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What's happened to geothermal?

Simple in concept—complex in application

Anthony Budd

Introduction

In the brief period 2005–2010, geothermal energy showed rapid growth in Australia with many tenements being taken up, significant exploration activities and a number of very deep wells drilled. Since that time, despite world-leading technical success, expenditure, activity, tenement holdings and personnel numbers have decreased markedly. Success has been achieved with the generation of electricity by Geodynamics Ltd at Innamincka, and the creation of a geothermal reservoir by Petratherm Ltd at Paralana. This article examines why this decline has occurred, and looks at the place of geothermal energy in Australia's Clean Energy Future.

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What is geothermal?

Geothermal energy is heat (thermal) from the Earth (geo). Heat is constantly generated within the Earth by the process of radioactive decay, and heat is still residual from planetary accretion (KamLAND collaboration, 2011). This heat passes from the inside of the Earth into outer space. We see evidence of this heat loss at volcanos and mid-ocean ridges, and in features such as geysers, hot springs, fumaroles and mud pots, however, heat flows everywhere across the globe at varying rates (Dickson and Fanelli, 2004).

Human kind has utilised geothermal energy for millennia, mostly using water from hot springs for cooking, bathing, heating and washing (Cataldi 1993). Electricity was first successfully generated from geothermal steam at Lardarello in Italy in 1904 and this field continues to produce 10 per cent of the world's geothermal power.

Most of the world's current utilisation of geothermal energy is in areas of active volcanism because that is where the heat flux is highest and most accessible. In Australia, a continent without active volcanism, high temperatures are generated by high heat producing rocks (particularly granites) within the upper part of the crust and from the underlying mantle. These are lower grade heat sources than the magmas at volcanos so a thermally-insulating blanket is needed to trap the heat and achieve sufficiently high temperatures. This blanket is provided by thick layers of fine-grained sediments and coals. Temperature measurement in parts of Australia shows that we do have many areas with temperatures high enough for power generation, and it is not widely appreciated that a small power plant has been operating at Birdsville for approximately two decades.

Australia's geothermal resources are said to be 'unconventional', because they are different to the volcanic-associated systems utilised elsewhere in the world for power generation. Some of our resources will be shallow and hot enough to be used in a manner similar to conventional systems - these are often called 'Hot Sedimentary Aquifer' systems (HSA), and the Birdsville power plant in the

Great Artesian Basin is an example. The systems in Australia that are hot enough to generate large amounts of power will mostly be deeply buried and therefore difficult to flow water through. Flow paths will need to be enhanced, so this type of utilisation is called an 'Enhanced (or Engineered) Geothermal System' (EGS) (Figure 1). To explain, cool water is pumped from surface down an injection well, flows through the hot rocks to be heated, then is recovered to surface for use via a production well—this works as a "closed loop". There are many other countries also interested in EGS and Australia will benefit from international collaboration.

Figure 1: Hydraulic stimulation at the Paralana-2 wellhead. Courtesy of Brooke Whatnall (The Advertiser Newspaper) via Petratherm Ltd.

Why geothermal?

Energy security is of vital importance to Australia as we are an energy intensive society. Our mining and manufacturing industries in particular are dependent on cheap power and heat.

Geothermal is a flexible source of heat energy which is very environmentally benign, and it also has excellent financial benefits for Australia. Geothermal is renewable and sustainable. Geothermal resources in Australia have no emissions nor produce other pollutants. If emissions throughout the full life cycle of power production are considered, geothermal is one of (if not the) cleanest form of power we have available to us. Geothermal plants have a small footprint for their energy production.

Geothermal energy has a high availability - energy is provided constantly (regardless of time of day or weather) and therefore a high capacity factor (for example, power plants produce at close to their maximum capacity, all the time). Load following is also possible. Heat energy is produced from the hot water, and can be used for electricity production or directly in a wide variety of industrial processes. Geothermal power stations can be modular or scalar, so can produce power at less than 1 megawatt (MW), through to gigawatts (in theory). This is a similar range to other baseload or peaking power stations. For example, in NSW the Liddell gas turbine station has a capacity of 50 MW, the Vales Point coal station is 1320 MW, and the Tumut 3 pumped hydro station is 1500 MW.

Geothermal power has been estimated to be one of Australia's cheapest future power options (Energy White Paper, 2012). Australia has a very large potential resource base. Geothermal energy cannot be traded internationally, providing price security, and it demands a high Australian workforce content at all stages of development and production.

