Queensland Geothermal Energy Centre of Excellence

ANNUAL REPORT 2009 - 2010

The University of Queensland

Queensland Government

Funded from the Renewable Energy Fund and the Climate Change Fund established as part of ClimateSmart 2050
Mission

To work with equipment manufacturers, geothermal companies, geothermal power station designers and consultants to research, develop and demonstrate new technologies for the geothermal industry and to collaborate with the Queensland State Government and other stakeholders to develop and promote geothermal energy in Queensland and in Australia.

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Established in September 2007 by a $15 million grant from the Queensland State Government from its Renewable Energy Development Fund and a $3.3 million contribution of expertise and other resources from The University of Queensland, the Queensland Geothermal Energy Centre of Excellence (QGECE) is already having an impact on the development of an Australian geothermal energy sector early in its life.

The QGECE is actively pursuing its mission to hasten the development of the industry through a research and development program which is focussing on scientific and technological innovations which will increase geothermal power plant efficiencies (turbines, heat exchanges and cooling towers), particularly in hot, arid regions; address long distance power transmission issues; and, increase understanding of geothermal reservoir geochemistry to enhance resource identification. To support the program, strong national and international scientific, research and technology commercialisation collaborations have already been established.

The Queensland State Government remains strongly committed to the development of this energy source as is evidenced through its commitment of $5 million to the Coastal Geothermal Energy initiative under the direction of the Geological Survey of Queensland and through the commitment of up to $4.3 million to Ergon to upgrade the only operating geothermal power station in Australia at Birdsville. The QGECE is actively associated with both of these projects. The recent passage of the Geothermal Energy Bill 2010, with accompanying Regulations to be forthcoming next year should provide added incentive and certainty for exploration and investment in the development of the geothermal resources of Queensland. The QGECE is involved in discussions aimed at identifying the role that it can play in encouraging such investment through increased knowledge of the resource and improved efficiencies in geothermal energy power conversion.

I would like to express my appreciation to my fellow members of the Board for their support and guidance to the QGECE Director, Professor Hal Gurgenci, and the staff of the Centre through the year. Special thanks is owed to the invited members from industry and government who serve on the QGECE’s Technical Advisory Committees established to provide specialist advice and critique of the research and development programs of the Centre.

Professor Trevor Grigg
Executive Summary

It has been a great first year for the Queensland Geothermal Energy Centre of Excellence, during which we have achieved the following:

• We formed a strong Advisory Board with very senior appointments bringing in substantive expertise to provide advice to the Centre in geothermal energy technology and industry issues, research commercialisation and research management.

• Our research strategies were strongly endorsed by its industry, academic and government stakeholders in the first Stakeholders Workshop held in March 2010. The Workshop had an impressive turn-out of 70 people representing eleven geothermal energy companies, two industry associations, seven service/consulting companies, three universities and research institutions, and two state governments. Their feedback was discussed at the QGECE Board Strategy Workshop in June 2010 and helped the Centre establish our future directions and current research portfolio.

• Technical Advisory Committees of industry experts were established for each one of our research areas. The aim of a Technical Advisory Committee is to provide ongoing detailed technical scrutiny of objectives and progress in its focus area. These committees held their inaugural meetings in June – July 2010 and strongly endorsed Centre research strategies. The Technical Advisory Committee membership is shown on page 22.

Another exciting development is the research collaboration agreement the Centre is signing with the US Turbine and Plant Manufacturer Verdicorp. This provides a platform to transfer the outputs of the Centre research to the geothermal industry in the area of supercritical turbines and cycles. An early manifestation of this collaboration will be the portable test plant expected to be commissioned in 2011. This will be a portable facility capable of generating 75 kWe from geothermal or waste heat sources. It will provide QGECE with a large-scale outdoors test facility that will enable the development and testing of sub- and transcritical power cycles, turbines and control systems.

Another highlight of last year was the signing of a Memorandum of Understanding (MoU) with the German Research Centre for Geosciences (GFZ) to work together to increase our understanding of heat produced in the Earth and the dependency of heat flow anomalies on radiogenic heat generation in rocks of the upper Earth crust. The QGECE and the GFZ will be working towards a joint Workshop to be held in Australia next year.

There are many other significant achievements highlighted in the reports from individual programs on the following pages including the establishment of out high-pressure laboratory to test small supercritical turbines; the heat exchanger laboratory where we started testing metal foams for heat transfer enhancement and scaled cooling towers; and collaboration with Power Link towards simulating the likely scenarios for connecting remote geothermal power to the Queensland power grid.
Advisory Board

The Queensland Geothermal Energy Centre of Excellence has an Advisory Board whose role is to set and monitor the strategic direction of the Centre and to monitor its performance. The following were the members of the Advisory Board as of 30 June 2010.

