The National Outlook - Australia's Hot Rocks

Goldstein, B.A.[1], Hill, A.J.[1], Budd, A.R.[2], Holgate, F.L.[2], and Malavazos, M.[1]
[1] *AGEG and Petroleum & Geothermal Group, PIRSA Level 6, 101 Grenfell St., Adelaide 5000*
[2] *AGEG and Onshore Energy & Minerals Division, Geoscience Australia, GPO Box 378 Canberra 2601*
Email: goldstein.barry@saugov.sa.gov.au; hill.tony2@saugov.sa.gov.au; anthony.budd@ga.gov.au; Fiona.Holgate@ga.gov.au; malavazos.michael@saugov.sa.gov

INTRODUCTION

Geothermal energy from amagmatic Hot Rocks (HR) is a source of inexhaustible, 24/7, free fuel for zero-emission power generation. These characteristics make Hot Rock (HR) geothermal resources a desirable addition to the world's portfolio of safe, secure and competitive energy supplies. Australia's vast HR resources (Figure 1) and comparative advantages for the development of Engineered Geothermal Systems (EGS) have attracted global interest, finance and government support for several HR – EGS proof-of-concept projects. Australia's long history of shared investment in mining and energy operations is also a key factor in Australia being recognised as leading the world in 'exploiting subterranean heat' (The Economist, 2008).

To 20 July 2008, 33 companies have applied-for 320 geothermal exploration licences[1] covering more than 245,000 km^2 in Australia with work program investment over the term 2002-13 totaling more than $853 million (Figures 2 and 3). This forecast excludes up-scaling and deployment projects assumed in the Energy Supply Association of Australia's scenario for 6.8% (about 5.5 GWe) of Australia's base-load power coming from geothermal resources by 2030 (ESSA, 2006).

This rapid growth has stimulated both whole-of-sector and industry alliances to form and mature. Formed in 2006, the Australian Geothermal Energy Group (AGEG) is Australia's whole-of-sector alliance of companies, government agencies and research organisations with an interest in the advancement of the use of geothermal energy. AGEG members share information and undertake high priority studies to foster efficiency on the road to commercialising Australia's geothermal resources. The Australian Geothermal Energy Association (AGEA) formed in 2008 as the peak representative Directorate for Australian geothermal industry companies. All AGEA member companies are also members of the AGEG. The AGEG's Technical Interest Groups (TIGs) are national networks that enable Australia's geothermal sector to reduce critical, shared uncertainties that left unsolved, act as impediments to geothermal energy development. Notably, the relevant AGEG TIG has developed a Code for Geothermal Resource and Reserves Reporting (AGEG, 2008a) to facilitate consistent public reporting of geothermal resources and reserves and to foster understanding of Australian HR projects. This Code has sustained considerable peer review and will be released for public consideration at the AGEG-AGEA Geothermal Energy Conference in August 2008.

Bi-partisan government support has and will be instrumental in progress attained by the geothermal sector, especially for HR-EGS projects, which are currently, all, in a pre-competitive state. It is heartening to note, that to 20 July 2008, government has committed more than $100,000,000 for geothermal projects (Table 1), and further support is expected. High priorities for government action will be articulated in the Australian Government's Geothermal Industry Development

[1] Includes 38 West Australian Perth Basin blocks covering 320 km^2 (each) that attracted bids.

