ASIA-PACIFIC PARTNERSHIP ON CLEAN DEVELOPMENT AND CLIMATE PROGRAMME (APP)

Identifying High Value Geothermal Resources in China

Final Report

Objective

Petratherm Ltd is a leading explorer and developer of geothermal energy, and the first Australian geothermal company to undertake exploration for new geothermal resources on mainland China. In 2007, Petratherm signed an exclusive agreement with four key Chinese geological/geothermal institutions to undertake a co-operative assessment to identify prospective geothermal projects in China, headed by the China Geothermal Energy Society and the China Institute of Geo-Environment Monitoring. The collaborative work program built a database (Milestone 1) of key geological and geothermal data, generated thermal models of key geothermal sites (Milestone 2) and produced economic models of each geothermal site identified from the study (Milestone 3).

The 3 phase study successfully met the objectives outlined in the APP funding agreement. The geothermal assessment identified four new geothermal prospect regions, in Southern and Eastern China, in areas which have a high demand for new electricity generation. The study also significantly raised the profile of engineered geothermal system (EGS) potential for China, within Chinese Government Departments. Petratherm played a key role in lobbying the government in collaboration with the lead partner, the China Geothermal Energy Society. These talks directly resulted in the triggering of government funding for EGS exploration in Jiangsu Province and the application for a large injection of new central government funding into EGS in China. Petratherm is in ongoing talks with local potential joint venture partners for projects in Fujian and Jiangsu Provinces.

Summary of Major Activities and Deliverables

Milestone 1 - China Geothermal GIS database
Petratherm geologists made three visits to China to meet with the Chinese collaborators, local provincial experts, and make site visits of prospective areas. Regions visited include Beijing, Yunnan, Guangdong, Jiangsu, and Fujian Provinces. Data for the Milestone 1 Activity - the construction of a Geothermal Characterization Geographical Information Systems (GIS) database - was collated during the period. The data has been formatted to allow interrogation and presentation of the data in GIS format.

Data was obtained from the Chinese Research Partners and various Chinese Government Institutions. Some data sets originally planned to be compiled were un-able to be obtained due to confidentiality or due to the security policy of the Chinese Government. This problem was foreshadowed in the original APP proposal. Notwithstanding, many key data sets were obtained which allowed the project milestones to completed successfully.

The Chinese GIS system and computer setup for Chinese language is different from what is used in Australia and so a decision was made to keep some of the data in the Chinese GIS format. This was because some of the Chinese data lost important attributes during

the transfer process into the Australian format. Petratherm employed a Chinese Australian Geologist and purchased Chinese computer and software to allow interpretation of the data unable to be transferred completely across, so as to not hinder interpretation of the data for milestone 2 activities.

GIS Data Inventory

A list of the data collected and formatted into the GIS package is presented below:

- Geological map of China, 1: 6,000,000 scale. Includes geological polygons, faults, mine sites, topographic features.
- Geological map of China, 1: 2,500,000 scale. Includes geological polygons, faults, mine sites, topographic features.
- Digital Provincial Geological Maps 1:1,000,000 scale. Includes geological polygons, faults, mine sites, topographic features.
- Geological maps in tiff-format: Guangdong, Fujian and Hainan Provinces 1: 200,000 scale.
- Chinese sedimentary basins and coal-bearing deposits
- China heat-flow dataset. Anomaly maps and contour shape files
- China hot springs
- China Topographic Map
- Total Magnetic Intensity Map of China
- Gravity Image Map of China
- Limited drill hole location and Uranium Thorium geochemical data

Milestone 2 – Geothermal Models

The thermal modeling study utilized data generated from the Milestone 1 - Geothermal Characterization Geographical Information Systems (GIS) database. In addition prospect scale reports were generated by Petratherm in consultation with the Chinese Research Partners and various local Chinese Government Institutions. In two key regions of interest (Fujian and Jiangsu Provinces), Petratherm has continued to work with the regional government and local geological experts to obtain further data and discuss tenure options to allow potential future exploration and development of these sites.

