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Coastal Geothermal Energy Initiative - an Approach to Quantifying the Geothermal Energy Potential of Queensland, Australia

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ABSTRACT

Globally, geothermal energy is utilised within active volcanic regions. The state of Queensland in Australia has few areas of recent volcanic activity, but has large volumes of identified hot granites at 3 to 5 km depth, most of which are located in the far south-west of the state, beneath the Cooper and Eromanga basins. This is potentially a vast source of thermal energy that can be tapped by Engineered Geothermal System technology for power generation purposes. However, their distance from potential markets and the existing national electricity grid, prevent economic viability of the resources in the near term.

The Queensland Government designed the Coastal Geothermal Energy Initiative program to investigate additional sources of hot rocks close to major population centres and existing infrastructure. The program targeted a variety of geological settings along the state's north and east coasts in a structured drilling and heat flow investigation program to collect new, pre-competitive geoscientific datasets for geothermal energy.

The new datasets indicate moderate to high heat flow values, between 67.0 and 113.0 mW/m^2, across the Millungera, Surat, Hillsborough and Maryborough basins. Using the newly established heat flow data, modelled temperatures of 187–240°C are estimated at 5 km depths. Monte Carlo simulations predict a cumulative total stored heat in-place of 1,280,000 PJ at 90% probability for the basins. The estimated stored heat is sufficient to generate electricity to meet the state's forecast demand over the next decade. Detailed exploration programs are required to refine geothermal energy potential across the highlighted basins.

1. INTRODUCTION

As Queensland's population and industry grow, the energy demand of the state will increase. Queensland currently has over 13,000 megawatts (MW) of installed electricity generation capacity (AEMO, 2014), and peak demand is expected to rise 3.0% per annum over the coming decade, based on the medium economic outlook (Powerlink Queensland, 2013). To meet future base-load electricity demand, there is a need for new energy sources. However, the environmental impact of any new energy source must be considered; thus, a low emissions alternative to fossil fuels would be advantageous. Geothermal energy can be used for power generation and, as such, has been identified as a potential future low emission energy resource for the State of Queensland.

Existing temperature (Gerner and Holgate, 2010) and heat flow (Hot Dry Rocks Pty Ltd, personal communication, 2011) data indicate southwest Queensland, beneath the Cooper-Eromanga basins, to have anomalously high temperature at 5 km depth and high surface heat flow (Figure 1). However, this potential is located far from existing infrastructure and energy markets, and the high cost of new infrastructure may limit the economic viability of its exploitation in the near term. Outside of this region, data density and reliability diminish, limiting the ability with which geothermal energy potential may be identified. In June 2007, the *ClimateSmart 2050 Queensland climate change strategy 2007: a low-carbon future* was released by the state government, embracing a commitment to investigate sources of hot rocks for geothermal energy close to existing transmission lines. The Coastal Geothermal Energy Initiative (CGEI) was a project that was established to undertake this investigation. The CGEI included a structured shallow drilling program and aimed to collect pre-competitive geoscientific data to redefine the State's geothermal potential resource areas through which Queensland's exploration opportunities will expand, and the reduction of risk for future explorers will be facilitated. The shallow drilling program provided a means of assessing regional-scale geothermal potential for areas with limited geothermal data coverage. The temperature and thermal conductivity data collected from the shallow drilling was used to determine heat flow which enabled temperatures to be estimated at 5 km.

2. METHODS AND RESULTS

2.1 Drilling and data collection

Potential targets were identified based on the current understanding of the geological and tectonic history of eastern and northern Queensland. These targets were considered to have the potential for hot rocks at depth, warranting further evaluation by drilling. The CGEI drilling program commenced in November 2010 and concluded in July 2012, with the successful completion of 10 boreholes to between 320–500 metres (Figure 2). Moderate to high heat producing intrusives of Proterozoic age, residual heat from Cenozoic volcanism and rifting, and younger low to moderate heat producing intrusives overlain by sedimentary basins with thick coal measures, were targeted through the drilling program (Fitzell et al., 2009; Talebi et al., 2010; O'Connor et al., 2015).

Boreholes were chipped from the surface to consolidated material, and upon reaching this level, continuous HQ coring was undertaken to total depth. Core samples of the dominant rock types, approximately 150 mm in length, were taken from the core approximately every 20 m interval, for thermal conductivity analysis, and were analysed under *in situ* moisture content. Temperature dependence of thermal conductivity data was also taken into account, following the method of Sekiguchi (1984). Each borehole was cased to total depth with PVC or VAM steel casing and the annulus grouted with cement. After completion, the boreholes were left to thermally stabilise for a minimum of six weeks before precision temperature logs were run.

