of projects. There have been four rounds of funding, with the successful applicants in the final round announced in June 2006. Every dollar of LEED funding is required to be matched by three dollars provided from other sources.

Western Australian Royalties for Regions funded, Exploration Incentive Scheme (EIS). The (EIS) is a Western Australian government initiative that aims to encourage exploration in Western Australia for the long-term sustainability of the State's resources sector. The $80 million initiative, funded by Royalties for Regions over five years, will stimulate increased private sector resource exploration and ultimately lead to new mineral and energy discoveries. Most of the activities in the EIS are focused in under-explored greenfield regions.

Emerging Renewables Program (ERP) The ERP was first established by ACRE and has since been expanded by ARENA. The aim of this program is to funds activities to support the development, demonstration and early stage deployment of renewable energy technologies with the potential to lower the cost, and thereby increase the supply, of renewable energy in Australia. The ERP has $215 million in funding available.

Grant Program	Matching Funding	Year	Recipient	Description	Amount	Amount Spent	Result
RECP	yes	2/1999	**Pacific Power/ANU**	**Validation of hot dry rock resources** **In the Hunter Valley, New South Wales.**	$790,000	$790,000	Drilling of heat flow wells, including one well to a depth of 1,946 m, a 19 km long seismic reflection line, a micro-gravity study and an assessment of the resource. Geodynamics Ltd. acquired this and two surrounding tenements soon after floating.
RECP	yes	2000	**Scope Energy Pty. Ltd. and UNSW**	**Hot dry rock geothermal reservoir development.** A project to evaluate the hot rock energy reservoir potential of the granite at the base of Big Lake 60 well.	$1,000,000	$1,000,000	Nothing Published, assumed to have been spent.
REEF	equity funding	2002	**Geodynamics Ltd.**	**Equity Investment in Geodynamics Ltd** Initial investment in 2001. $100k for 7% equity and made a number of follow on investments. Corner-stoned and partially under-wrote IPO (2002) and a number of subsequent capital raisings as required.	$1,800,000 ($1,200,000 govt share)	$1,800,000 ($1,200,000 govt share)	Assisted in initial floating of Geodynamics Ltd. and contributed equity for early operations near Innamincka. CVC REEF Ltd. exited Geodynamics on market in 2006, like a profit.
R&D Start	yes	2002	**Geodynamics Ltd.**	**Development of Hot Dry Rock Resources in the Cooper Basin.** Funding for field operations in the Cooper Basin (Innamincka)	$5,000,000	$5,000,000	Drilling of the Habanero 1 well.
R&D Start	yes	2003/2004	**Geodynamics Ltd.**	**Development of Hot Dry Rock Resources in the Coope r Basin** Funding for field operations in the Cooper Basin (Innamincka) in South Australia.	$1,500,000	$1,500,000	Top up of 2002 Start Program grant because of higher than anticipated costs of Habanero 1.
PACE 2	yes	4/2005	**Petratherm Ltd**	**Callabonna Geothermal and Petroleum Evaluation Well.** Funding to support the drilling of a geothermal evaluation well at Callabonna in South Australia.	$140,000	$140,000	The Yerila-1 was drilled in August 2005 to 693.5 metres. A botom hole temperature of 64°C was measured and the overall thermal gradient determined from the data is at least 68°C/km.