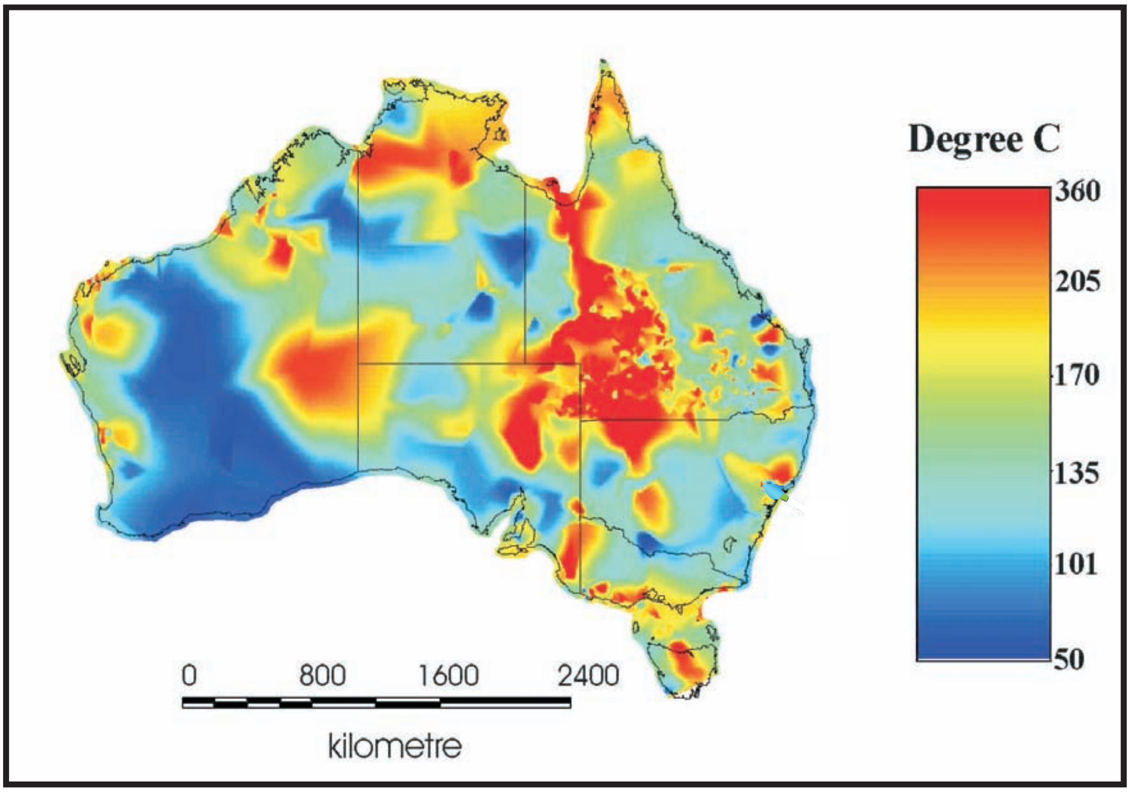

Figure 1. Estimated temperatures at 5 km in Australia (Sommerville et al., 1994).

Framework, (GIDF) and the associated Geothermal Technology Roadmap that is now being developed for consideration by the Council of Australian Governments (CoAG).

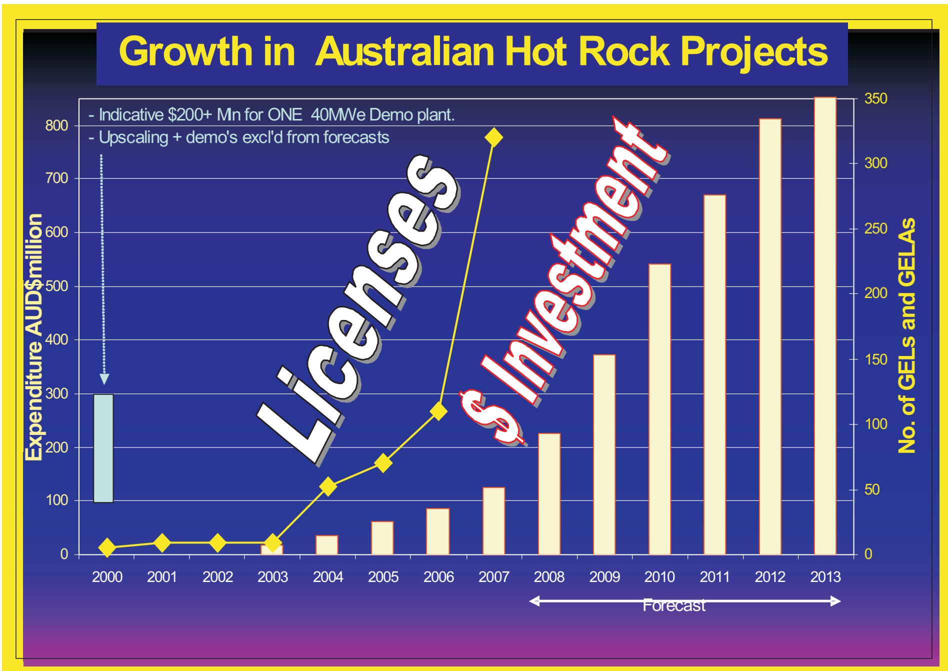

Figure 2. Cumulative actual (2000-07) and forecast (2008-13) expenditure on geothermal proof-of-concept projects and growth in Australian geothermal licences.