To generate anomalously high temperatures at relatively shallow depths in non-volcanic regions, two key parameters need assessment, the local heat flow and thermal insulating

properties of the host rock. This is because the rise in temperature with depth (i.e. temperature gradient) is a function of the heat flow divided by the thermal conductivity (insulating properties) of the host rock. In general, geological basin areas contain thick rock sequences with good insulating properties. Sedimentary basin strata are undeformed and contain thick packages of low thermal conductivity material which make them ideal insulators for traping heat. Many of China's basins contain thick coal measures which have exceptional thermal insulating properties. The study initially identified areas where high heat flow and basins overlapped as a means of locating potential high temperature geothermal sites (Figure 1). Detailed basin geology was accessed for each basin and thermal conductivity data for the indvidual rock sequences was used in order to build the thermal models.

The exception to this arrangement is in South East China where many natural fault controlled hot springs occur. Heat flow is only moderate in this region and thermal conductivities are high, however local hot spots have formed through the circulation of hot fluids from great depth to the surface along existing faults. Four target regions were identified from the study, East Yunnan, the Subei Basin, Hebei Basin, and fault controlled geothermal sites of Fujian in South East China.

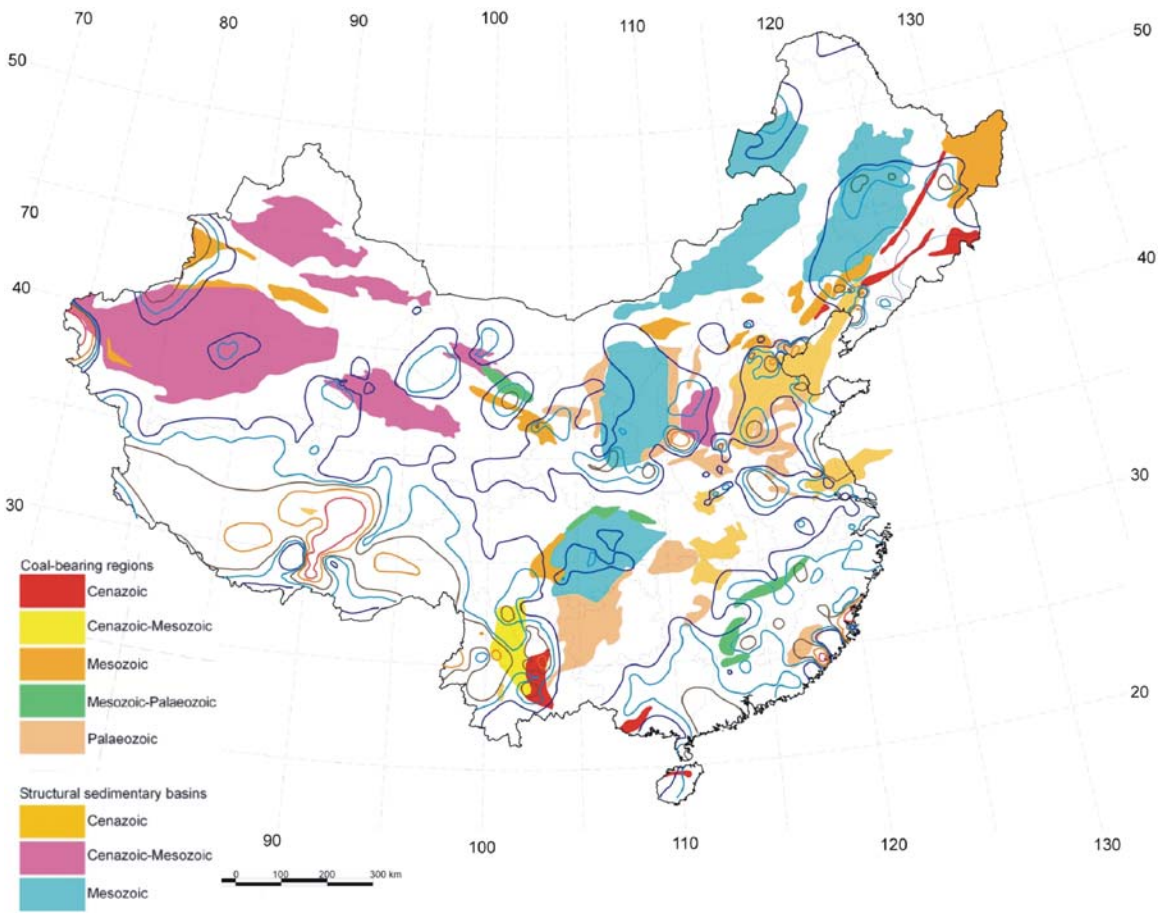

Figure 1 - Heat Flow Contours and Major Basins of China

Milestone 3 – Economic Models

The economic modeling study applied Petratherm's in house proprietary economic modeling software to assess the four geothermal regions identified from the study (Milestone 1 and 2 activities). The software was developed over several years within the company to specifically model the economics of geothermal systems anywhere in the world. The model includes connection and transmission issues and the time factor to drill the wells and construction of the power plant into the overall project economics.

Model Inputs:

- The model has been developed in A$.

- *Resource Parameters:*
  - Temperature
  - Flow Rate
  - Ratio of production to injection wells

- The resource parameters were defined based upon the reasonable assumptions of Petratherm's geological team using existing data and interpretations from similar known systems elsewhere in the world.

- Temperature of resource is derived from detailed thermal modeling study for each project area (i.e. the Milestone 2 Activity)

- Flow rates were determined from an understanding of the local permeability and porosity of the host rock at each geothermal site, and consideration of the likely pumping rates, given the resource and standard geothermal pumps available.

- Temperature and flow rate combine to deliver the output per well, which then determines the number of production wells required to meet the demand. The production: injection well ratio then determines the number of injection wells required.