Professor Trevor Grigg  
- Independent Chair

Mr Greg Nielsen  
Office of Clean Energy,  
Department of Employment, Economic Development & Innovation

Professor Max Lu  
Office of the Vice-Chancellor,  
The University of Queensland

Professor Graham Schaffer  
Faculty of Engineering, Architecture, Information Technology & Electrical Engineering, The University of Queensland

Dr Richard Suttill  
Origin Energy

Dr Adrian Williams  
Buddina Projects

Mr Greg Withers  
Office of Climate Change,  
Department of Environment & Resource Management

Professor Halim Gurgenci  
- Centre Director  
School of Mechanical & Mining Engineering,  
The University of Queensland
Research

Reservoir Program

Understanding Queensland Geothermal Resources and Developing New for Radiogenic Granite Exploration

<table>
<thead>
<tr>
<th>Program leader</th>
<th>Dr Tonguc Uysal</th>
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<tbody>
<tr>
<td>Research team</td>
<td>Ms Victoria Marshall, QGECE PhD Student</td>
</tr>
<tr>
<td></td>
<td>Mr Craig McClarren, QGECE PhD Student</td>
</tr>
<tr>
<td></td>
<td>Mr Alexander Middleton, QGECE PhD Student</td>
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<tr>
<td></td>
<td>Mr Jacobus van Zyl, QGECE PhD Student</td>
</tr>
<tr>
<td></td>
<td>Mr Behnam Talebi, Part-time QGECE PhD Student</td>
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<tr>
<td></td>
<td>Dr Massimo Gasparon, Associate Professor</td>
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This Program is aiming to answer the following questions:

- What makes granite “hot”?
- What are the origins of the granites in Queensland?
- Why do some granites have more heat-producing elements than others?
- What caused the generation of heat-producing granites in Queensland?
- How can we locate such granites without drilling deep exploration holes?

We are currently producing a comprehensive geochemical dataset including major/trace element and isotope geochemistry, and radiometric age dating of granites and hydrothermal alteration minerals in selected areas in Queensland, WA and north-central SA (Figures 1-3); studying trace element and noble gas geochemistry of near-surface water samples from geothermal potential areas in Queensland; evaluating geochemical, mineralogical and geochronological data in relation to regional geology; and investigating the Cooper Basin hosting some of the hottest granites in the world, a superb natural laboratory for understanding of radiogenic heat enrichment process.

In a separate project, we collaborate with others to examine sub-surface CO₂ and their mineral precipitates from existing geothermal sites in Turkey with naturally elevated CO₂ concentrations to develop an understanding of CO₂ accumulation and degassing in tectonically active regimes and natural geothermal systems driven by CO₂-rich fluids. This will help us model artificial CO₂ injection in Australian hot sedimentary aquifers to enhance geothermal reservoir performance.

High Heat Producing Granites

To better understand the origin, tectonic setting and generation of high heat producing granites (HHPG) on the Australian continent and provide target criteria for the exploration of granite-hosted Enhanced Geothermal Systems (EGS), the QGECE is investigating European analogues. There are three areas of long-standing interest for EGS in Europe - Cornwall, UK; Soultz-sous-Forêts, France; and Erzgebirge, Germany. As shown in Table 1, they have higher than average heat flow (at surface and depth), and higher than average upper crustal levels of radioactive elements Uranium (U), Thorium (Th) and Potassium (K).
We have identified many similarities between European and Australian HHPG, while noting differences (see the summary in Table 1). An agreement has been signed with the Deutsches GeoForschungsZentrum (GFZ) to collaborate in this area.

Table 1: Compositions of targeted HHPG for EGS

<table>
<thead>
<tr>
<th>EGS TARGETED GRANITES</th>
<th>AGE (Ma)</th>
<th>LITHOLOGY</th>
<th>SiO2 (wt%)</th>
<th>K2O (wt%)</th>
<th>U (ppm)</th>
<th>Th (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carnmenellis, Cornwall, UK</td>
<td>295-270</td>
<td>Mega-crystic biotite and two-mica granites</td>
<td>70-76</td>
<td>4-4.3</td>
<td>4.3-35 (12.1 mean)</td>
<td>11-25 (19.3 mean)</td>
</tr>
<tr>
<td>Land’s End, Cornwall, UK</td>
<td>277-274.5</td>
<td>Early mega-crystic biotite granites, younger Li siderophyllite granites</td>
<td>66-73</td>
<td>3.5-6</td>
<td>6.9-38</td>
<td>4.4-46.2</td>
</tr>
<tr>
<td>Soultz, France</td>
<td>334-319</td>
<td>Porphyritic monzogranite</td>
<td>67-69</td>
<td>3.8-4</td>
<td>6.2-14.1</td>
<td>23-37</td>
</tr>
<tr>
<td>Erzgebirge, Germany</td>
<td>325-315</td>
<td>Transitional I-S and A Type biotite granites, two-mica granites and S and A Type Li-mica granites</td>
<td>67-77 (biotite)</td>
<td>3.8-5.4</td>
<td>9-30.9</td>
<td>10.4-34.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>71-76 (two-mica)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>73-76 (Li-mica)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooper Basin, Australia</td>
<td>298-323</td>
<td>Coarse grained two feldspar biotite granite moderately weathered</td>
<td>11 - 27</td>
<td>17 - 117</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Continental Crust</td>
<td>66</td>
<td>3.4</td>
<td>2.7</td>
<td>10.7</td>
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</tbody>
</table>

Alteration Mineralogy

The alteration mineralogy is one of the widely used techniques when performing exploration for potential ore deposits. However, this method has not yet been deployed for the acquisition of enhanced geothermal systems. In this project, alteration mineralogy of HHPG, particularly with the emphasis on trace element and stable isotope geochemistry is investigated. A successful outcome may revolutionise geothermal exploration techniques.

The principle areas of interest for sampling are the Cooper Basin, Galilee Basin, Innot Hot Springs region, Hodgkinson Province, Styx Basin, Maryborough Basin and North d’Aguillar Block, Wandilla Province. These research targets have been based on granitoidal emplacement during the Hunter-Bowen Supercycle and are Late Devonian to Triassic in age.

The fluid history for Cooper Basin is being constructed to better understand the nature of the geothermal resource there.