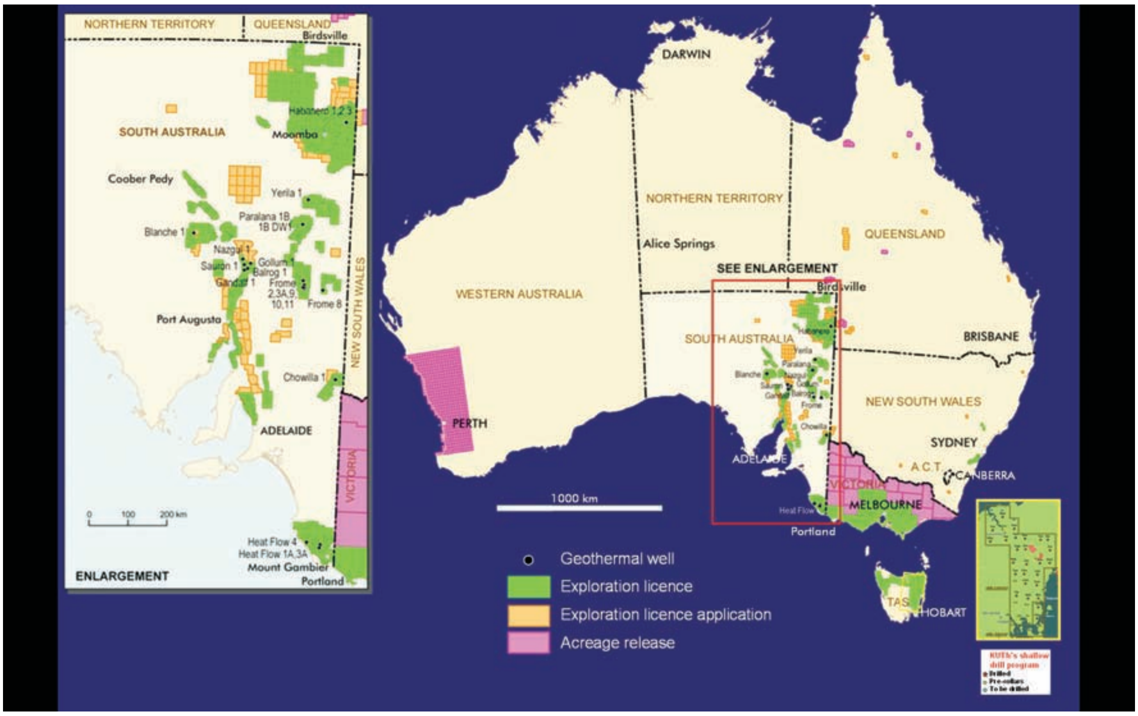

Figure 3. Geothermal licences, licence application areas and wells drilled in Australia to 1 July 2008.

Given compelling success in current proof-of-concept and subsequent demonstration projects, Australia's world class 'amagmatic' HR resources have potential to fuel competitively-priced, emission free, renewable baseload power for centuries to come (AGEG, 2008b).

Table 1. Government grants for geothermal energy projects since 2000.