Mythbusting geothermal

Geothermal energy is new to Australia, and the general populace as well as decision makers and investors are right to question whether this technology should be deployed in Australia. This section outlines some of the concerns that the author has come across in speaking to people about geothermal, and attempts to provide information for readers to have an informed view.

It will cool the Earth

The concerns expressed here range from catastrophic (freezing the Earth), to questions as to whether this is actually a renewable energy resource. Even if geothermal was very widely utilised, heat would still only be extracted from a very minor volume of the outermost part of the Earth's crust—it will have a negligible effect on the Earth's temperature.

It will heat the atmosphere

Here the concern expressed is that heat would be extracted and removed from the Earth at a rate faster than would happen naturally, and that this heat is then dumped into the atmosphere as a by-product of energy production. However, burning fossils fuels, as done now, releases both heat and emissions. Geothermal can displace the use of fossil fuel, lowering the amount of heat released into the atmosphere.

It is not renewable

As explained above, heat within the Earth comes from the core and from heat generated during radioactive decay. The extraction of geothermal heat does not affect the production of heat in the Earth, which is a natural and recurring process; that is, the heat budget of the Earth is self-renewing. Therefore geothermal energy is renewable—our activities will not impact future generations' ability to access geothermal resources.

The closed loop is to contain radioactive elements

This concern arises from the belief that because the heat driver for geothermal systems in Australia is from radioactive decay, the systems must be highly radioactive. Further, the suspicion is that water is returned to the geothermal reservoir because it is highly radioactive. Neither of these fears are correct. The abundances of uranium, thorium, and potassium in the granite heat source rocks is absolutely natural, is much lower than ores that are mined for nuclear fuels, and orders of magnitude lower than that of nuclear weapons. Indeed, there are some beach sands that are more radioactive than granites. The return of reservoir fluid to the reservoir once it has been passed through the power plant is for the purposes of water conservation, as well as for maintaining reservoir pressure and temperature. The use of a closed loop is fundamental to water management and heat extraction and is not an attempt to engineer a 'natural' nuclear reactor.

It can be used anywhere

Some prospective geothermal developers have used the term 'EGS Anywhere' to try to explain that the use of geothermal energy is not restricted to the areas immediately around volcanos. However, in Australia geothermal power has not yet been demonstrated to be economic from any EGS reservoir, let alone from low-grade reservoirs. It will be some time before it is economic to drill to depths of more than six kilometres and we need more robust reservoir enhancement methods before we can deploy the technology to very low grade resources and have a suitable return on investment.

It causes earthquakes

Seismic activity is well-known to be associated with many of humankind's activities, such as mining and water damming. Hydro-shearing, the most common method used for improving permeability of geothermal reservoirs, uses high-pressure water to force existing fractures further open (by fractions of a millimetre only) and this does cause earthquakes. No earthquakes larger than magnitude 4 are known to have been caused by any EGS geothermal development in 35 years of operations worldwide, and none have been shown to have caused damage to buildings or other infrastructure. Extensive research is being undertaken for the dual purpose of enabling suitable regulation and effective reservoir development.

It is too remote

This is one of the most common reasons given as to why geothermal will never work in Australia, with the assumption being that building power lines is too expensive and line losses will be high. High-voltage direct-current power lines have very low line losses and are already used as long interconnectors in Australia. The need to build long power lines during the construction phase of power plant development would certainly be an additional financial burden, but there are four mitigating factors that need to be considered. Firstly, small local markets may exist close to some geothermal resources, enabling income during scale-up. Secondly, further exploration work may reveal resources close to off-grid markets, which are likely to provide better power prices than connecting to the over-supplied National Electricity Market. Thirdly, geothermal projects are potentially very large so that the expense could be financially justifiable. Lastly, being remote generally means less complicated approvals processes, including objections to induced seismicity.

Virtually every resource used in Australia requires transport, and this issue needs to be addressed by geothermal projects, but is not per se an issue that will prevent geothermal development.

It doesn't work

The Enhanced Geothermal Systems concept was developed at Fenton Hill in the United States of America in the early 1970s, and several other experimental deep projects have been undertaken since then. In Australia, Geodynamics Ltd has successfully produced power from its Innamincka pilot plant in mid-2013. There are no technological barriers to producing power at commercial scales, rather technology developments and improvement in our knowledge of particular reservoirs are required to bring costs down in order to attract the investment necessary to scale the projects up.

If it was easy, it would have been done by now

Geothermal energy is simple in concept, however in Australia it has been proven to be more complex in application—something that should come as no surprise with hindsight. Most technologies go through a difficult development phase including where their costs are higher than competing technologies which they eventually displace. Still, it is no more complicated than oil and gas extraction methods carried out routinely. The difference is that EGS is deep so drilling costs are high (including in the resource discovery phase), and fossil fuels have always been cheap in comparison, making the leap from a proven energy source to an unproven one—no matter how much cheaper and cleaner it may be in the longer term—has proven too risky for the current investment market.