Core analysis results

Cores taken from the granite and overlying sediments in the Cooper Basin show varying degrees of alteration, with a range of incompatible element enrichment, such as U and Th. The highly altered zones have a predominant greisen-style sericite (illite) and re-precipitated quartz assemblage. We believe that this alteration may well have caused the localised enrichment in radiogenic element-bearing minerals such as illite, K-feldspar, and particularly accessory minerals (thorite etc.).

The fluid history of the Cooper Basin can be deduced from crystallinity and stable isotope analyses of the illite. Illite crystallinity is a useful indicator of the temperature gradient in active geothermal systems and for locating fossil hydrothermal systems associated with ore deposition. Illite crystallinity is controlled by crystallisation temperature, water/rock ratio, and time available for crystallization. Better-developed crystalline illites show narrower 001 basal illite peaks and have lower IC values. Such illites were formed at higher temperatures or during prolonged heating events. Higher IC values (wider peaks), on the other hand, indicate lower crystallisation temperatures and/or rapid precipitation during hydrothermal processes. Illite crystallinities are seen to progressively increase with increasing core depth, insinuating a higher crystallisation temperature and hence hydrothermal fluid temperature at depth. The granite intersected in Jolokia and McLeod 1 seems to have experienced highest temperatures.

Figures 1, 2 and 3: UQ is one of the few universities in Australia that provides access to most of the necessary equipment and laboratory facilities. Thus much of the analytical work such as ICP-MS for trace element analysis, ICP-OS for major element analysis and TIMS for radiogenic isotope and geochronological studies is being carried out within the UQ campus.

Figure 4: Radon in Queensland borehole waters
**Water geochemistry**

Water samples have been collected over a large area of eastern Queensland, extending from Stanthorpe in the south to southern Cape York in the north. Sample geochemistry has been analysed by ICP-MS and by ICP-OES, the results of which are still presently being processed. Radon concentrations were measured in the field and that data is presented in Figure 4. At present, we have collected filtered and unfiltered water samples, and radon samples, from approximately forty sites and will continue to collect more from central and western Queensland in the coming months. We will soon be acquiring an on-site helium detector and we are currently formulating plans to collect helium samples for future in-lab isotope analysis. Both radon and helium are products of heat-producing U/Th decay series. Higher concentrations of these noble gases in the ground water indicate degassing from a U- and Th-rich source. In Figure 4, red and purple colours show areas with relatively high radon contents. These are particularly Hodgkinson Province near Cairns, Yarrol Province near Rockhampton and Stanthorpe granites.

**Cooper Basin Impact**

We found evidence of a major asteroid impact about 300 million years by examining the quartz crystals from rocks underlying the Cooper Basin (see Figure 5). The presence of signatures of shock metamorphism within the altered top basement zone suggests extensive hydrothermal activity triggered by a large asteroid impact, as has been documented in large impact structures. Based on association of hydrothermal alteration with impact effects, the extent of the impact aureole may be outlined by the altered zone, which covers an area larger than 10,000 km² in the Cooper Basin. The evidence for impact has potential implications for the origin of K-U-Th enrichment in the basement.

Figure 5: Planar deformation features (PDF) in quartz deflected along a post-impact fracture, McLoed-1 3745m

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Work with Geological Surveys Queensland to explore what may be a major geothermal source in the basement of Galilee basin

**Drummond Basin trace element geochemistry**

Igneous rocks of the Drummond Basin occur as the basement of the adjacent Galilee Basin of Upper Carboniferous to Middle Triassic age. The late Permian coal deposits and carbonaceous pelitic rocks in the Galilee Basin are ideal heat insulating sediments that would store the radioactive heat generation in the basement. The Drummond Basin hydrothermal silica deposits are unique in having anomalously enriched incompatible element (Cs, Li, Be, W, U, Th and REE) concentrations in comparison to hydrothermal quartz veins from various granitic-pegmatitic systems elsewhere. In support of these arguments, temperatures of about 80°C at 1000 m were observed in coal seam gas drilling boreholes in the Galilee Basin (pers. commun. with A. Falkner - AGL) that indicate high heat flux from the basement. Furthermore, the vitrinite reflectance data obtained from core samples taken in past mineral exploration can be correlated with the geological maximum temperatures. In Galilee basin, these correlations consistently result in high temperature gradients (75 - 100°C/km). Work continues in this area in a joint project between the QGECE and GSQ.
# Power Conversion Program

*Generating More Power from a Geothermal Reservoir*

<table>
<thead>
<tr>
<th>Program leader</th>
<th>Dr Peter Jacobs</th>
</tr>
</thead>
</table>
| Research team        | Dr Andrew Rowland, Research Scientist  
|                      | Dr Emilie Sauret, Research Scientist  
|                      | Dr Paul Petrie-Repar, Research Scientist  
|                      | Mr Hugh Russell, Research Engineer  
|                      | Mr Aleks Atrens, QGECE PhD student  
|                      | Mr Jason Czapla, QGECE PhD student  
|                      | Mr Carlos Ventura, QGECE PhD student  
|                      | Mr Rajinesh Singh, QGECE PhD student  
|                      | Mr Braden Twomey, QGECE PhD student |

Supercritical cycles and expanders will increase the power output from a given reservoir investment by up to 50%.

The overall aim of is to increase the power output from a given capital investment in a geothermal reservoir by 50%. Increased power production while maintaining similar capital investment levels leads to a proportional and direct increase in the reward from a given subsurface investment. This is equivalent to achieving a higher electricity sales price and, obviously, would have a significant effect on whether a geothermal project proposal is seen as viable.