Grant	Date	Recipient	Project	A$ Amount
Fed. RECP	2000	Pacific Power/ANU	Hunter Valley Geothermal Project	$790,000
Fed. START	2002	Geodynamics	Habanero Project	$5,000,000
Fed. REEF	2002	Geodynamics	Habanero Project	$1,800,000
Fed. GGAP	Mar-05	Geodynamics	Kalina Cycle to produce energy from waste	$2,080,000
Fed. REDI	Dec-05	Geodynamics	Habanero Project, Cooper Basin, SA	$5,000,000
Fed. REDI	Dec-05	Scopenergy	Limestone Coast Geothermal Project, SA	$3,982,855
SA PACE 2	Apr-05	Petratherm	Paralana Geothermal Project, SA	$140,000
SA PACE 2	Apr-05	Scopenergy	Limestone Coast Geothermal Project, SA	$130,000
SA PACE 2	Apr-05	Eden Energy	Witchellina Project, SA	$21,000
SA Grant	Jun-05	U of Adelaide	Induced seismicity – Cooper Basin	$50,000
SA Grant	Dec-05	Geodynamics	Cost: benefit of hot rock development	$40,000
SA PACE 3	Dec-05	Geothermal Resources	Curnamona Geothermal Project, SA	$100,000
SA PACE 3	Dec-05	Green Rock	Olympic Dam Geothermal Project, SA	$68,000
Fed. REDI	Jul-06	Geothermal Resources	Frome Geothermal Project	$2,400,000
Fed. REDI	Dec-06	Proactive Energy	Adapting supercritical cycles to geothermal power application	$1,224,250
SA PACE 4	Dec-06	Torrens Energy	Heatflow Exploration in Adelaide Geosyncline	$100,000

Grant	Date	Recipient	Project	A$ Amount
SA PACE 4	Dec-06	Eden Energy	Renmark Geothermal Project, SA	$100,000
SA PACE 4	Dec-06	Geodynamics	High Temperature Borehole Image logging of Habanero 3, Cooper Basin, SA	$100,000
Fed. REDI	Feb-07	Petratherm Ltd	Paralana Geothermal Project, SA	$5,000,000
SA Grant	May-07	U of Adelaide	Induced seismicity protocols – SA	$50,000
SA Grant	Jun-07	U of Adelaide	Research posed by the AGEG	$250,000
Fed. REDI	Aug-07	Torrens Energy	3D modelling of hot rock resources, SA	$3,000,000
Qld Grant	Oct-07	U of Queensland	Geothermal energy research	$15,000,000
SA PACE	Feb-08	Petratherm	Shear wave splitting for Hot Rock exploration	$100,000
SA PACE	Feb-08	Torrens Energy	2D seismic on a Hot Rock play in the Adelaide Plains	$100,000
REDI	2008	KUTh	Tamar Conductivity Zone (TCZ)	$1,800,000
WA Grant	Mar-08	U of WA	WA Geothermal Centre of Excellence	$2,300,000
SA Grant	Jun-07	U of Adelaide	Research posed by the AGEG	$250,000
SA Grant	Jun-08	U of Adelaide	Research posed by the AGEG	$250,000
Fed. Renewable Energy Fund	Announced	TBD	Geothermal Drilling Program	$50,000,000

AUSTRALIAN HOT ROCK PLAYS

HR plays have a heat source, insulating strata to trap and store heat, and permeable fabrics that combine to provide at least enough heat transfer to be useful. The Australian continent has extensive sources of prospective radiogenic heat trapped by and stored within overlying sedimentary rock units. Included are the Proterozoic granitoids in the Cooper Basin that have been described as the hottest amagmatic rocks in the world. The Cooper Basin HR play is part of a more extensive prospective region that exhibits an anomalously high mean heat flow of 92±10 μWm^{-2} which is almost twice the global average for continents of 51–54 μWm^{-2} (Neumann et al., 2000). Elsewhere in Australia, radiogenic iron oxides, hydrothermal systems, high-heat producing granites of Archaean and Palaeozoic age and hot depocentres associated with recent volcanic activity also constitute attractive source rocks for geothermal energy resources

The map in Figure 1 shows estimated temperatures at a depth of 5 km; the areas shown in orange and red represent temperatures in excess of 175 °C, and exploration now underway is expected to add to the inferred extent of prospective HR plays.

In addition to having some of the hottest amagmatic geothermal source rocks in the world, Australia's convergence with Indonesia on a plate scale gives rise to stress fields manifested by extensive horizontal fracture fabrics. Examples include the water-saturated Hot Fractured Rocks (HFR) found at ~ 4km in Geodynamics' Habanero wells in the Cooper Basin. These HFR reservoirs are susceptible to hydraulic fracture stimulation to enhance and extend connectivity and form EGS.