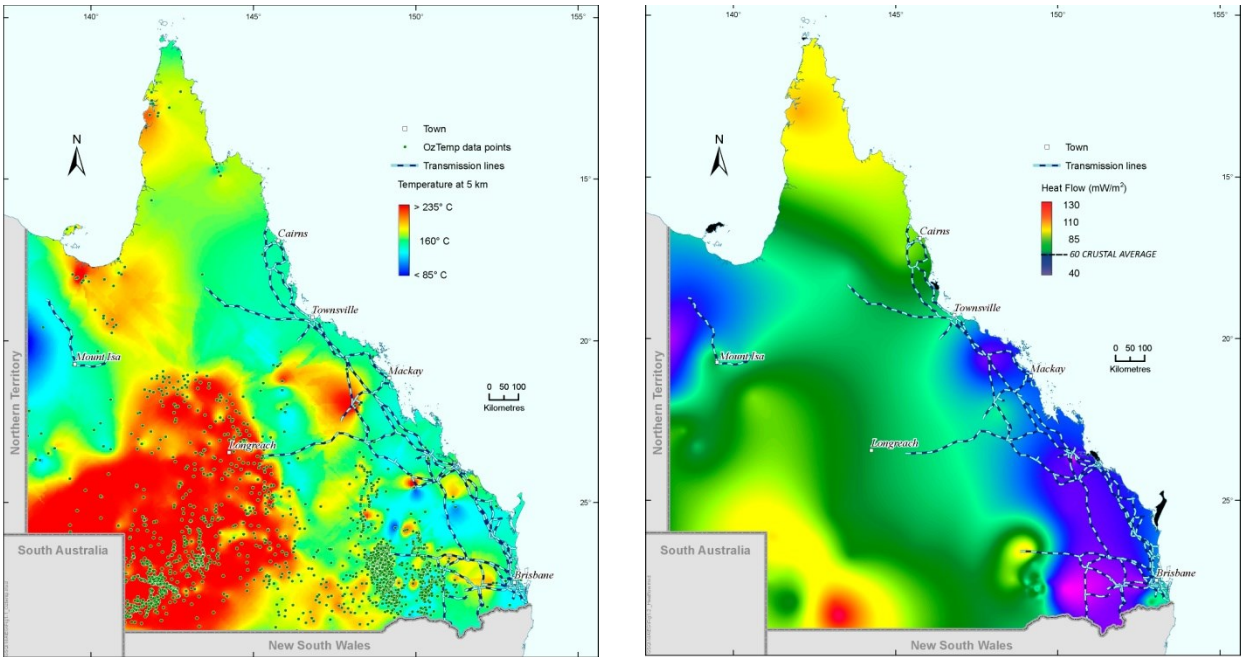


Figure 1: Temperature map at 5 km (left) and surface heat flow map (right) of Queensland.

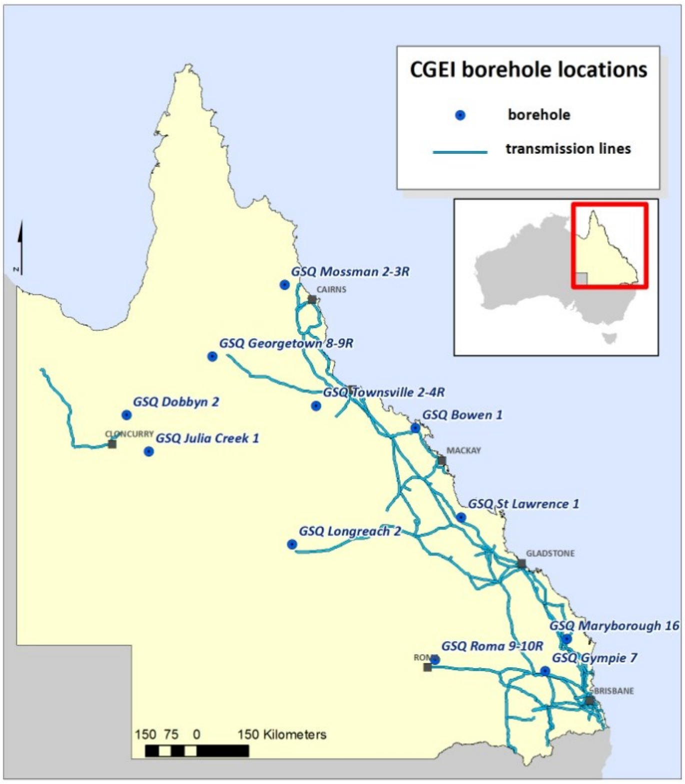


Figure 2: Location of CGEI boreholes.

2.2 Heat Flow modelling

The collected temperature and thermal conductivity data were used to determine vertical conductive heat flow in each borehole using the inversion modelling technique. Modelling was carried out using in-house developed software named HF1D. HF1D computed theoretical temperature data for a given magnitude of heat flow. The computed data was then graphically compared with the observed temperature log and the magnitude of the heat flow value in the model was adjusted until the computed temperature data best matched the logged temperatures. The modelling indicated vertical conductive heat flow of the boreholes ranges between 37.5 and 113.0 mW/m^2 (Table 1). The uncertainty in the heat flow is calculated by propagating the relative uncertainty in the average thermal conductivity of the rock units intersected.

Table 1: A summary of all modelled heat flow values for CGEI boreholes.