- The exact ratio will depend on the specific geological setting, but a ratio of 2:1 is a reasonably conservative benchmark used at this stage of analysis.

- *Cost Parameters*

  - Cost per well
  - Production : Injection well ratio
  - Cost of generation plant and above ground installations
  - Cost of transmission connections

- The cost per well has been based on estimates of the local Chinese costs and are thus substantially lower than the equivalent for an Australian project. These have been based on some local feedback from our Chinese sources.

- The cost of generation plant and above ground installations is assumed to be constant across all Petratherm projects regardless of the location. This is due to the plant being ordered from outside China and the cost being denominated in US$. Potential upside therefore exists from sourcing the plant from local, cheaper, sources

- These costs have been provided to Petratherm previously by the geothermal consulting group Global Power Systems (GPS), which were confirmed as accurate through the TRUenergy due diligence on farming into the Paralana project.

- The temperatures being assumed are more conducive to binary (organic rankine cycle) plant. With the current exchange rate, the cost per MW installed for above ground work is A$2.5m/MW

- Transmission connection costs have also been assumed to be similar to the cost of Australian connections – say within 20 kms. To accommodate the likelihood these costs would in fact be lower, a small distance of connection has been used to minimize the overestimate effect.

- It is understood that one potential option for transmission is for the Chinese Government to pay for the connection, thus removing the need for transmission connections. This represents further upside to the project but has not been run as sensitivity.

- *Revenue*
    - Capacity Factor assumption (giving total MWh produced)
    - Transmission losses
    - Unit price of output
    - Rate of Return
    - Carbon Value – through Carbon Development Mechanism

- Geothermal power production is base load and so has a high capacity factor. 95% has been assumed for this study based on previous input from GPS.

- Transmission losses also impact on revenue as they are MWh produced but not delivered. Until further information is available, transmission losses have been assumed to be zero for this study.

- Our understanding of price is that the regional government pays the benchmark coal price to local production and the Federal PRC Government pays a specific renewable tariff which it sets based upon the specific project economics. The price will therefore be project specific and given the lack of geothermal benchmarks available, a reasonable estimate on price is not possible.

- The analysis therefore uses a given rate of return and works out what price is required to provide this return.

- The rate of return assumed is 10% post tax real (i.e. excludes inflation from the analysis). Assuming a 3% long term average inflation rate, this is equivalent to a 13% post tax (nominal) return.