Grant Program	Matching Funding	Year	Recipient	Description	Amount	Amount Spent	Result
PACE 2	yes	4/2005	**Scopenergy Ltd**	**Limestone Coast Geothermal Project** **Drilling** Drilling of a heat flow well in the Otway Basin, near Beachport in South Australia.	$130,000	$130,000	Scopenergy drilled several heat flow wells in their tenement, GEL 173 and GEL 170. Also received a REDI grant for this project.
PACE 2	yes	4/2005	**Eden Energy Ltd**	**Evaluation and Interpretation of RIO at West Well.** Evaluation of existing data for geothermal resources based on the Radiogenic Iron Oxide model, near Witchellina in South Australia.	$21,000	$21,000	Unclear, expect that desktop study was completed and existing well may have been re-entered. No record of any drilling.
GGAP	yes	5/2005	**Geodynamics Power Systems (Subsidiary of Geodynamics Ltd.)**	**Commercialising the Kalina Cycle**. A project to demonstrate the Kalaina Cycle in a waste heat recovery project at the Mt Keith Nickel Plant. While the heat source is not geothermal, the Kalina Cycle is well suited to geothermal resources and this grant was awarded to a geothermal energy company.	$2,076,000	$0	Mt Keith Nickel Plant changed owners after the grant was awarded and before contractual terms could be agreed.
PACE 3	yes	12/2005	**Greenrock Energy Ltd.**	**Olympic Dam Geothermal Project, SA** Drilling of a second heat flow well near Olympic Dam in South Australia.	$68,000	$0	Project withdrawn.
PACE 3	yes	12/2005	**Havilah Resources Ltd. (Geothermal Resources Ltd.)**	**Curnamona Geothermal Project, SA.** For drilling several holes to around 500 metres to determine the subsurface heat flow across the Frome project area in South Australia.	$100,000	$100,000	Several shallow heat flow wells drilled. Also received a REDI grant from the federal government for the same project.
REDI	yes	12/2005	**Geodynamics Ltd**	**Innamincka Hot Fractured Rock Power Plant** For a project that integrates sustainable heat mining from a Hot Fractured Rock (HFR) geothermal reservoir to produce zero-emission electricity. The project comprises the construction and operation of a high efficiency Kalina cycle generation plant based on existing geothermal wells near Innamincka, SA.	$5,000,000	$4,261,568	Continued operations at Innamincka, including the drilling of the Habanero 2 well. Failed to complete the planned pilot power plant.

Grant Program	Matching Funding	Year	Recipient	Description	Amount	Amount Spent	Result
REDI	yes	12/2005	**Scopenergy Ltd.**	**Geothermal Power in the Limestone Coast** For a proof-of-concept project on the Limestone Coast which will lead to a 50 MW geothermal power plant. The project will better define prospects for more than 1000 MW of geothermal power in the region.	$3,982, 855	$3,982, 855	Developed a better understanding of the resource potential in the Otway Basin. Heat flow drilling
REDI	yes	7/2006	**Geothermal Resources Ltd.**	**Heat generating capacity of buried hot radiogenic granite** The project will seek to identify, and ultimately map, the composition of granites in the Curnamona Craton region of South Australia. It is anticipated the high uranium/thorium-bearing granites in this region will generate abundant heat. Once an understanding of the heat generating capability and thermal conductivity of the granites has been established, the heating capacity will be mapped in three dimensions for the purpose of assessing the geothermal energy potential.	$2,409,702	$2,409,702	Comprehensive program of activities completed, incuding seismic surveys and drilling 13 wells including a 1761 m and 1809 m well with bottom hole temperatures of over 90 °C.
REDI		12/2006	**Proactive Energy Developments Ltd.**	**A novel regenerator for adapting supercritical cycles to geothermal power applications.** The project aims to develop an innovative regenerator (heat exchanger) that makes possible the use of high efficiency Regenerative Supercritical cycles for production of low-cost zero-emission electricity from geothermal reservoirs.	$1,224,250	$0	No information other then the awarding of the grant available
PACE 4		12/2006	**Torrens Energy Ltd.**	**Heatflow Exploration in Adelaide Geosyncline** For exploration drilling in the Barossa-Clare Project, South Australia.	$100,000	$100,000	Several heat flow wells drilled in 2010.