Tectonic Unit	Borehole Name	Total Depth (mGL)	Modelled Interval (m)	Harmonic Mean Thermal Conductivity (W/mK)	Mean Temp. Gradient (°C/km)	Modelled Heat Flow (mW/m²)
Maryborough Basin	GSQ Maryborough 16	387.40	61-380	1.97 ± 0.13	34.37	67.0 ± 2.9
Tarong Basin	GSQ Gympie 7	338.60	54-337	1.18 ± 0.08	31.78	37.5 ± 1.4
Eromanga-Galilee basins	GSQ Longreach 2	330.00	84-310	1.40 ± 0.06	41.75	60.0 ± 2.5
Surat Basin (Roma Shelf)	GSQ Roma 9-10R	335.90	106-336	2.11 ± 0.10	39.04	82.5 ± 2.4
Styx Basin	GSQ St Lawrence 1	340.00	90-338	1.51 ± 0.04	42.66	64.5 ± 1.1
Millungera Basin - South	GSQ Julia Creek 1	500.02	120-480	2.19 ± 0.08	52.82	113.0 ± 2.9
Millungera Basin - North	GSQ Dobbyn 2	500.04	91-500	1.68 ± 0.04	66.31	107.5 ± 1.7
Etheridge Province	GSQ Georgetown 8-9R	320.15	43-265	3.74 ± 0.12	16.09	48.5 ± 2.3
Hodgkinson Province	GSQ Mossman 2-3R	339.70	62-265	3.96 ± 0.08	19.80	77.0 ± 0.9
Hillsborough Basin	GSQ Bowen 1	321.00	89-321	2.14 ± 0.11	33.06	71.0 ± 2.3

2.3 Temperature estimation to depth

Estimation of the temperature profile to 5 km is a key factor in assessing the geothermal energy potential of an area. The depth of 5 km is deemed as a cut-off for the economic extraction of geothermal energy (Chopra and Holgate, 2005). In lieu of deep drilling and direct measurements at depth, heat flow modelling provides a basis for reasonably accurate estimation of temperatures to depth. In a purely conductive heat regime, downward estimation of steady-state temperature to a depth *z* can be performed by:

$$T_z = T_0 + q_0 \cdot \int_0^z \frac{d_z}{k_z} \tag{1}$$

Where: k_z is thermal conductivity of the interval

d_z is the thickness of the interval

q_0 is the heat flow at the top of the interval

T_0 and T_z represent the temperature at the top and bottom of the interval respectively

The heat flow at the top of the interval is assumed to be purely conductive and therefore constant with depth *z*. Although this linear relationship is a simplification of a complex dynamic system, it is a reasonable first order approximation in the absence of direct measurements at depth.

For each CGEI target drilled, first the geological succession to 5 km was inferred from geological and geophysical data to estimate the thicknesses of the stratigraphic units and their representative rock types to that depth. Then thermal conductivity values were assigned to formations with uniform rock types using either the measured values or those reported in the literature. Where a mixture of rock types is present in a formation, a representative thermal conductivity was calculated from the weighted harmonic mean of the component rock types (Beardsmore & Cull, 2001). As an example, Table 2 shows estimated stratigraphy and associated thermal conductivity profile to 5 km beneath GSQ Dobbyn 2 in the Millungera Basin. These established thermal conductivity profiles and conductive modelled heat flow values were then used to estimate temperatures to 5 km using equation (1). The estimated temperatures at 5 km range from 106 to 240°C. In addition, depth to 150°C isotherm was also estimated using the same approach in order to evaluate viability of the drilled target. The 150°C isotherm is defined as the cut-off temperature or geothermal production window in a basin setting (Cooper and Beardsmore, 2008) which could allow commercial deliverability from a production well. Where the 150°C isotherm was present at a depth less than around 4 km with estimated temperature at 5 km greater than around 190°C, then the target area was classified as high prospectivity basin for which a preliminary resource assessment was undertaken.

Results of temperature estimation at 5 km, and depth estimation to the 150°C isotherm, are presented in Table 3. Uncertainty in the estimated temperatures was calculated solely by propagating the relative uncertainty in the average thermal conductivity of the rock units predicted to 5 km. Based on the temperature estimations, the Millungera, Surat, Hillsborough and Maryborough basins were identified as high prospectivity basins for geothermal energy with six inferred resource areas highlighted within these basins. As an example, Figure 3 shows a two-dimensional cross section of the inferred resource area in the vicinity of GSQ Dobbyn 2 drilled in the Millungera Basin.