- The analysis establishes a price required to deliver a specific (10%) return. This price can either be considered to be bundled across regional and federal government tariffs with or without CDM. Based upon discussions with local utilities about the potential attractiveness of CDM and the need for 51% of the project to be owned by a Chinese domiciled party, the analysis assumes no CDM value in the base case.

- Finally, to provide an indication of the return applicable to the base case under a reasonable price assumption, we have calculated the IRR for the base case scenario assuming a bundled price (including CDM) equal to A$100/MWh.

Summary of Economic Modelling Analysis

An economic valuation model of four potential engineered geothermal sites for China (Yunnan, Fujian, Jiangsu and Hebei) was undertaken. The sites were identified from exploration and modelling work undertaken by Petratherm and the Chinese Research Partners as part of the Milestone 1 and 2 activities. The resource parameters were defined based upon the reasonable assumptions of Petratherm's geological team using existing data and interpretations from similar known systems elsewhere in the world. Results from the modelling indicated the Jiangsu and Fujian Geothermal plays had potenital to be commercially viable.

The key assumptions for each project area are shown in the table below:

Assumption	Yunnan	Hebei	Jiangsu	Fujian
Temperature	180ºC	160ºC	200ºC	150ºC
Flow Rate	75 lps	100 lps	100 lps	100 lps
Net Well output	3.4 MW/well	3.6 MW/well	5.6 MW/well	3.1 MW/well
Production: Injection Ratio	2:1	2:1	2:1	2:1
Drilling Depth (km)	5.0km	5.0km	5.0	3.0km
Drilling Cost per well 30 MW	$4.1m	$4.1m	$4.1m	$2.6m
AUD:USD Exchange rate	0.76	0.76	0.76	0.76
Plant and above ground capex 30 MW	US$1.9m/MW	US$1.9m/MW	US$1.9m/MW	US$1.9m/MW
Carbon Value	$0/MWh	$0/MWh	$0/MWh	$0/MWh
Return (post tax real)	10%	10%	10%	10%

The base case scenario implies the following in respect of capital expenditures and price outcomes for a 30MW development:

Base Case Capital Requirements	Yunnan - 30 MW Development	Hebei – 30MW Development	Jiangsu – 30MW Development	Fujian – 30MW Development
Total Wells	14	14	9	15
Drilling Capital ($m)	$57m	$57m	$28m	$39m
Above Ground & Plant Capital ($m)	$75m	$75m	$75m	$75m
Transmission Capital ($m)	$13m	$13m	$13m	$13m
Total Capital ($m)	$146m	$146m	$116m	$135m
Break-even price for 10% return ($/MWh)	99	99	82	88
Real post-tax IRR @ $100/MWh price (%)	10.2%	10.2%	12.8%	11.8%

Concluding Remarks

China's demand for new electricity capacity is the highest in the world, and underpins the countries growth. There is enormous potential to utilize EGS energy resources identified in the study in Southern and Eastern China. EGS energy is large scale, base load, and emission free. The principal technical challenges to commercializing the technology have been to lower drilling costs, and the engineering of a robust sub-surface heat exchanger on large commercial scale. In recent years the engineering issues of building the heat exchanger to a commercial level has been overcome as demonstrated with the operation of small EGS plants in France and Germany.

The challenge now is to build these systems on a large scale. Petratherm sees China as the perfect location to make this next step in EGS development, with low cost drilling, strong engineering capability and the capital and desire for new large scale renewable power generation. The APP geothermal study has seeded strong interest from government and private industry in China. Petratherm is in advanced negotiations with third parties to secure land title and finance exploration and development in Fujian and Jiangsi Provinces.

The methodology and staged programme for the activity delivered the projects stated objectives of evaluating and highlighting new EGS potential for China. Each milestone activity added significant value, and built a solid base, from which or other interested parties can now make an informed evaluation on the EGS potential for different areas of China. The Activity has generated interest within China, and it is hoped new developments will grow out of this initial project. The general methodology of the program could be easily transferable to other Countries, most notably APP member country, India which has a huge demand for new large scale renewable electricity generation, and the geology is seen as favorable for engineered geothermal developments.