The threshold for economic heat exchange efficiency defines the top of a geothermal play and can be characterised as the minimum flow of a useable level of heat energy.

The practical maximum depth-range for HR targets is limited by drilling and completion technologies (defining a base). It is worth noting the current depth record for oil well drilling is 10,421 m below sea level in a water depth of 1,067 m.

HR reservoirs within the lower reaches of insulating cover in the Paralana area in South Australia have been called Heat Exchange Within Insulator (HEWI) targets. Stress conditions favoring the development of near-horizontal reservoirs are likely to exist at many of the Australian EGS project areas.

HR sandstone reservoirs in the depocentres of the Eromanga, Otway and Gippsland Basins have been referred to as Hot Saline Aquifer (HSA) targets. If enhanced with reservoir stimulation methods, both HEWI and HSA are also forms of EGS.

In general, HFR and HEWI plays are being explored for at depths below 3.5 kms of insulating cover. Australian HSA plays now being investigated tend to lower temperature resources at shallower depths as compared to current HFR and HEWI targets.

High permeability and somewhat lower temperature targets are also widespread in Australia. The world's largest artesian groundwater basin, underlying about 22 % of the Australian continental landmass, is the Great Artesian Basin. Groundwater comes out at wellheads at temperatures ranging from 30–100 °C. The very permeable sedimentary aquifers in the West Australian Perth Basin are expected to be an excellent source of high flow rates of water at temperatures of around 80 °C and these moderately hot waters can to used for MW-scale direct heat applications to generate power for local use (Regenauer-Lieb et al., 2007, 2008).

PROSPECTIVE MATERIALITY OF AUSTRALIA'S HOT ROCK RESOURCES

As one measure of materiality, converting just 1 % of the Australia's estimated crustal energy between the depths to 150 °C and 5 km (190 million PJ) to electricity would supply around 26,000 years of Australia's primary power usage in 2005, and that neither takes into account the renewable characteristics of hot rocks, nor the resource below 5,000 m.

The potential materiality of Hot Rock project areas remains to be fully demonstrated but proponents of geothermal energy development believe there is sufficient information to conclude:

- Hot, wet, fractured granites in Geodynamics' South Australian Cooper Basin geothermal tenements (covering 1,983 km^2) represent a potentially accessible *in-situ* resource of 282,150 PJ in 10 GRL's and 115,200 PJ in GEL99 that may in future be able to support > 10,000 MW of emissions-free power generation (note: this estimate does not comply with the Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves ~ The Geothermal Reporting Code ~ 2008 Edition);
- Heat exchange within insulator (HEWI) hot rocks covering just 20 km^2 area by 1 km thick with an average temperature of 200 °C in Petratherm's Paralana project area in the northern Flinders Range in South Australia could support the generation of 520 MW of electricity to the National Electricity Market over 25 years; and
- Hot wet sandstones in Panax's Limestone Coast Geothermal Project in the South Australian Otway Basin geothermal tenements (covering 2,674 km^2) represent a possibly accessible generating potential in excess of 1,500 MW_e.

THE AUSTRALIAN GEOTHERMAL ENERGY GROUP

The Australian Geothermal Energy Group (AGEG) is Australia's whole-of-sector representative body for the organisations with an interest in the advancement of the use of geothermal energy. AGEG members:

- are representatives of companies, government agencies, research organisations and non-profit organisations with an interest in the advancement of geothermal energy development; and
- cooperate to attain a shared aspiration, which is to realise the vision of geothermal resources providing the lowest cost emissions-free renewable base load energy for centuries to come.

The AGEG's purposes and terms of reference are to:

- provide support for Australia's membership in the IEA's Geothermal Implementing Agreement (GIA) and facilitate engagement with the international geothermal community.
- foster the commercialisation of Australia's geothermal energy resources by:
  - cooperating in research and studies to advance geothermal exploration, proof-of-concept, demonstration and development projects;
  - cooperating to develop, collect, improve and disseminate geothermal-related information;
  - identifying opportunities to advance geothermal energy projects at maximum pace and minimum cost; and
  - disseminating information on geothermal energy to decision makers, financiers, researchers and the general public e.g. outreach

Many of the company members of the AGEG are also members of the Australian Geothermal Energy Association (AGEA) – the peak representative Directorate for Australian geothermal industry companies.