In a conventional Rankine cycle, a significant fraction of the geothermal heat is unutilized because of the heat exchanger irreversibilities caused by the constant evaporator temperature. This can be overcome by either a cycle where evaporation occurs over varying temperature range (i.e. Kalina) or a cycle where no evaporation occurs (i.e. the supercritical cycle in Figure 6). The QGECE focus is on the latter.

To minimise parasitic losses, the turbine with the supercritical inlet is designed to exit to a subcritical pressure and the cycle fluid condenses as in a regular Rankine cycle. Transcritical cycles (condensing cycles with supercritical heaters and expanders) with suitable, dense working fluids are expected to deliver higher power production compared to conventional Rankine cycles. The principal gain comes from allowing the high-side heat exchanger to more efficiently extract heat from the hot brine stream. The expanders that we study initially are radial-inflow turbines and the cycle fluids are refrigerants such as R134a and R245fa in the short term which will serve medium-temperature (150°C) geothermal applications, working up to high-pressure carbon dioxide in the long term for high-temperature EGS power conversion (250°C).

A recent paper\(^4\) describes the benefits of a supercritical cycle in comparison against conventional geothermal binary plants. This is a relatively new area. QGECE and a US manufacturing company Verdicorp has established a partnership to develop supercritical turbines and supercritical cycle equipment for geothermal, solar thermal and waste heat power generation applications and new cycle fluids and fluid mixtures suitable for supercritical cycles. We are expecting a small (<5 kW) laboratory prototype in 2011 and a relatively larger (100 kW) unit in 2013 and aiming a field demonstration at 1-MWe scale after that.

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Our activities fall into two broad categories: (1) analytical and computational modelling to enable the evaluation of technical concepts; and (2) experimental studies to prove the concepts via demonstration. The experimental work also anchors the analytic and computational work, allowing us to calibrate those modelling tools with reality. A high-pressure power plant test loop is being built to test supercritical expanders being designed and built by the QGECE.

**Analytical Studies**

**Cycle and Working Fluid Analysis**

To set the context for the high-pressure loop design, a study of available fluids was made. This study considered a range of temperatures for the various geothermal resources and a selection of sub-critical and transcritical cycle options.

For the temperatures limited to 150°C, R134a and R245fa transcritical cycles look promising. Figure 6 shows the transcritical R134a on a T-S diagram. Figure 7 shows the flow sheet for the implementation of this cycle in our laboratory. At higher temperatures, e.g. 250°C, a transcritical CO2 cycles offers the optimal solution provided there is access to a cooling medium at below 30°C to condense the CO2.

**Turbine Design and Analysis**

Licences for the software packages RITAL and AXCENT (from Concepts NREC) have been purchased to aid in the design of radial-inflow turbines. These are sophisticated packages and require expert users so a significant effort has been expended on getting some of the group familiar with it. We are now able to do preliminary design and CFD analysis of proposed machines and are presently learning to export the design data for further analysis and for manufacture of a trial rotor. Figure 8 shows one of the geometries considered in this project.
To complement the use of commercial codes we are continuing the development of our in-house code Eilmer3 as a flow solver suitable for turbomachinery flows. A flow solver capable of handling fully three-dimensional geometries and complex equations of state will be an important tool in analysing flow losses in dense-gas turbines. The work of including body-force terms for a rotating frame of reference and the implementation of a “mixing plane” boundary between stator and rotor inlet has been done and the results presented at the ECCOMAS CFD conference mid-year. Recent efforts have focused on the importing and exporting of meshes so that we could make use of the RITAL/AXCENT initial designs.

Figure 8: Model of Stator Blades and Turbine Rotor

Figure 9: Rotor and Stator Blades with Mesh for Computational Analysis

A range of commercial and in-house turbine design and CFD software give us the ability to produce high-fidelity simulations of industrial turbines under design and off-design conditions.

It has been difficult to find standard test cases for radial turbines in order to calibrate our turbine flow analysis. Initially we have made use of a NASA design from the 1960s, however, the documentation for the NASA turbine is missing some important details. Present efforts have refocussed on another small, high-pressure turbine designed through a US Army program for small power applications. The three-dimensional geometry has been recreated using RITAL and AXCENT and the flow analysis capability of the PushButtonCFD component of the AXCENT software package is being explored presently. A comparison between this software, Ansys-CFX, Fluent and Eilmer3 is also being made using the experimental results as the baseline.

**Experimental Studies**

In the QGECE laboratory on the UQ St Lucia campus, two small-scale cycle rigs are being built. The first is a low-pressure loop with air as the working fluid and a turbocharger as the expander. On its own, it will become the test bed for a PhD thesis on control. This thesis will investigate techniques such as predictive control of components such as the compressor, turbine and bypass valves and of the integrated loop. Optimal control of the power loop in the presence of changing conditions is important for both the safety of lab-scale experiments and for achieving adequate performance of the field demonstration units.
The second loop being developed in the QGECE St Lucia laboratory is a dense-fluid loop with R134a as the working fluid (Figure 10). It will become the initial test bed for dense-fluid expanders and be our entry into transcritical cycles. Presently a scroll expander is in place but in early 2011, we expect to have a small impulse turbine of our own design and construction.

As part of the development of our laboratory facilities, we have been building some custom instrumentation and control devices. These include analog sensors for temperature, pressure and speed with microcontroller-based node boards. The node boards are networked to supervisory computer via RS485 with MODBUS protocol. Although this network has low bandwidth, it integrates nicely with the variable-speed motor control for our compressors and the control valves embedded in the loops.