2.4 Stress regime

In order to maximise the efficiency of heat extraction from hot rock resources, the permeability of the reservoir rocks needs to be enhanced through a hydro-fracturing stimulation process. A critical factor in the successful development of Engineered Geothermal

System (EGS) is the response of the fracturing process to the *in situ* stress field. *In situ* stress fields also exert significant control on fluid-flow patterns in fractured rocks. Knowledge of both the regional and prospect scale stress regimes is important to understand the effects of stress-dependent fracture permeability. In EGS, knowledge of the stress regime is critical in predicting reservoir growth direction when undertaking hydro-fracturing stimulation (Department of Trade and Investment of NSW, 2010). A reverse or thrust faulting stress regime that facilitates horizontal to shallow dipping fracture growth is considered optimal for development of EGS reservoirs. This requirement was considered when investigating stress regime of the CGEI targets. Although there were no adequate qualitative and quantitative data available to conduct a reasonable study on this particular matter, a mixture of normal, strike-slip and thrust faulting stress regimes was noted to be present at the selected high prospectivity basins. This resulted in the overall stress regime being evaluated as moderately conductive to hydraulic fracturing within the targeted reservoir rocks in the Millungera, Surat, Hillsborough and Maryborough basins .

Table 2: Estimated stratigraphy and thermal conductivity profile to 5 km depth, GSQ Dobbyn 2 - Millungera Basin.

Depth interval (m)	Tectonic unit	Formation	Rock type	Thermal conductivity (W/mK)
0-146[1]	Carpentaria Basin	Allaru Mudstone[1]	Mudstone, sandstone[1]	1.14 ± 0.02[1]
146-226[1]		Allaru Mudstone[1], Toolebuc Formation[1]	Mudstone, calcareous mudstone, sandstone[1]	1.14 ± 0.02[1]
226-390[1]		Wallumbilla Formation[1]	Mudstone, sandstone[1]	1.13 ± 0.05[1]
390-1500[2,3]	Millungera Basin	Millungera Basin (Undiff)[1,2]	Sandstone[1]	6.64 ± 0.18[1]
1500-3000[3]	Mount Isa Province	Williams Super Suite[3]	Granitoid[4]	3.20 ± 0.73[5]
3000-5000[3]		Soldiers Cap Group (Undiff)	Metasediments[4]	3.26 ± 0.87[5]

[1]GSQ Dobbyn 2 (Fitzell et al., 2012)
[2]Korsch et al. (2011)
[3]GSQ gravity modelling
[4]Geological Survey of Queensland (2011)
[5]GSQ unpublished database

Table 3: Temperature estimates at 5 km depth and depth estimates to 150°C isotherm, CGEI boreholes.

Tectonic Unit	Borehole Name	Temperature at 5 km (°C)	Depth to 150°C isotherm (m)
Maryborough Basin	GSQ Maryborough 16	207 ± 15	3357
Tarong Basin	GSQ Gympie 7	106 ± 9	8063
Eromanga-Galilee basins	GSQ Longreach 2	140 ± 13	5407
Surat Basin (Roma Shelf)	GSQ Roma 9-10R	187 ± 14	4041
Styx Basin	GSQ St Lawrence 1	171 ± 16	4235
Millungera Basin - South	GSQ Julia Creek 1	238 ± 18	3190
Millungera Basin - North	GSQ Dobbyn 2 – Area A	232 ± 17	3239
	GSQ Dobbyn 2 – Area B	240 ± 15	3098
Etheridge Province	GSQ Georgetown 8-9R	109 ± 5	7574
Hodgkinson Province	GSQ Mossman 2-3R	138 ± 1	5462
Hillsborough Basin	GSQ Bowen 1	204 ± 16	3880

2.5 Preliminary resource assessment

A volumetric approach was used as the preferred method for preliminary resource assessment of the CGEI inferred resource areas (Muffler, 1979). The total stored heat in-place in a geothermal system is given by:

$$\text{Total stored heat} = \text{Stored heat in rock} + \text{Stored heat in water} + \text{Stored heat in steam}$$

