# Concentrated Solar Thermal & Geothermal Steam and Power Assessment

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The Australian Meat Processor Corporation acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

# EXECUTIVE SUMMARY

This study was commissioned to review, assess and determine the national application of modular Concentrated Solar Thermal (CST) and Shallow Geothermal (SG) technologies for the industry, aimed at improving energy security, lowering energy costs and reducing reliance on gas network supplies. The abattoir industry is uniquely positioned as a large consumer of both energy and gas for general lighting and cooling as well as the production of steam for rendering.

The study has focused on the viability of modular CST and SG technologies across the different climatic/geographic zones to provide the industry with clarity as to the business case for multiple operations in selected regions of Australia. The data used to assess the different options was collected and analysed from various abattoir sites across these zones to establish a zonal pre-feasibility calculation to understand the system size and output available within each zone. The intent was to define the economics and high priority regions where the technologies could be applied to deliver measurable benefits to the industry.

Evidence provided in this study validates that the deployment of SG and modular CST is technically feasible and appropriate for the needs of the industry to displace gas based energy in the delivery of steam for processing. This Study has not investigated individual sites but adopted a zonal/regional approach to look at the feasibility of the technologies in broad geographic areas.

Shallow geothermal is a well understood, proven and technically robust source of renewable energy already used in industries and local communities, that delivers a small site footprint and low O&M cost technology. Though it is currently limited to areas that are known to have access to suitable exploitable aquifers, it has the advantage of being a 24/7 reliable renewable energy supply capable of producing electrical energy as well as thermal heat. This experience and consistency of energy supply allows for a more robust economic argument to be made for shallow geothermal applications.

Geothermal zones were created during this Study to assess if an AMPC member site was in a moderate to high productivity aquifer zone. This would allow AMPC and individual operators to assess their particular suitability based on the outcomes of this Study and the associated mapping information. In figure 1 you can see the 5 geothermal zones around Australia.

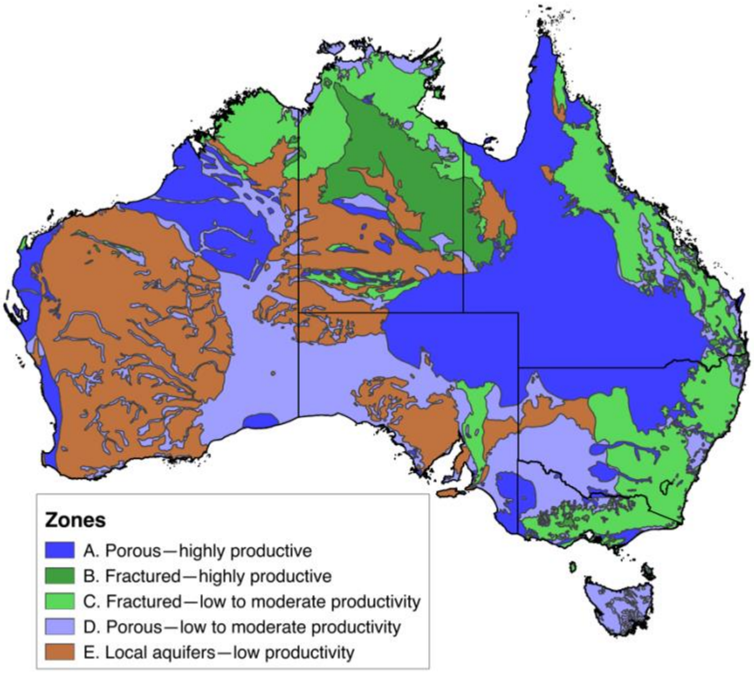


*Figure 1: Australian Geothermal Zones*

The zones were further broken down into aquifer identification and temperatures available at 1 km and 1.5 km depths. To understand if the technology was suited to any particular site, a general average operating model was developed that applied an average water use of 365M litres a year across all zones. Due to the importance of ambient surface and geothermal temperatures, the average temperature change between surface water temperature and aquifer temperature was developed to assess the average savings in gas usage over the year.