Grant Program	Matching Funding	Year	Recipient	Description	Amount	Amount Spent	Result
PACE 4		12/2006	**Eden Energy Ltd.**	**Renmark (Chowilla) Geothermal Project, SA** For drilling of a geothermal well to acquire drill core and temperature measurements from within the Renmark Trough to confirm the anomalous heat flow status of the Renmark area, South Australia.	$100,000	$100,000	Chowilla 1 well drilled to a depth of 515 m in December 2007. Results of temperature logging were disappointing.
PACE 4		12/2006	**Geodynamics Ltd.**	**High Temperature Borehole Image logging of Habanero 3, Cooper Basin, SA** Funding to bring to Australia a US Government (Sandia Laboratories) high temperature image logging tool to be run in Habanero .3	$100,000	$100,000	Project completed.
REDI	yes	2/2007	**Petratherm Ltd.**	**Testing the HEWI model at the Paralana Geothermal Energy Project.** The grant funds have been offered to Petratherm to develop the next stage of its Paralana Geothermal Energy Project, 130 kilometres east of Leigh Creek. This will involve the creation of an underground heat exchanger within the insulating rocks above the granite heat source, that is, Petratherm's HEWI Model (Heat Exchanger Within Insulator) and will require the drilling of two wells and establishing circulation of water between those wells.	$5,000,000	$5,000,000	Contributed to the drilling of the Paralana 2 well and stimulation activities.
REDI	yes	8/2007	**Torrens Energy Ltd.**	**3D Temperature Field Data Collection and Modeling** Funds will be used to accelerate exploration drilling and temperature modelling to reduce risk by mapping heat flow over highly prospective geothermal targets in South Australia	$3,000,000	$3,000,000	Conducted extensive heat flow drilling program including one well to 1,807 m depth that has helped to define the Parachilna resource.

Grant Program	Matching Funding	Year	Recipient	Description	Amount	Amount Spent	Result
PACE 5	yes	2/2008	**Petratherm Ltd.**	**Trial of a New Method of Resource Mapping at the Paralana Project** Passive seismic monitoring to map fractures at depth using shear wave splitting.	$100,000	$100,000	Seismic array installed and, although insufficient seismic events were detected to allow the analysis of shear-wave splitting as an exploration tool, the study was deemed to have been a technical and operational success, allowing background seismicity to be determined.
PACE 5	yes	2/2008	**Torrens Energy Ltd.**	**3D Temperature Field Data Collection and Modeling** Funds will be used to accelerate exploration drilling and temperature modelling to reduce risk by mapping heat flow over highly prospective geothermal targets in South Australia	$100,000	$100,000	Two 2D Seismic lines collected at the Paralchina prospect in 2009.
CCFERD	yes	11/2008	**Geodynamics Ltd.**	**Hunter Valley Geothermal Power Project.** **Th**e first commercial hot rock geothermal energy project in NSW, which will draw geothermal energy from hot rocks with estimated temperatures above 200°C at depths of 4000–5000 metres. Deep wells will feed a 10 MW binary cycle power station that will generate approximately 80 gigawatt hours of zero emission baseload power a year for at least 30 years. The project will demonstrate the potential of the Hunter Valley hot rock resources and pave the way for expansion to a 50 MW plant.	$10,000,000	$0	Project withdrawn. Geodynamics Ltd. have focused on their Cooper Basin activities.
GDP (Round 1)	yes	4/2009	**Petratherm Ltd.**	**Paralana Project.** Contribute to the costs associated with drilling a doublet for proof of concept at the Paralana Geothermal Project.	$7,000,000	$4,200,000	Paralana 2 well completed in 2009. The remaining $2.8 was relinquished in 2013 in conjuction with the award of an Emerging Renewables Program grant.