It is too expensive

With expected improvements in flow rates achieved from wells, and better drilling procedures, EGS energy in Australia could be our cheapest zero-emission base-load power source. The problem is that until a 10s of megawatts demonstration plant has been successfully operated in Australia and shown to be profitable, no investors are presently willing to make the risk on investment. Deep geothermal cannot be demonstrated in a cheap fashion in the way that other energy technologies can be—from laboratory bench-scale to pilot to demonstration.

What's gone wrong?

Several development projects have been undertaken in Australia and overseas, but with little progress in evidence, it is commonly assumed that unconventional geothermal systems do not work. Here I examine the events that have contributed to this view, and comment on the significant learnings that have come from each of them. Unfortunately these events are seen as failures, and the very valuable learnings and advances from each are not broadly recognised.

The geodynamics experience—Habanero EGS project

In October 2003, Geodynamics Ltd completed the Habanero-1 well to a depth of 4421 metres, and found unexpectedly high fluid pressures as well as the high temperatures expected. The high fluid pressures required changes to the drilling configuration to use a heavy mud rather than water in order to control the overpressures. This led to a doubling of the original budget—to approximately $11 million—to complete the well

(Geodynamics, 2003). Two fractures were able to be stimulated in this well, creating a reservoir considerably larger than previously managed at any other EGS project in the world.

Habanero-2 was drilled in July 2004 and successfully intersected the fractured reservoir created from Habanero-1, with flow demonstrated between the two wells at higher rates than had previously been achieved elsewhere. However a stuck drill pipe during a well clean up and intervention event caused the well to be abandoned in June 2006. The final cost of drilling was significantly above the original budget of $10.5 million (Geodynamics ASX Announcement 12 July 2004).

In response to the host of drilling problems of Habanero-2, Geodynamics bought their own rig. This was used to drill Habanero-3 (August 2007 – February 2008, 4221 metres, 250 °C), Jolokia-1 (March–September 2008, 4911 metres, 278 °C) Savina-1 (October 2008–February 2009, ~3700 metres), and Habanero-4 (March–September 2012, 4024 metres,). Drilling progressed without significant incident in Habanero-3 and Jolokia-1 but stuck pipes caused the abandonment of Savina-1, although a good overpressured fracture was intersected within granite prior to the abandonment.

> "On 6 December 2006 a magnitude 3.4 earthquake occurred at Basel, Switzerland where an EGS operation was conducting hydraulic stimulation in a well sited within the city itself."

During mid-2009 Geodynamics successfully achieved closed-circuit flow between Habanero-1 and Habanero-3, a very significant technical feat. Within a week prior to connecting the flow circuit to a 1 MW generator, the steel casing in the upper part of Habanero-3 cracked. A detailed investigation determined that an incomplete cement job left an air pocket between the steel casing and the rock formation. As hot water was cycled through the well, expansion and contraction of the casing eventually caused work hardening and then failure of the steel. Geodynamics received a major proportion of the cost of the well back from well insurance.

The joint venture partners spent $9 million on the design of Habanero-4 to mitigate all of the issues encountered in the previous wells. In the later part of 2012 Geodynamics conducted further hydraulic stimulation and flow testing from Habanero-4 and achieved the highest ever open-well flow rates from an EGS well. Geodynamics successfully commissioned the 1 MW pilot power plant in Quarter 2 2013 using Habanero-1 as injector and Habanero-4 as producer.

The successful drilling of Habanero-4 reflects the vast experience that has been gained at this project by Geodynamics. These learnings have come at a high cost—in excess of $0.5 billion—but will provide the basis for making EGS technology more available.

Fears of induced seismicity, and changed market conditions

Two events overseas raised awareness of geothermal induced seismicity, and concerns raised at a potential Australian project caused far reaching effects.

On 6 December 2006 a magnitude 3.4 earthquake occurred at Basel, Switzerland where an EGS operation was conducting hydraulic stimulation in a well sited within the city itself. Public outcry caused the immediate suspension of the project and legal action against the project proponents, although no charges were upheld. No damage was caused to buildings, although the geothermal company did pay out insurance claims because it was cheaper to do so than to go through a legal process with many claimants.