Successful outcome of the above projects will produce new expanders for transcritical cycles capable of extracting significantly more power from the same geothermal brine stream. We will be collaborating with the US turbine manufacturer Verdicorp to transform the research outcomes to commercial equipment. As part of this collaboration, we are planning to have an experimental rig in mid 2011 with a capacity of 75-100 kWe. The first implementation will use conventional organic Rankine cycle but the rig will have the high-pressure capability to test supercritical turbines to be developed by the QGECE in the future.
Heat Exchangers Program

Advanced Heat Exchanger Technologies and Natural Draft Dry Cooling Towers

Program leader  Dr Kamel Hooman
Research team  Dr Zhiqiang Guan, Research Scientist
Dr Katsuyoshi Tanimizu, Research Scientist (until June 2010)
Mr Ampon Chumpia, QGECE PhD student
Mr Mehryar Sakhai, QGECE PhD student
Mr Zheng Zou, QGECE PhD student
Mr Mostafa Odabaee, QGECE PhD student
Mr Yuanshen Lu, QGECE PhD student

Adoption of natural draft dry cooling towers will increase the net power production by up to 15% in Australian geothermal plants with air-cooled condensers.

Based on a cycle efficiency of 15%, a 50-MWe power plant needs to have a 283-MWe heat sink. To dispose of this heat using a wet cooling tower consumes water at about a rate of 100 kg/s or 3.2 million tonnes per year. In many geothermal plant locations, the water is too scarce to be used so profligately and air cooling is the only option. Air-cooled heat exchangers work by forcing air across a heat exchanger array either using electrical fans or the buoyancy-driven updraft through a tall tower acting like a chimney. Both of these types are referred to as dry cooling towers even though fan-driven systems usually look like large squat boxes rather than towers.

The fan-driven systems can be built quickly and at relatively low cost but their operating costs are higher due to their higher maintenance requirements and the parasitic losses associated with running the fans. At high ambient temperatures, the air velocity needs to be increased to try to maintain the cooling load. This increases the parasitic power losses and the net plant output falls.

Natural draft dry cooling towers have low maintenance requirements and no parasitic losses but they are also much more expensive to build and they also suffer similar performance losses on hot days.

The QGECE research will focus mainly on natural draft dry cooling towers and seek improvements through the following avenues: (a) Advanced heat exchanger technologies; and (b) tower design optimisation and innovation.

Advanced Heat Exchangers

Compared to coal-fired power plants, geothermal plants have higher heat dump requirements due to their lower efficiencies. Therefore, the impact of efficient heat exchangers is higher on the plant economics.

Air-cooled condensers traditionally use finned tube bundles where the cycle fluid condenses in the tubes. There are two competing performance requirements: (a) higher heat transfer per tube; and (b) lower air pressure drop. Fins improve the heat transfer performance but at the same time lead to higher pressure drop compared to bare tubes. A good design is a successful trade-off between these two opposing effects.

Given the fact that fins can increase the pressure drop significantly, the question is to see if a more efficient heat transfer augmentation technique can be found with less pressure drop. An alternative to finned tubes is a class of porous materials called metal foams. They offer low densities and novel thermal, mechanical, electrical and acoustic properties mainly because the foams are lightweight with...
QGECE developing a new heat exchanger technology using porous metal foams. These offer substantial improvements over conventional alternatives.

Numerical and experimental studies are being conducted.

The high strength and rigidity and high surface area. These help the energy absorption and heat transfer in heat exchangers where the rate of heat transfer is extremely enhanced by conducting the heat to the material struts, which have a large accessible surface area per unit volume, along with high interaction with the fluid flowing through them. As the flow paths through the foams are interconnected the flow will be available in all areas leading to smaller and lighter heat exchangers.

Parametric models have been generated for prediction of heat transfer and pressure drop resistance of finned tube heat exchangers by reducing their complex geometry into a standard porous medium paradigm. The approach was verified against published experimental data and established correlations and serves as a basis for CFD simulations and design of the cooling tower and fan-cooled condensers.

Numerical models have been generated to simulate the flow and heat transfer characteristics for a foam-covered tube. These models are now being expanded to cover tube bundles. To validate the models, an experimental apparatus was constructed to measure heat transfer and pressure drop for foam covered tubes and tube bundles. A single foam-wrapped tube was examined first under the isothermal (similar to a condenser) conditions. Similar experiments are now being conducted on a finned-tube bundle. A very accurate pressure transducer has been purchased for this purpose. Things are ready for the next phase, which is examining the foam-wrapped tube bundles.

Figure 12: QGECE students, Chumpia and Odabaee, testing heat transfer from a foam-covered single tube placed in a cooling air stream

Figure 13: Gurgenci and Hooman with QGECE students Odabaee and Sakhaei examining the scaled laboratory model for a natural draft dry cooling tower

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Odabaee, Hooman and Gurgenci, to be published in Transport in Porous Media.
A scaled tower was built to study air flows in natural draft cooling towers at different environmental conditions.

**Design and Optimisation of Natural Draft Dry Cooling Towers**

A small scale (2m height) cooling tower (made of polycarbonate) is built in our QGECE labs and is shown in Figure 13. An electrical heater and an in-house developed temperature control box are utilized to allow for preliminary temperature measurements. The results will be applicable to real-size towers through the cooling tower scaling law by the QGECE\(^7\). The scaling law was developed and validated versus numerical and experimental data for both towers with a horizontal placement of the heat exchangers as well as Heller towers where the heat exchangers are oriented vertically.