To 20 July 2008, the AGEG has 75 member organisations (57 companies, 10 Universities and lead agencies (for geothermal) within the Australian, State and NT governments. The AGEG's current TIGs are described in Table 2.

Table 2. Australian Geothermal Energy Group's Technical Interest Groups.

	TIG TOPICS	**Purpose:** **Share Information to Learn While Doing with Maximum Effect & Efficiency**
1	Land Access Protocols (induced seismicity, emissions, native title, etc)	Management of environmental concerns and potential impacts of geothermal energy and devises protocols to avoid or minimise impacts.
2	Reserves and Resource (Definitions)	Align with similar International forums.
3	Policy Issues Industry Forum (AGEA) Whole-of-Sector Forum (AGEG)	Industry advice to Governments. Formative whole-of-sector discussion of policy. Submission to Garnaut Review on behalf of the Geothermal Sector (AGEG 2008c).
4*	Engineered Geothermal Systems	Investigate technologies for enhancing geothermal reservoirs for commercial heat extraction.
5	Interconnection with Markets Industry Forum (AGEA) Whole-of-Sector Forum (AGEG)	Transmission, distribution, network, NEM issues. Industry advice to Government.
6*	Geothermal Power Generation	Develop scenarios as a basis for comparison of cycles, plant performance and availability, economics and environmental impact and mitigation. The output would be a database and guidelines of best practice.
7*	Direct Use of Geothermal Energy (including geothermal heat pumps)	Direct use for heating and cooling, with emphasis on improving implementation, reducing costs and enhancing use.
8	Outreach (Including Website)	Create informed public through accessible information. Provide educational kits for media, K-12 and university education.
9	Data management	Database design, contents and ongoing enhancements.
10*	Wellbore operations	Cover drilling, casing, logging, fracture stimulation, testing, etc.