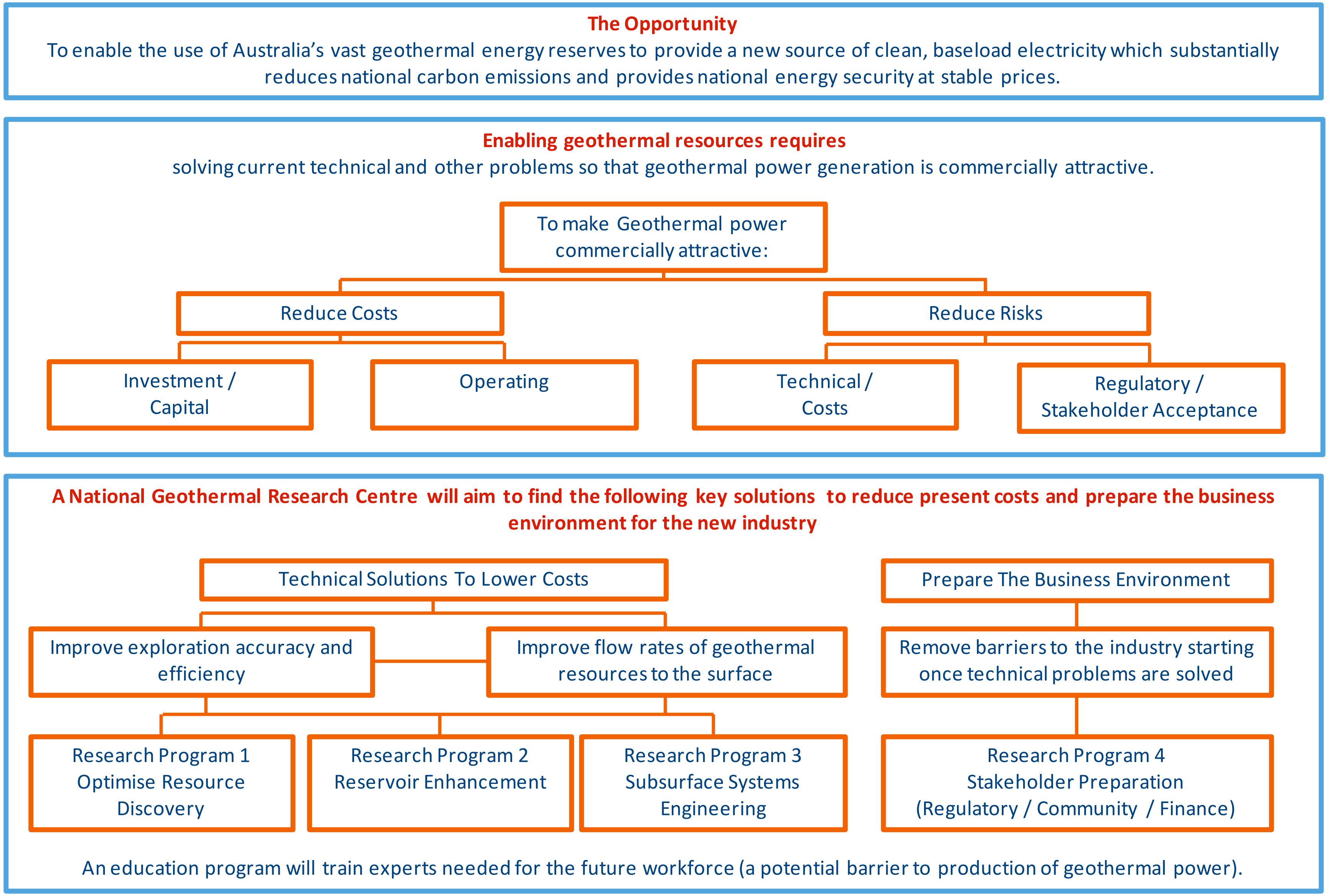
Grant Program	Matching Funding	Year	Recipient	Description	Amount	Amount Spent	Result
GDP (Round 1)	yes	4/2009	**Panax Ltd.**	**Penola Project.** Contribute to the cost associated with drilling a single production well at the Penola Geothermal Project.	$7,000,000	$7,000,000	Salamander 1 well completed in 2010. Disappointing flow test results have lead to the project being suspended.
RDIF	yes	4/2009	**Geodynamics Ltd.**	**Innamincka Project** Funding for the construction of a power line from the Habaenero site to Innamincka.	$560,000	$560,000	Project completed.
REDP	yes	11/2009	**Geodynamics Ltd.**	**Cooper Basin Geothermal Demonstration Project.** The 25 MW Cooper Basin Geothermal Energy Project aims to demonstrate the potential of hot-rock geothermal energy. The total cost of the project is $338.6 million.	$90,000,000	$32,400,000	Geodynamics Ltd. ran their 1 MWe pilot plant in 2013, achieving an important milestone in their REDP grant
REDP	yes	11/2009	**Petratherm Ltd.**	**Paralana Geothermal Energy Project** The 30 MW Paralana Geothermal Energy Project is an engineered geothermal system project based on Petratherm;s Heat Exchanger Within Insulator model. The total cost of the project was $188.3 million.	*$62,760,000* original grant **$24,500,000** (re-scoped grant in 2013)	$0	This project was re-scoped in 2013 in conjuction with the award of an Emerging Renewables Program grant for the drilling of the Paralana 3 well. The project is now for a 7 MWe plant with two additional wells with a total cost of around $75 million
ETIS	yes	12/2009	**Greenearth Energy Ltd.**	**Geelong Geothermal Project** $25 million for Stage 1 (Proof of Concept, $5 million) and Stage 2 (12 MWe Demonstration, $20 million) for the company's flagship domestic project , the Geelong Geothermal Power Project located northwest of the township of Anglesea Victoria.	$25,000,000	$0	Grant relinquished – unable to raise remaining funding.
GDP (Round 2)	yes	12/2009	**Hot Rock Ltd.**	**Koroit Project.** Contribute to the costs associated with drilling a doublet for proof of concept at the Paralana Geothermal Project.	$7,000,000	$0	Grant relinquished – unable to raise remaining funding.