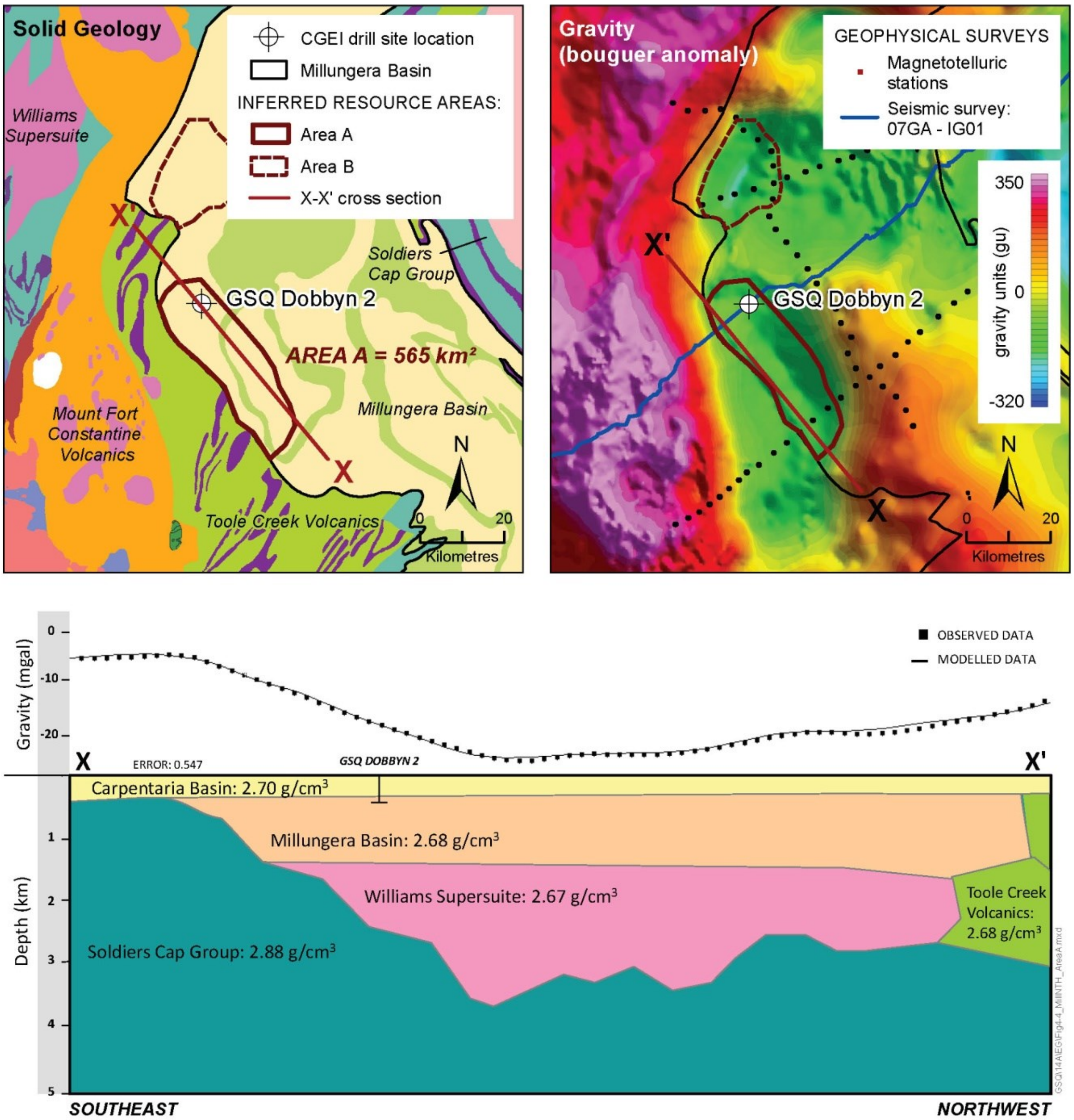


Figure 3: Inferred resource area and cross section through inferred resource area, in the Millungera Basin – North.

Sanyal and Sarmiento (2005) indicated that heat in the rock is known to strongly dominate the above equation, even for high porosity rocks with fluid contents. Furthermore, porosity and presence of fluid (water/steam) at depth are unknown for the CGEI inferred resource areas. Therefore, the inferred resource rocks are assumed to have negligible porosity and, hence, negligible fluid content. A more simplistic equation was then adopted and used for the stored heat in-place estimates presented here, in the following form:

$$Q \approx \rho_r C_r V (T_R - T_r) \quad (2)$$

where:

Q Stored heat in-place, Joule (J)

ρ_r Rock density, kg/m^3

C_r Rock specific heat capacity, J/kg°C

V Rock (resource) volume, m^3, (=AH) where

A=Rock (resource) surface area, m^2

H=Rock (resource) thickness, m

T_R Rock (resource) mean temperature, °C

T_r Reference (base) temperature, °C

Density of the resource rock was taken between 2600 and 2900 kg/m^3, which is a reasonable approximation for many inferred resource rocks within the highlighted areas, based on the current geological knowledge. *Specific heat capacity* of the resource rock is estimated to be between 900 and 1000 J/kg°C, at the cut-off temperature of 150°C and above, based on data presented by Vosteen and Schellschmidt (2003) for typical plutonic, metamorphic and sedimentary rocks. A resource *surface area* should ideally be defined as the areal extent of the 150°C isotherm (cut-off temperature). As there are insufficient data to map the areal extent of this isotherm, the surface area of the inferred geothermal energy resource is defined as the lateral extent of the intrusive or the area of optimal sedimentary thickness as determined from geophysical data. The *thickness* of the inferred resource is estimated by the depth at which the cut-off temperature of 150°C is exceeded to the base of the resource – 5 km. Resource *mean temperature* is the average between the cut-off temperature (150°C) and the temperature at the base of the resource (5 km). The *reference (base) temperature* is typically defined as the average temperature between the reinjection and production wells (Williams, 2007). However, for the purposes of this assessment, the reference temperature is assumed to be the average of the cut-off temperature (150°C) and the rejection temperature (the temperature of the geothermal fluid after the heat extraction process in the power plant). The rejection temperature is set at 70°C, this being the typical temperature for rejected fluid by an Organic Rankine Cycle binary plant with an air cooling system. For the purposes of this study, the reference temperature was assumed to be 110°C.