* Parallels an IEA R&D Annex

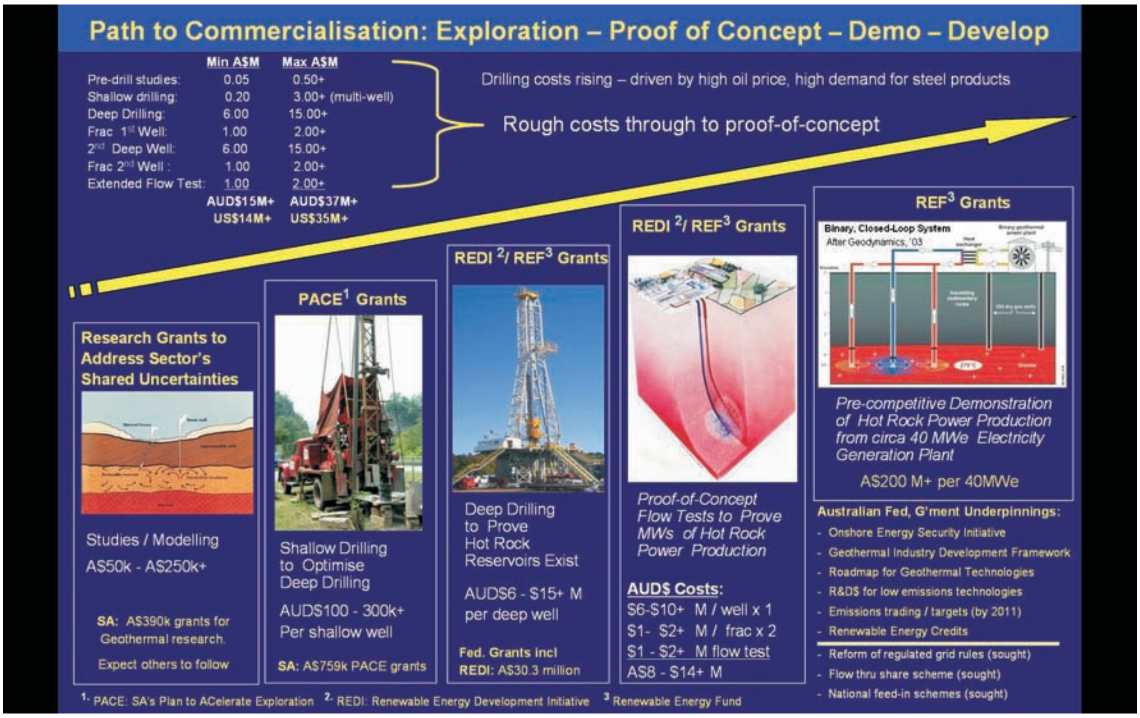

Figure 4. The life-cycle of Hot Rock Engineered Geothermal Systems projects and Federal initiatives that underpin such projects.

THE LIFE CYCLE OF HOT ROCK PROJECTS

The path to developing a HR-EGS supply of power entails HR play selection; licensing; reconnaissance exploration (research), including geophysical surveys and shallow drilling;

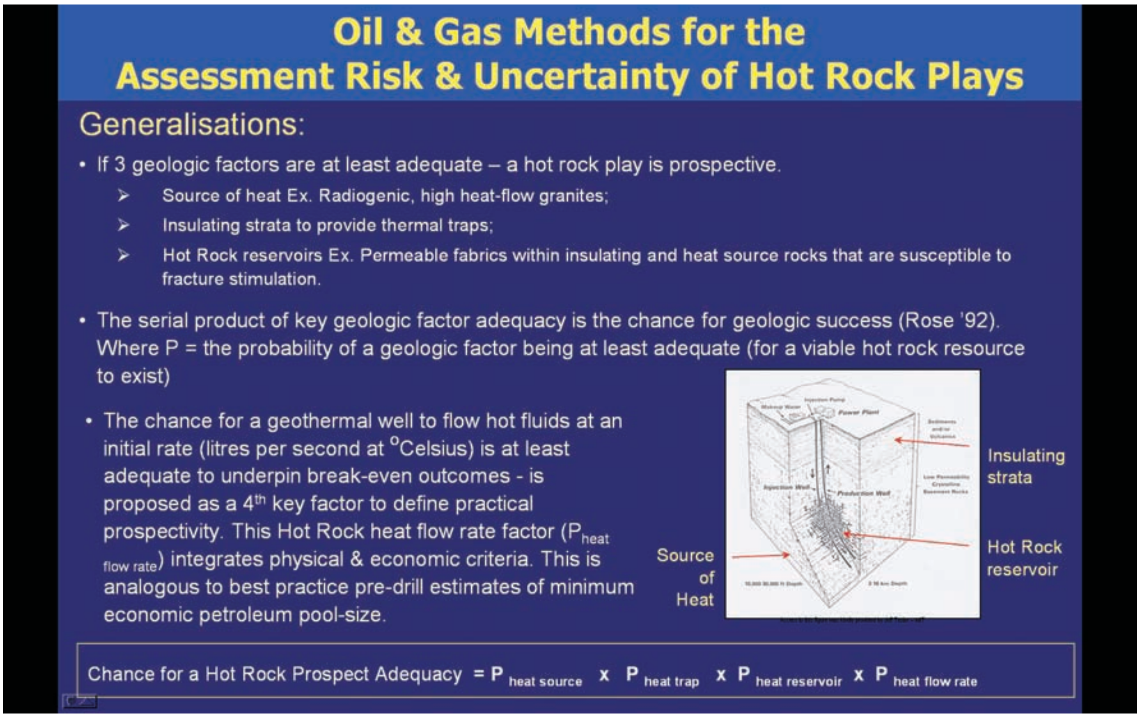

Figure 5. Risk and uncertainty assessment for hot rock plays.

proof-of-concept deep drilling; fracture stimulation and flow testing; pre-competitive demonstration of power generation; and up-scaling to a marketable power supply. Figure 4 illustrates that the cost of proving HR-EGS closed-loop production of prospective geothermal energy from one production and one injector wells is expected to be $15 to $37+ million. Also shown is the array of Australian Government initiatives underpinning such investment in addition to the grants listed in Table 1.