A MATLAB program has been developed for sizing the heat exchangers and the cooling tower geometry. This has been incorporated into the QGECE power plant cycle analysis program to predict the performance of geothermal plants under varying ambient conditions.

![Figure 13: Natural draft dry cooling tower](image1)

**Figure 13:** Natural draft dry cooling tower

A MATLAB program has been developed for sizing the heat exchangers and the cooling tower geometry. This has been incorporated into the QGECE power plant cycle analysis program to predict the performance of geothermal plants under varying ambient conditions.

![Figure 14: Solar enhanced natural draft dry cooling tower](image2)

**Figure 14:** Solar enhanced natural draft dry cooling tower

![Figure 15: The type of equipment being considered for dust monitoring](image3)

**Figure 15:** The type of equipment being considered for dust monitoring

An interesting enhancement of the natural draft cooling tower technology is being considered in a PhD study that started this year. As shown in Figure 14, the proposal is to use solar heat to increase the buoyancy in the cooling tower after the air is past the heat exchangers. Preliminary studies show that the size of tower and heat exchanger can be greatly reduced by using this enhancement. Work is in progress towards parametric optimisation and cost analysis.

Concerns were raised in the March 2010 Stakeholders Workshop about the effect of dust, especially when using advanced heat exchanger technologies such as metal foams. A new project was initiated this year for long-term monitoring of environmental dust in Cooper Basin. Most dust monitoring studies in the past were limited to respirable dust with limited relevance to heat exchanger design. Total suspended particulate material will be continuously monitored in this project using self-powered stand-alone equipment (e.g. see Figure 15); the dust concentration and the size distribution will be continuously sampled over an extended period of time to record daily, seasonal and yearly variations in dust.

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Transmission program

Connecting remotely generated geothermal electricity to the national power grid

Program leader  Professor Tapan Saha
Research team  Dr Mehdi Eghbal, Research Scientist
Ms Huong Mai Nguyen, QGECE PhD student
Mr Kazi Nazmul Hasan, QGECE PhD student

The objective of this project is to investigate High Voltage DC (HVDC) and high Voltage AC (HVAC) transmission link options to interconnect expected geothermal power plants to a remotely located existing HVAC power grid. Specifically, power system stability and reliability, cost benefit, reactive power requirements and transmission loss issues of each option are investigated.

Stability and Reliability of the Power Systems

The two PhD projects address the two issues related to bringing remote generation to the grid: stability of the supply and reliability of the supply:

- System Stability – Different aspects of system stability including voltage stability and small signal stability are investigated. A comparative study on the performance of HVAC and HVDC transmission lines is in progress. The outcome of this project will be stability analysis tools useful for integrating remotely located geothermal energy sources into the Australian National Electricity Market (NEM) Grid.
- System reliability project – Reliability and cost benefit assessment of different transmission options is investigated. The outcome of the project will be a probabilistic reliability analysis tool useful for integrating geothermal energies into the NEM with volatile market situations, including uncertainties associated with the carbon price.

Figure 16: Point of collapse related to interconnection distance
The two main technologies for HVDC/HVAC conversion were reviewed and compared for their application in bringing remote geothermal generation, e.g. Cooper Basin, to the national grid on HVDC lines. Current Source Converters have been found to be superior to the Voltage Source Converter (VSC) option.

HVAC and HVDC power flow models were developed in the DIgSILENT Power Factory software environment. A simplified 14 generator South-East Australian power system was used to implement voltage and small signal stability analyses. A measure of stability is provided by the so-called Point of Collapse (PoC), which represents the overloading that can be tolerated before the power network collapses. Results of this work as shown in Figure 16 indicate that bipolar HVDC is clearly more stable than HVAC and hybrid HVDC even at short distances. Moreover, when the transmission distance is increased, the stability offered by bipolar HVDC stays constant whereas the stability of HVAC and Hybrid HVDC drops almost linearly with the transmission distance. The methodology developed in this study needs to be extended to the Australian network grid.

A parallel study is being undertaken to examine how the power system reliability is affected by different transmission options. Market simulation tool (PLEXOS) is under investigation to address the electricity market behaviour. A comparative reliability versus cost benefit analysis between HVDC and HVAC link options for connecting future geothermal power plants to the Australian electricity network will be conducted.

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8 M H Nguyen, T K Saha and M Eghbal, 2010 IEEE PES General Meeting, July 26 - 29, 2010, Minneapolis, Minnesota, USA
**Queensland Geothermal Power Deployment Costs**

An investigation is under way to estimate the cost of connecting possible geothermal energy resources to the Queensland electricity grid. Levelised cost of energy from geothermal resources at the candidate points will be calculated considering the output range of the power plants and associated uncertainties. System stability and reliability will be considered in investigating the most efficient transmission option for each scenario taking into account the optimum voltage level. PSS/E, Powerfactory and MatLab tools will be used to analyse the power system performance.

Network expansion plans of Powerlink in Queensland, specifically in Surat Basin and South Queensland are identified and will be considered in our current study. Preliminary simulations prove that compensation is crucial for long distance HVAC transmission lines to connect 500MW geothermal power plant located in Cooper Basin area to the Queensland network at Bulli area. Figure 17 illustrates transmission networks areas in Queensland. Bulli area is most likely the area for connecting future geothermal power from Innamincka. Currently active and reactive power losses calculations are being conducted using the power flow data of Queensland network.