Using the simplified equation (2), stored heat in-place was calculated for each CGEI inferred resource area which ranges between 88,591 and 402,565 petajoules (PJ). For comparison purposes and to present a more tangible figure, the estimated stored heat in-place was then converted to equivalent electric power generation potential in megawatt (MW) and annual electricity generation potential in gigawatt-hour (GWh). Following assumptions were made when converting the stored heat in-place to electricity:

- Stored heat recovery factor: 5%
- plant thermal conversion efficiency: 7%
- plant capacity factor: 90%
- plant lifetime: 25 years.

As a result, the estimated stored heat in-place is equivalent to 437–1986 MWe power generation capacity or 3,445–15,655 GWh annual electricity generation potential over 25 years continuous production (Talebi et al., 2014). The input parameters, estimated stored heat in-place, equivalent power generation and annual electricity generation potentials are presented in Table 4. The inferred resource areas are shown in Figure 4.

Table 4: Input parameters, stored heat in-place, equivalent electric power potential and annual electricity generation, CGEI inferred resource areas.

Tectonic unit		Inferred resource thickness (m)	Resource mean temp. (°C)	Resource surface area (km^2)	Rock density (kg/m^3)	Rock specific heat capacity (J/kg°C)	Stored heat in-place (PJ)	Gross power generation potential (MWe)	Estimated annual electricity generation (GWh)
Millungera Basin - South		1811	194	848	2880	1000	372 499	1837	14 483
Millungera Basin - North	Area A	1761	191	565	2880	1000	231 433	1142	9004
	Area B	1902	195	339	2880	1000	157 805	778	6134
Surat Basin (Roma Shelf)		959	169	2621	2680	900	355 057	1751	13 808
Hillsborough Basin		1120	177	456	2870	900	88 591	437	3445
Maryborough Basin		1643	179	1465	2680	910	402 565	1986	15 655

2.6 Monte Carlo simulation

Because of the limited data and large uncertainty associated with the assumptions made, some degree of caution and conservatism was also taken into account in the estimates. This approach, which accounts for a risk factor, can be quantified with reasonable approximation using the Monte Carlo simulation. It applies a probabilistic method of evaluating the estimated stored heat in-place or equivalent power output that captures uncertainty. Given the complexity and heterogeneity of the geological formations of most geothermal systems, this method is preferred over the usual deterministic approach, which assumes a single value for each parameter to represent the whole system. Instead of assigning a 'fixed' value to an input parameter, numbers within the range of the distribution model are randomly selected and drawn for each cycle of calculation. Sampling is usually done through 1000 iterations to obtain a good representation of the distribution. The results are then analysed in terms of the probability of occurrence of the estimated stored heat in-place or equivalent power output in the range of values over the resulting population.

Whilst the availability of sufficient quantitative data is required to justify the application of the probability approach, for this study a Monte Carlo simulation was used to provide an indication of likely uncertainties in the estimates. The assigned input parameters were categorised as “most likely”, “minimum”, and “maximum” scenarios, by assuming 10% uncertainty for each input parameter, except for the resource mean temperature which inherits its actual uncertainty from the heat flow error. The Monte Carlo simulation result is then presented as a plot of relative and cumulative frequency distribution against the estimated stored heat in-place or equivalent power output.