Grant Program	Matching Funding	Year	Recipient	Description	Amount	Amount Spent	Result
GDP (Round 2)	yes	12/2009	**Geodynamics Ltd.**	**Hunter Valley Project.** Contribute to the costs associated with drilling a doublet for proof of concept at the Hunter Valley Geothermal Project.	$7,000,000	$0	Grant relinquished.
GDP (Round 2)	yes	12/2009	**Torrens Energy Ltd.**	**Parchilna Project.** Contribute to the costs associated with drilling a doublet for proof of concept at the **Parchilna** Geothermal Project.	$7,000,000	$0	Grant relinquished – unable to raise remaining funding.
GDP (Round 2)	yes	12/2009	**Green Rock Energy Ltd.**	**Perth Metro Project.** Contribute to the costs associated with drilling a doublet for proof of concept at theUniversity of Western Australia District Heating/Cooling Project.	$7,000,000	$0	Grant relinquished – unable to raise remaining funding.
GDP (Round 2)	yes	12/2009	**Greenearth Energy Ltd.**	**Geelong Project.** Contribute to the costs associated with drilling a doublet for proof of concept at the Geelong Geothermal Project.	$7,000,000	$0	Grant relinquished – unable to raise remaining funding.
Queensland Renewables Program	yes	2009	**Ergon Energy Ltd.**	**Upgrade of Birdsville Geothermal Power Station** A one off grant to upgrade the Birdsville Geothermal Power station.	$4,300,000	$0	Project did not progress after a tender process failed to find suitable technology..
CDI	yes	3/2010	**Geodynamics Ltd.**	**Queensland Cooper Basin Project** Funding for heat flow drilling.	$150,000	$0	Project withdrawn
PACE 6	yes	5/2010	**Gradient Energy Ltd. (Planet Gas Ltd.)**	**Leigh Creek Temperature Anomaly Study.** Funding for an innovative systematic geothermal exploration program which was aimed at identifying and mapping the surface expression of deep Hot Fractured Aquifer (HFA) geothermal systems using satellite thermal imagery, satellite alteration mapping and surface/near surface water geochemistry within its Leigh Creek Project.	$80,000	$80,000	Due to the difficult economic climate within the geothermal sector in 2010-2011, only some of the originally proposed project analysis covered by the PACE Grant could be completed, and no field activities were done.

Grant Program	Matching Funding	Year	Recipient	Description	Amount	Amount Spent	Result
PACE 6	yes	5/2010	**Terratherma Ltd** **(subsidiary of Eden Energy Ltd.)**	**Coorichina, Torrens Hinge Zone.** Exploration activities north of Olympic Dam	$40,000	$0	Eden Energy Ltd. exited Geothermal Exploration in 2011. Grant relinquished.
EIF Sustainability Round	no	6/2010	**CSIRO**	**Sustainable Energy for the Square Kilometer Array – Geothermal Component.** This project was originally intended to provide cooling power for a supercomputer in Perth by accessing hot water from a HSA at 3 km and using it in an absorption chiller. This grant could arguably be considered as R&D support. As it was essentially funding for a demonstration project is included as a grant to 'industry'.	$19,800,000	$6,100,000	Rising costs and other commercial risks along with a decrease in the cooling needs of the supercomputer led this project to be substantially re-scoped. The cooling is now provided by heat rejection in to a shallow aquifer, and the project costs have reduced to around $6.1 million. The remaining funding has been relinquished.
LEED (Round 3)	yes	9/2010	**Greenrock Energy Ltd.**	**Perth Metro Project.** Contribute to the costs associated with drilling a doublet for proof of concept at theUniversity of Western Australia District Heating/Cooling Project. Complimented GDP grant.	$5,400,000	$0	Grant relinquished – unable to raise remaining funding.
LEED (Round 4)	yes	6/2012	**Greenrock Energy Ltd.**	**Mid West Geothermal Power Project.** Proof of concept project in the North Perth Basin.	$5,380,000	$0	Additional funding currently being sought, including ARENA Emerging Renewables Program Project funding. JV partner secured.
EIS	yes	6/2012	**Greenpower Energy Ltd.**	**Esperance Geothermal Project** Funding will be used for the completion of two drill holes to 400 m one each in Greenpower's GEP38 and GEP39 tenements.	$120,000	$120,000	One heat flow well was drilled to 400 m. No anomalous heat flow found and the leases were relinquished.