The outputs of this study will include recommendations for the most efficient way of delivering the geothermal power to the best locations of the Australian NEM grid with optimum stability and reliability. This Program also addresses the challenging issue that not all expected geothermal power plants will become available at the same time. A multi-stage transmission expansion planning methodology will be developed to arrive at the most efficient network expansion solutions that will also deliver acceptable reliability at minimum cost.
Industry Engagement

The Centre is engaged with the industry through the following mechanisms:
- Stakeholders Workshops
- Technical Advisory Committees
- Australian Geothermal Energy Group
- Australian Geothermal Energy Association

QGECE Stakeholders Workshop, March 2010

On 17 March 2010, the Queensland Geothermal Energy Centre of Excellence (QGECE) held its first Stakeholders Workshop. The purpose of the Workshop was to present the Centre Research Program to the industry and other stakeholders; to demonstrate how the Centre is planning to add value to the development of the industry; and to form a basis for gaining industry feedback and bridging the gap between industry needs and our activities.

The attendance represented a good cross-section of the sector including:
- the geothermal industry (18 delegates from 11 companies);
- industry associations (three delegates from AGEA and Queensland Resources Council);
- service/consulting companies (13 delegates from seven companies);
- research/academic community (31 delegates from UQ, Griffith University and CSIRO); and
- government (five delegates from QLD and SA)

The feedback from the delegates was positive. High expectations were expressed and the industry was almost unanimously enthusiastic about the Centre. Most of the Centre of research was strongly supported while there were also a number of suggestions on how things could be revised and improved.

The feedback from the Stakeholders Workshop was discussed at the QGECE Board Strategy Workshop in June affecting the Centre directions and the current projects.

Mobile Plant Focus Group Meeting

Following the support given to the idea of a portable geothermal test plant at the QGECE Stakeholders Workshop, a focus group meeting was organised to seek inputs on the critical parameters for such a project. The parameters established in this meeting form the basis of the design specifications for the portable test plant described earlier in the Power Conversion section.

Technical Advisory Committee Meetings

Technical Advisory Committees were established in broad program areas. The role of a Technical Advisory Committee (TAC) is to provide advice to the Director about the conduct of the Centre in a particular research area or a research project. The members of the TAC are expected to be people with relevant expertise nominated by the Director and approved by the Board. Written minutes are kept and these Minutes are presented to the QGECE Board. The current Technical Advisory Committee membership is Table 1.
Table 2: Technical Advisory Committee Membership

<table>
<thead>
<tr>
<th>Committee Area</th>
<th>Membership</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir Geology</td>
<td>Richard Suttill, Origin Energy&lt;br&gt;Behnam Talebi, Queensland Geological Surveys&lt;br&gt;Doone Wyborn, Geodynamics&lt;br&gt;Randall Cox, DERM&lt;br&gt;David Champion, Geosciences Australia&lt;br&gt;Graeme Beardsmore, Hot Dry Rocks Pty Ltd&lt;br&gt;Scott Bryan, QUT&lt;br&gt;Tonguc Uysal, QGECE&lt;br&gt;Massimo Gasparon, QGECE</td>
</tr>
<tr>
<td>Power Conversion</td>
<td>Allan Curtis, Principal Engineer - Thermal Generation, PB&lt;br&gt;Stephen Hinchliffe, SKM&lt;br&gt;Peter Schmidt, Geodynamics (until June 2010)&lt;br&gt;Tony Roe, Geodynamics (after October 2010)&lt;br&gt;Peter Jacobs, QGECE&lt;br&gt;Kamel Hooman, QGECE&lt;br&gt;Zhiqiang Guan, QGECE</td>
</tr>
<tr>
<td>Transmission</td>
<td>Terry Miller, Manager Network Development, Powerlink Queensland&lt;br&gt;Luke Falla, Senior Engineer, Australian Energy Market Operator Ltd&lt;br&gt;Tapan Saha, QGECE&lt;br&gt;Mehdi Eghbal, QGECE</td>
</tr>
</tbody>
</table>

**Australian Geothermal Energy Group (AGEG)**

Australian Geothermal Energy Group (AGEG) is a national association of individuals and companies with interest in geothermal energy. In 2009 AGEG incorporated and subsequently became an affiliate organisation with the International Geothermal Association. QGECE is an active member of the AGEG. The QGECE Director is a member of the AGEG Executive Committee; chairs the AGEG Technical Interest Group on Power Conversion (TIG 6); and has been serving as the Chair or Co-chair for the past three Australian Geothermal Energy Conferences.

**Australian Geothermal Energy Association (AGEA)**

AGEA is the national industry association for the Australian Geothermal Energy Industry. Since its establishment in 2007, AGEA has focused on building positive relationships with the Federal and State Governments and is ensuring that geothermal energy is promoted as an important and viable solution to Australia’s future energy security and to the reduction for greenhouse gas emissions.

Australia’s leading geothermal energy companies and service providers are members of the AGEA. The Queensland Geothermal Energy Centre of Excellence is an Associate Member of the AGEA.
Education

The Centre is actively involved in providing a geothermal energy training option for undergraduate and postgraduate students at the University of Queensland.

Undergraduate programs

- Thesis Projects – Engineering students take a project course in their final year at the University of Queensland. Over ten such thesis project topics were supervised last year by Centre staff.
- Honours Thesis Projects – One Honours student at the School of Earth Sciences was supervised and supported by the Centre for the project expenses
- Visiting lectures – The Centre staff is invited to energy-related undergraduate courses to deliver lectures on geothermal energy
- Design Project – Third year mechanical engineering design students designed a natural draft dry cooling tower in 2009; and an evaporator and a single-stage impulse expander in 2010.