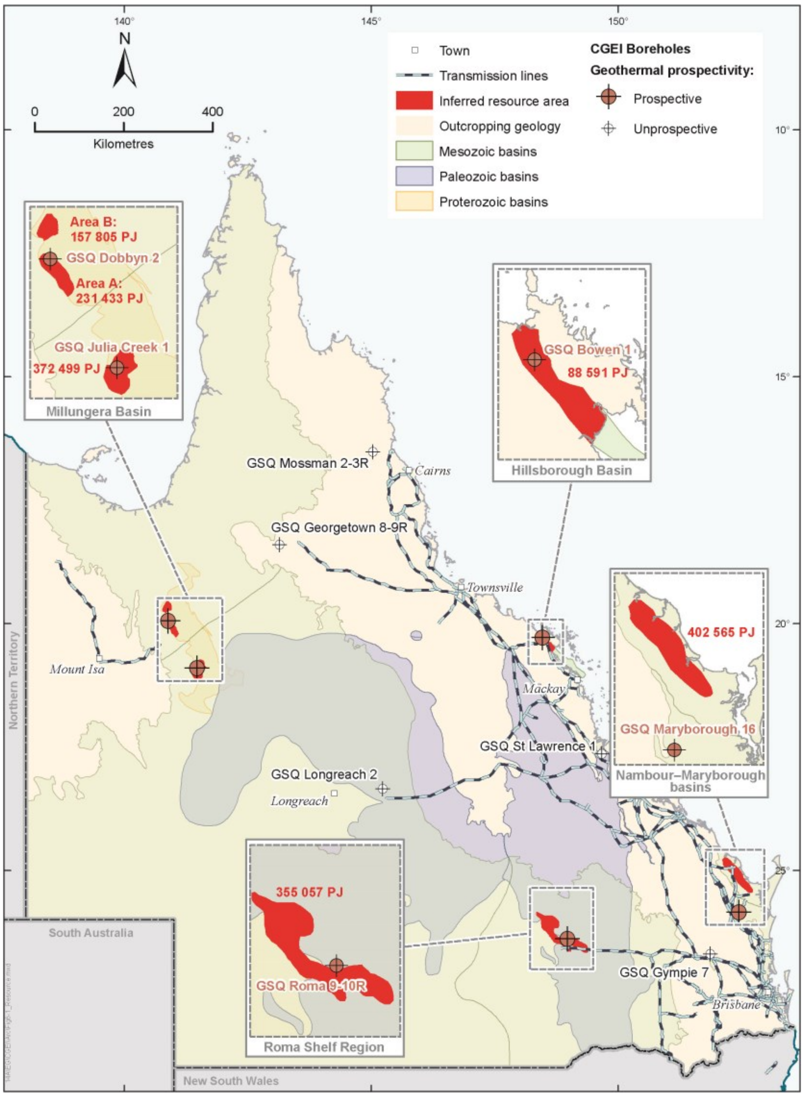


Figure 4: Areas of inferred geothermal energy potential highlighted by the CGEI program.

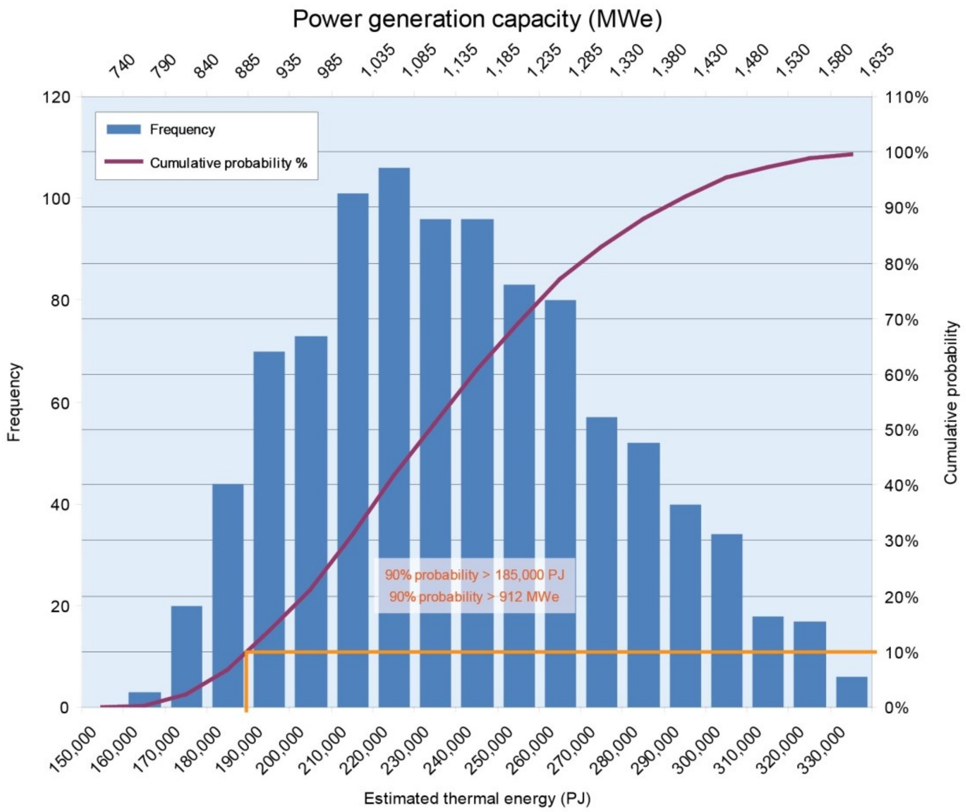
There is no doubt that the reliability of the results from a Monte Carlo simulation depends on the type, amount, and quality of the geoscientific data, which are in turn dependent on the stage of development and maturity of the target area. Generally, the reliability increases as the target area is drilled, with direct measurements and more quantitative data becoming available.

The Monte Carlo simulation was undertaken for each CGEI inferred resource area. The simulation results show that the estimated stored heat in-place of 70,000–320,000 PJ can be expected from the inferred resource areas at 90 per cent probability. This figure is equivalent to electric power generation potential of 345–1578 MWe or annual electricity generation of 2720–12,441 GWh at the same probability rate (Table 5). Figure 5 shows the input parameters used and the result of the Monte Carlo simulation for the estimated stored heat in-place and equivalent power generation capacity in the vicinity of GSQ Dobbyn 2 drilled in the Millungera Basin.

Table 5: Result from Monte Carlo simulation, estimation of stored heat in-place, equivalent power output and annual electricity generation for the inferred resource areas at 90% probability.