Grant Program	Matching Funding	Year	Recipient	Description	Amount	Amount Spent	Result
ERP Project	yes	6/2013	**Petratherm Ltd.**	**Paralana Project** Funding to assist the next stage of works at Paralana, including the drilling and stimulation of the Paralana 3 well - a producer well into the hot rock reservoir created around the existing Paralana 2 well, as part of an applied research project into the site's commercial potential.	$13,000,000	$0	A condition of this grant is that Petratherm secures an additional $5 million in equity within 6 months of the grant date. The company has not announced whether this has been achieved.
Totals					**$315,348,952**	**$76,112,270**	
				Allocated, unspent and still available	**$100,480,000**		

A.2 Overview of The Geothermal Research Initiative's Research Plan



A.3 Companies in Australia that currently hold geothermal tenements as at December 2013.

ASX Listed Companies	States with tenements, notes
Geodynamics Limited	Qld, SA, NSW and NT
Green Rock Energy Limited	SA, WA (directly and through their subsidiaries and JV's Green Heat Resources Pty Ltd, Green Rock Geothermal Pty Ltd, and Mid West Geothermal Power Pty Ltd
Greenearth Energy Ltd	Vic
Hot Rock Ltd	Vic
KUTh Exploration Pty Ltd	Tas, Qld
Petratherm Ltd.	SA (through their subsidiary MNGI Pty. Ltd.)
Raya Group Ltd (formerly Panax)	SA (directly and through their subsidiaries Osiris Energy Ltd and Scopenergy Limited)
Torrens Energy Ltd	SA, NT
Unlisted Geothermal Companies	
Clean Energy Australasia Pty Ltd	Qld, SA
Deep Energy Ltd	SA
Earth Solar Power Pty Ltd	Qld
Granite Power Limited	Qld, NSW, Vic, WA
New World Energy Solutions Pty Ltd	WA
Roxby Geothermal Pty Ltd	SA
Terra Estus Resources Pty Ltd	Qld
Small, mixed resource companies (Private and Listed)	
Greenpower Energy Limited	WA
Havilah Resources Ltd	SA (through their wholly owned subsidiary Geothermal Resources Limited)
Icon Energy Limited	Qld
Kagara Ltd	WA
OZ Minerals Carapateena Pty Ltd	SA
Stuart Petroleum Pty Ltd (Now Senex Energy Ltd)	SA
Western Desert Resources Ltd^	NT
JV Partners	
Beach Energy Limited	SA (with Petratherm)
Origin Energy Ltd	SA (with Geodynamics)
Lakes Oil Limited	Vic (with Greenearth Energy)
AWE Limited	WA (with Green Rock Energy)
Large Energy Companies with direct holdings	
AGL Ltd	Qld (through their wholly owned subsidiary, Geogen Victoria Pty Ltd.)
Centennial Fassifern Pty Ltd	NSW (subsidiary of a large Thai owned coal miner with geothermal tenements coincident with several of their mining operations)
Pacific Hydro Limited	SA (One of Australia's largest renewable energy companies, also JV'd with Green Rock Energy)
Other	
NSW Director General - Department of TIRIS	NSW (NSW Govt using geothermal lease for Carbon Storage drilling program)

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FOR FURTHER INFORMATION

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