The above activities help the university graduate engineers and scientists with exposure to geothermal energy sector and basic understanding of the issues involving geothermal energy utilisation.

Postgraduate Students

The main involvement of the Centre in education area is post-graduate education. The current list of QGECE PhD students are given in Table 2.

Table 3: QGECE Post-graduate student list

<table>
<thead>
<tr>
<th>Student</th>
<th>Topic</th>
<th>Commencement</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Atrens</td>
<td>Supercritical CO2 Geothermal Siphon</td>
<td>Mar-08</td>
</tr>
<tr>
<td>A Chumpia</td>
<td>Metal Foam Heat Exchangers</td>
<td>Mar-10</td>
</tr>
<tr>
<td>J Czapla</td>
<td>Supercritical impulse turbine</td>
<td>Nov-09</td>
</tr>
<tr>
<td>K N Hasan</td>
<td>Power system reliability</td>
<td>Mar-10</td>
</tr>
<tr>
<td>Y Lu</td>
<td>Opportunities for improvement for dry cooling towers in geothermal plants</td>
<td>Oct-10</td>
</tr>
<tr>
<td>V Marshall</td>
<td>Queensland high heat producing granites</td>
<td>Jan-10</td>
</tr>
<tr>
<td>C McClaren</td>
<td>Queensland heat flow/geochemistry</td>
<td>Jul-09</td>
</tr>
<tr>
<td>A Middleton</td>
<td>Queensland fluid flow events</td>
<td>Jan-10</td>
</tr>
<tr>
<td>H M Nguyen</td>
<td>Power system stability</td>
<td>Mar-09</td>
</tr>
<tr>
<td>M Odabaee</td>
<td>Modelling metal foam heat exchangers</td>
<td>May-09</td>
</tr>
<tr>
<td>M Sakhaei</td>
<td>Scaled cooling tower tests in the laboratory</td>
<td>Mar-10</td>
</tr>
<tr>
<td>R Singh</td>
<td>Supercritical cycle control issues</td>
<td>May-09</td>
</tr>
<tr>
<td>B Talebi</td>
<td>Eastern Queensland Heat Flow regime and Geothermal Prospectivity</td>
<td>Feb-10</td>
</tr>
<tr>
<td>B Twomey</td>
<td>Mobile geothermal plant design/testing</td>
<td>Apr-10</td>
</tr>
<tr>
<td>C Ventura</td>
<td>Supercritical radial turbine</td>
<td>Mar-09</td>
</tr>
<tr>
<td>J van Zyl</td>
<td>Geochemistry of heat producing granites</td>
<td>May-09</td>
</tr>
<tr>
<td>Z Zou</td>
<td>Solar/Geothermal Tower Optimisation</td>
<td>Mar-10</td>
</tr>
</tbody>
</table>
Table 4 summarises the Centre performance against the Key Performance Indicators established in the Centre Agreement.

<table>
<thead>
<tr>
<th>KPI</th>
<th>Target over five years</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of post-graduate students</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>Number of competitive research grants</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Number of projects with industry funding</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Number of refereed publications</td>
<td>40</td>
<td>35</td>
</tr>
<tr>
<td>Number of research projects undertaken in Queensland</td>
<td>8</td>
<td>2</td>
</tr>
</tbody>
</table>

**List of Competitive Grants**

2. $204,000 for V Rudolph and K Hooman. Metal foam heat exchangers for dry cooling. ANLEC R&D Research Grant.
4. $202,000 for K Hooman, A novel air-cooled fuel cell system, ARC DP Grant.

**Projects with industry participation**

1. Birdsville Geothermal Plant Expansion, H Gurgenci providing advice to Ergon Energy on geothermal plant technology.
2. Supercritical turbine and cycle development with Verdicorp.

**Number of research projects undertaken in Queensland**

1. Birdsville Geothermal Plant Expansion, H Gurgenci providing advice to Ergon Energy on geothermal plant technology.
2. Supercritical turbine and cycle development with Verdicorp.
Financial Summary

The total revenue and expenditure in the following table cover the period from the beginning of the Centre (1 January 2009) until the end of the 2009/2010 Financial Year (30 June 2010).

Table 5: Revenue and Expenditure

<table>
<thead>
<tr>
<th>Total Revenue</th>
<th>$7,039,879</th>
</tr>
</thead>
<tbody>
<tr>
<td>State Government Grant</td>
<td>$7,000,000</td>
</tr>
<tr>
<td>Queensland International Fellowship</td>
<td>$26,000</td>
</tr>
<tr>
<td>US Dept of Energy Reimbursement</td>
<td>$13,879</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Expenditure</th>
<th>$2,446,765</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Conversion Program</td>
<td>$881,950</td>
</tr>
<tr>
<td>Heat Exchangers Program</td>
<td>$335,241</td>
</tr>
<tr>
<td>Reservoir Geology Program</td>
<td>$382,314</td>
</tr>
<tr>
<td>Transmission Program</td>
<td>$205,562</td>
</tr>
<tr>
<td>Management</td>
<td>$306,501</td>
</tr>
<tr>
<td>Infrastructure (lab refurbishment)</td>
<td>$335,197</td>
</tr>
</tbody>
</table>

| Carry Forward to 2009/2010              | $4,593,114 |
Publications

Refereed Journal Publications


Refereed Conference Proceedings


Other Conference Presentations


Reports