Tectonic unit		Total stored heat – PJ (90% probability)	Electric power potential – MWe (90% probability)	Annual electricity generation – GWh (90% probability)
Millungera Basin - South		>296 000	>1 460	>11 510
Millungera Basin - North	Area A	>185 000	>912	>7 190
	Area B	>130 000	>640	>5 045

Surat Basin (Roma Shelf)	>280 000	>1 380	>10 880
Hillsborough Basin	>70 000	>345	>2 720
Maryborough Basin	>320 000	>1 578	>12 441



Input Parameters	Minimum	Most Likely	Maximum
Resource surface area (km²)	509	565	622
Resource thickness (m)	1585	1761	1937
Resource mean temperature (°C)	177	191	205
Rock density (kg/m³)	2592	2880	3168
Rock specific heat capacity (J/kg°C)	900	1000	1100

Recovery factor: 5%
Thermal conversion efficiency: 7%
Plant life time (years): 25
Plant capacity factor: 90%
Reference temperature (°C): 110

Statistics	Total Thermal Energy (PJ)	Equivalent Power Capacity (MWe)
Trials	1000	1000
Base case	231,433	1,142
Minimum	150,610	743
Maximum	350,905	1,731
Mean	232,174	1,145
Median	229,079	1,130
Variance	1,387,281,135	33,754
Standard deviation	37,246	184
Mean std. error	5	74
Skewness	0.3828	0.3828
Kurtosis	-0.41	-0.41

Figure 5: Input parameters and result from Monte Carlo simulation, vicinity of GSQ Dobbyn 2, Millungera Basin.

3. CONCLUSIONS

With Queensland's growing population and resource industries, there is a need for additional base-load electricity capacity. Due to this need, and to reduce environmental impact, the need for cleaner energy sources is an imperative. Amongst all cleaner energy sources, geothermal energy is the best alternative to provide base-load electricity throughout the year with negligible greenhouse gas emissions. The CGEI drilling program resulted in new pre-competitive geoscientific data sets, including temperature and thermal conductivity data, being collected from selected sedimentary basins and metasedimentary terranes of northern and eastern Queensland with the aims of expanding Queensland's exploration opportunities, and facilitating the reduction of risk for future explorers. These data were used to determine vertical conductive heat flow, an important parameter for assessing geothermal energy potential. Steady-state heat flow models for each of the boreholes were built based on an inversion modelling technique. Required input data included precision downhole temperature logs and thermal conductivity data of the core samples. To ensure that the input data best reflected the actual thermal conditions of the boreholes, the temperature logs recorded at thermally equilibrated conditions (at least six weeks after borehole completion date), and thermal conductivity of the core samples analysed at their *in situ* conditions. The modelling process indicated that vertical conductive heat flow for the CGEI boreholes ranges between 37.5 and 113.0 mW/m^2. No terrain corrections were applied for the effect of local topography in the heat flow models, as all the drill site locations were deliberately selected away from any major topographic feature and relief.

Using the established heat flow models, temperatures of 106–240°C were estimated in one dimension at 5 km in the vicinity of boreholes drilled. The estimated temperatures at depth demonstrate that under sufficient insulation, even moderate heat sources can retain high temperatures at depth such as at Maryborough Basin. Stacked sedimentary basins, commonly containing coal measures, cover a large portion of Queensland, and typically act as the efficient thermal blanket insulating intrusions and regions of Cenozoic magmatism and volcanism (O'Connor et al., 2015). The CGEI results suggest that geothermal energy potential may exist in areas previously overlooked due to the lack of high heat producing intrusives, or no or poor quality temperature data. However, given the complexity and heterogeneity of geological formations in most geothermal systems, 1D-modelling of heat flow and temperature has limitations in that heat does not always flow vertically in areas where significant lateral contrasts in thermal conductivity exist. Similarly, lateral differences in heat producing elements will also cause local variations in heat flow. For the CGEI targets, lateral contrasts in thermal conductivity as well as heat producing elements were not investigated in more than one dimension. Heat flow modelling in more than one-dimension, is required in future work to understand two- and three-dimensional distribution of the temperature field, to accurately describe the thermal state of the CGEI targets.

Based on temperature estimations at 5 km and depth estimates to 150°C isotherm (or cut-off temperature), the Millungera, Surat, Hillsborough and Maryborough basins have been identified as high prospectivity basins for geothermal energy highlighting six inferred resource areas. Using the volumetric approach, stored heat in-place of 88,591–402,565 PJ was estimated for the inferred resource areas accumulating to total amount of 1,608,000 PJ. Powerlink Queensland's Annual Planning Report (2013) indicates that peak demand in Queensland under a medium economic-growth scenario is forecast to increase at an average rate of 3.0% per annum to 2022–23. This equates to an average increase in peak demand to approximately 240 MWe per annum over the next decade. The Monte Carlo simulations predicted a cumulative total stored heat in-place of 1,280,000 PJ at 90% probability for the highlighted inferred resource areas. The estimated stored heat in-place is equivalent to gross electric-power-generation potential of 6,300 MWe which is sufficient to generate electricity to meet the state's forecast demand over the next decade. However, these estimates are purely hypothetical because of a lack of sufficient quantitative data. They will need to be revised once detailed exploration programs are undertaken and direct measurements at greater depths are obtained.

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