*Table 1: Geothermal CAPEX and Savings Overview*

| Aquifer | 1 km | | | | | 1.5 km | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ΔT | Gas Offset | CAPEX | NPV | Savings (30 years) | ΔT | Gas Offset | CAPEX | NPV | Savings (30 years) |
| **Great Artesian Basin (Zone A)** | 43 | ~ 65,589 GJ | $2.92M | $9M | $30.77M | 67 | ~ 102,197 GJ | $5.28M | $13.74 M | $49.13M |
| **Perth Basin (Zone A)** | 23 | ~ 35,083 GJ | $2.33M | -$3.24M | -$1.67M | 35 | ~ 53,387 GJ | $4.33M | $-3.02M | $4.18M |
| **Otway Basin (Zone B)** | 36 | ~ 54,912 GJ | $2.71M | $2.33M | $13.10M | 56 | ~ 85,419 GJ | $4.96M | $2.96M | $21.02M |

In contrast modular CST technology relies on Direct Normal Irradiance (DNI) that can be concentrated onto receivers and stored within the chosen medium. For the purpose of this Study, Australia's solar irradiance has been split into 4 zones to assess modular CST performance within these zones. As seen below, the zones are split by highest DNI, zone 1, to lowest DNI, zone 4, to show the viability of implementing the selected modular CST technology, Magaldi STEM,.

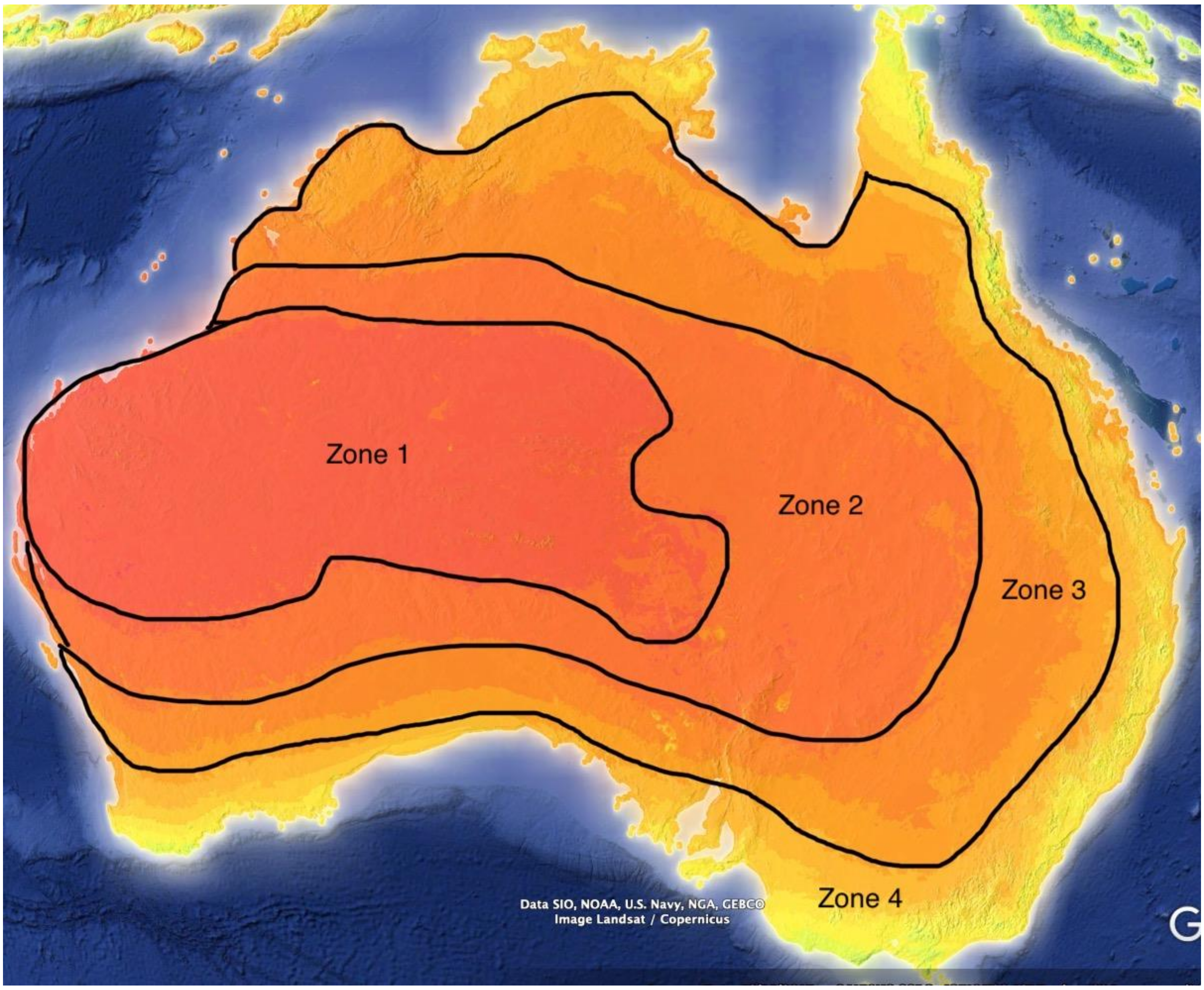


*Figure 2: Australian DNI Solar Zones*

Because the high DNI zones fall further inland in Australia's and away from major cities, no AMPC members fall within Zone 1 and only two members fall within zone 2. The majority of the AMPC members are located within zone 3 and 4 within the medium to low DNI solar productivity areas. To quickly assess if any member sites would benefit from the selected modular CST technology, an assessment linking each zone to the capital cost requirements and corresponding cost savings was established.