A company undertaking drilling for an EGS trial at The Geysers geothermal field, California, stopped its work partly due to public opposition. This project had US Department of Energy (DoE) funding for the work, which caused embarrassment to the department and Government. As a consequence the DoE commissioned the development of a protocol for addressing induced seismicity associated with enhanced geothermal systems (Majer et al. 2012).

An Australian company (Greenearth Energy Pty Ltd - GRE) operating in the Otway Basin near Geelong made an application for Round 2 of the Geothermal Drilling Program (GDP) during late 2009. Based on news reports from the two overseas incidents above, a local resident, seeing plans for an EGS trial on the GRE website, raised concerns about induced seismicity. This happened at the same time as the Home Insulation Program was caught up in controversy and Government enforced a higher level of risk mitigation in its programs. This required adjustment to the GDP that delayed it by six months. By then the full effects of the Global Financial Crisis (GFC) were being felt and risk capital had become unavailable meaning that the five geothermal companies awarded Round 2 GDP grants ultimately relinquished the grants because they were unable to meet the matching funding obligations. Also, during this time, the price of oil went up resulting in higher drilling costs, and power demand in the National Electricity Market declined.

Petratherm received a Round 1 grant from the GDP, drilled Paralana-2, successfully hydraulically stimulated the metasedimentary reservoir (July 2011, Figure 1), and achieved good flows from the well in October 2011 (Figure 2). However, despite these good results, Petratherm was unable to raise sufficient matching funds from the investment market to match the remainder of its GDP grant.

Figure 2: Water flowing from the Paralana-2 open well flow test. Courtesy Petratherm Ltd.

Other setbacks

In December 2009 the proposed Carbon Pollution Reduction Scheme failed to pass through the Senate, and the Government subsequently announced a decision to delay implementation of any such scheme. This, combined with the GFC, acted to further reduce investment in the renewable energy sector, including geothermal companies.

Significant flooding occurred in central South Australia during 2009 and 2010, leading to delays in drilling at the Paralana and Habanero projects.

Panax Geothermal Ltd drilled the Salamander-1 well in the western Otway Basin. Flow testing in early 2010 failed to produce the high flow rates predicted by the company. In 2011 Geodynamics announced that the Celsius-1 well in the Cooper Basin did not have the permeability required to achieve economic flow rates. Both of these wells were targeting 'Hot Sedimentary Aquifer' resources, and the low flow rates achieved were received by the media and other observers as a failure of geothermal technology in Australia.

Government policy

Successive Australian Governments have had programs and other measures in place to assist the uptake of renewable energy in Australia. The largest of these has been the Renewable Energy Target. Geothermal projects have not advanced at a sufficient rate to benefit from this scheme.

Uncertainty around carbon pricing schemes has also not helped to encourage investment in geothermal companies.

The Australian Centre for Renewable Energy (ACRE) was established in October 2009 to promote the development, commercialisation and deployment of renewable energy and enabling technologies and improve their competitiveness in Australia. ACRE managed over $690 million of funding committed to support renewable energy and enabling technology development, and the Emerging Renewables Program was designed to include support for technologies such as geothermal energy. ACRE was incorporated into the Australian Renewable Energy Agency (ARENA) on 1 July 2012. ARENA is an independent statutory authority established under the Commonwealth Authorities and Companies Act 1997, tasked with the objectives of improving the competitiveness of renewable energy technologies and increasing the supply of renewable energy in Australia. ARENA is part of the Clean Energy Future package and has $3.2 billion of funding.

Geothermal exploration and drilling projects have received funding from the Australian Government through the Renewable Energy Demonstration Initiative, the Renewable Energy Demonstration Program, and the Geothermal Drilling Program. Several State Government grant funds have also been made available to geothermal companies.

Geothermal exploration and research and development activities have also been made eligible for tax rebates.

Each State and the Northern Territory have legislation and regulations in place that allow for geothermal exploration and extraction.

In 2008 the Department of Resources, Energy and Tourism produced the Geothermal Industry Development Framework, and Geothermal Industry Technology Roadmap. ARENA is conducting a geothermal review in the latter half of 2013 with an international panel of experts.

The future of geothermal in Australia

Despite the many advantages offered by geothermal, investment in geothermal development has been inadequate to sustain the pace of development forecast by companies in the mid-2000s. Further demonstration projects are needed to increase investor confidence in the technology, together with improvements across the resource discovery, characterisation and extraction processes to lower the costs of energy delivery. The challenge for geothermal in Australia is to rapidly build a level of understanding that will allow robust and reliable resource utilisation, in a timeframe shorter than the century or so over which technologies in the minerals and petroleum sectors have developed. This will require coordination, collaboration and increased funding. The geothermal sector is now working with ARENA in each of these areas.

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