GEOLOGIC RISK ASSESSMENT OF HOT ROCK PLAYS

Standard investment management methods including the aggregation of risk-weighted (expected) net present values will inevitably be applied to steward funding for efficient and effective exploration, proof-of-concept and pre-competitive demonstration projects.

Goldstein et al. (2008) proposed a portfolio approach to foster efficient investment in HR-EGS plays. The methodology posed enables consistent estimates of the costs and benefits of precompetitive learning-while-doing (cost curves) through research (drilling), proof-of-concept (stimulating and flow testing) and demonstration (pre-competitive power generation) phases of HR-EGS projects. The methods are as defined by Capen (1992) and Rose (1992) for dealing with exploration uncertainties and estimating the chance of economic success in petroleum exploration. These methods are well recognised as world's best practice for petroleum exploration, and have proven to be effective in managing geologic uncertainties in very competitive oil and gas markets. The process for assessing a single HR-EGS play is described in Figure 5.

KEY TAKE-AWAYS

Australia's comparative advantages for HR-EGS development are:

- Extensive radiogenic basement (heat source) at drillable depths below insulating cover;
- Plate scale compression creating extensive horizontally fractured HR that are attractive EGS candidates;
- Receptive investors experienced in buying shares in green-field exploration projects;
- Bi-partisan political support leading to government programs and policies that support meritorious proof-of-concept, demonstration, demonstration and deployment of low emissions and renewable energy technologies to sustain Australia's diverse portfolio of safe, secure, socially accepted and competitively priced energy supplies.

REFERENCES

AGEG 2008a. Code for Geothermal Resources and Reserves Reporting.

AGEG 2008b. Vision, Terms of Reference, Technical Interest Groups and Membership of the Australian Geothermal Energy Group. See: http://www.pir.sa.gov.au/geothermal/ageg

AGEG 2008c. The role of geothermal energy in the future in Australia, submission to the Garnaut review, See: http://www.pir.sa.gov.au/__data/assets/pdf_file/0010/71389/AGEG_Submission_Garnaut_4April08.pdf

Capen, E. C., 1992. Dealing with exploration uncertainties, *in:* Steinmetz, R., (*ed.*), *The Business of Petroleum Exploration. AAPG Treatise of Petroleum Geology—Handbook of Petroleum Exploration, AAPG, Tulsa*, Chapter **5**, 29-61.

The Economist, 19 June 2008, article titled, Beneath your feet.

ESSA (Energy Supply Association of Australia), 2006. Energy and emissions study – Stage 2, Emissions Targets and Least Cost, Generation Options. Download from: http://www.nsw.gov.au/energy/Docs/submissions/ESAAAttachment3.pdf

Goldstein, B.A, Hill, A.J., Budd, A.R., Holgate, F.L. and Malavazos, M., 2008. Hot Rocks in Australia – National Outlook, *Proceedings, Thirty-Third Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California*, January 28-30, 2008, SGP-TR-185

Klaus Regenauer-Lieb, 2008. personal communication.

Neumann, N., Sandiford, M. and Foden, J. 2000, Regional geochemistry and continental heat flow; implications for the origin of the South Australian heat flow anomaly. *Earth and Planetary Science Letters*, **183**, 107-120.

Regenauer-Lieb, K. and Horowitz, F.G., 2007, The Perth Basin Geothermal Opportunity in Petroleum Western Australia, April 2007 pp 42-44.

Regenauer-Lieb, K., Chua, H. T., Wang, X., Horowitz, F.G. and Wellmann, F.J. 2008, Direct-Heat Use for Australia, Extended abstract in AGEA-AGEG Australian Geothermal Energy Conference proceedings.

Rose, P.R., 1992. Chance of success and its use in petroleum exploration. *In:* Steinmetz, R., (*ed.*), *The Business of Petroleum Exploration. AAPG Treatise of Petroleum Geology—Handbook of Petroleum Exploration, AAPG, Tulsa*, Chapter **7**, 71–86.

Somerville, M., Wyborn, D., Chopra, P.N., Rahmann, S.S., Estrella, D. and van der Muellen, T., 1994. Hot Dry Rocks Feasibility Study, *Australian Energy Research and Development Corporation* Report **94/243**, pp 133.