*Table 2: Solar CAPEX and Saving Overview*

| Zone | Average DNI | Productivity | Surface Area | Gas Offset/Unit (±10%) | CAPEX | Cost Savings/Unit |
|---|---|---|---|---|---|---|
| Zone 1 | 2,922 + | High | 7ha | ~105,000 GJ | $13.5M | $1.26M |
| Zone 2 | 2,774 | Medium/High | 7ha | ~97,000 GJ | $13.5M | $1.16M |
| Zone 3 | 2,373 | Medium | 7ha | ~78,000 GJ | $13.5M | $936k |
| Zone 4 | 1,826 | Low/Medium | 7ha | ~64,000 GJ | $13.5M | $768k |

The table above shows the average DNI in each zone and the displacement of gas possible per Magaldi unit and the land area needed per unit. Because the Magaldi units can be modularised, more than one can be built depending on land area available and amount of gas offset needed.

The smaller scale CST technology is still a maturing technology, which is at the beginning of the production efficiency cost curve, hence the high capital cost requires assistance in order to increase the long-term energy cost saving potential. CST is also limited by the amount of land area available for uptake and needs a high, Zone 1 & 2, year-round sunlight index to be considered viable in the first instance.

Any trial of modular CST or shallow geothermal will be a close collaboration between a highly qualified site with a renewable energy agency such as ARENA. There is clear potential in Western New South Wales for these technologies to reduce the cost of steam production. Shallow Geothermal presents the most likely technology to be developed due to the lower capital costs. Further review is required for modular CST and potential Government assistance due to the current capital costs limiting the economics of this technology in the industry.

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# 1 INTRODUCTION

The Australian Meat Processor Corporation (AMPC) represent abattoirs located in every state of Australia with a concentration on regional towns associated with stock grazing and farming. The operations of abattoirs are dependent upon power, hot water and steam supplies for the purpose of general lighting and control, refrigeration, sterilisation and more intensive requirements such as rendering. Across Australia's varied power and gas networks, abattoirs are facing challenges of rising costs, particularly in the eastern states where gas prices have increased significantly. Whilst the AMPC has reviewed the potential for energy efficiency and solar PV applications, the AMPC and the industry still require solutions that can address both steam and power requirements that are significantly impacting on operating costs. AMPC is focused on identifying opportunities that present broad scale application of renewable energy technologies to generate power and/or steam to address the requirements of a broad range of abattoir operations.

ResourcesWA has been engaged by AMPC to evaluate the potential to implement renewable energy technologies for steam alternative steam generation for Australian abattoirs based on location, geology, operating conditions/demand and climate.

This report is focused on evaluating the potential for renewable energy technologies of small-scale Concentrated Solar Thermal (CST) and Shallow Geothermal (SG) to provide alternative steam generation solutions to gas-based steam generation. These solutions are ideally suited to regional abattoir locations with abundant sunlight and known geothermal aquifers that will ensure strong economic conditions for these technologies. This Study is designed to assess regions across Australia that are well suited to these technologies, the comparable economics of the technologies to existing gas-based steam generation and the potential application by the industry.

# 2 KEY PROJECT PARTNERS

To deliver this renewable energy study, AMPC brought several key organisations together with the experience and resources required to deliver a nation-wide study. The lead consultancy engaged by AMPC for this study was ResourcesWA Pty Ltd (ResourcesWA), a Western Australia based energy consultancy specialising in offgrid and edge of grid energy solutions.

ResourcesWA is a Western Australia advisory and project development company focused on off-grid and edge of grid power solutions. ResourcesWA has a global network of technology, engineering design, operations and financing partners that can deliver project portfolios of this scale.

ResourcesWA has been supported by Magaldi Power Pty Ltd, Rockwater Pty Ltd and Hot Dry Rocks Pty Ltd.

# 3 AMPC ALTERNATIVE/ RENEWABLE GAS GENERATION STUDY

## 3.1 Background

The meat processing industry is a large national industry and significant employer in both metropolitan and regional areas. The ongoing viability of meat processors and international competitiveness of the industry is heavily dependent on labour and energy costs. These primary drivers can impact on the viability of operations and the potential for new operations to be developed. With the increase in both gas and electrical energy prices across the eastern states of Australia, there has been an increasing need for the industry to look at alternative lower cost solutions that can replace entirely or in part, the current network supply configuration. This study is focused on assessing the potential for modular Concentrated Solar Thermal (CST) and Shallow Geothermal (SG) technologies to provide an alternative option to current network gas solutions for the production of steam and determine the potential scale of application.

## 3.2 Project Overview

A Research Agreement was established for this study between AMPC and ResourcesWA to review, assess and determine the national application of CST and SG technologies for the industry aimed at improving energy security, lowering energy costs and reducing reliance on gas network supplies. The abattoir industry is uniquely positioned as a large consumer of both energy and gas for general lighting and cooling as well as the production of steam for rendering.

The project aims are as follows;

1. Confirm suitability of meat processor sites for identified Modular CST and SG technologies, by mapping locations against known environmental data relating to solar radiation and geothermal aquifers;
2. Model real-life operational and cost data of selected sites (approx. 5) to develop a base design for assessing the applicability of the technologies and potential gas offset that can be achieved;
3. Model energy cost savings, Levelised Cost of Energy (LCOE), Investment Case and Funding Models; and
4. Confirm suitability and expected results across the full national list of meat processor sites to benefit the entire industry.

At conclusion of the Study, it is intended that a clear determination of high priority locations and the business case economics for the application of the selected technologies will be defined.

This Report represents the final concluding document as part of the Study. This has comprised of two key stages of development that included:

### 3.2.1 Stage 1

The Stage 1 component of the study focused on data gathering, location analysis and technology review. Environmental and infrastructure research and data from different climate zones throughout Australia were used to assess member locations and their suitability to the use of SG or modular CST technology for the production of processing steam as a primary renewable energy source to mitigate or eliminate their current gas energy costs.

Each location was assessed against a climate criterion representing the different climatic and geographic positions for the appropriate combination of renewable technologies possible.

To complete Stage 1 the following steps were taken;

- Data collection: consisting of solar radiation, geothermal wells, transmission lines, gas pipelines and information pertaining to the electricity and gas markets.
- Data collection from the locations of AMPC members.
- Technology audit and overview.
- Financial model shell to include cost of energy, CAPX, OPEX and IRR, to compare against current operations.

The Stage 1 activities were compiled in an interim report that was submitted on the 9th August 2019.

### 3.2.2 Stage 2 – Finalisation and Report

Stage 2 of the study focused on the application of the two technologies to the different climate zones around Australia and the financial viability of installation within each of the zones. This allowed the Study to assess the viability of modular CST and SG technologies across the different climatic/geographic zones to provide the industry with clarity as to the business case for multiple operations in selected regions of Australia. The data was collected and analysed from various abattoir sites across these zones and establish a zonal pre-feasibility calculation to understand the system size and output available within each zone.

Once the system size was matched with the data-sets applicable to the respective zones, the CAPX and OPEX of the two technologies were assess against the detailed information from participating locations in each of the zones to test the viability of investing into either of the technologies. Funding and/or financing options were reviewed for possible support in more detailed feasibility studies or deployments to support the business case for implementation.

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### 3.3 Energy Market

The Australian electricity market is supplied by two main networks, the National Electricity Market (NEM, 45GW capacity) and the South-West Interconnected System (SWIS, 5.9GW capacity). The eastern states are serviced by the NEM accounting for ~85% of the Australian electricity market, while Western Australia is serviced by the SWIS, accounting for approximately 10% of the market. The remaining 5% of the market is small remote industrial (3.5GW capacity) and community (1GW capacity) networks.

Both gas and electricity prices have been increasing year on year with projections leading to higher wholesale costs and thus increasing the need to find alternative energy generation options onsite or near to site.

The gas network in Australia consists of over 15,000 kilometers of natural gas pipelines that connect sources of supply and markets across Australia.

The domestic gas market consists of three distinct regions, separated on the basis of the gas basins and pipelines that supply them.

**Eastern gas region**

Australia's eastern and southern states and territories are interconnected by this gas network. The gas basins in South Australia, Victoria and Queensland that supply this market contain around one third of Australia's gas reserves.

**Western gas region**

The gas basins of the western gas market contain over one half of Australia's gas reserves. This market is heavily focused on exports but also supplies domestic consumption in Western Australia. Western Australia is Australia's largest exporter of LNG, but it requires the reservation of 15% of its production for local demand, due to policies in place by the Western Australian Government.

**Northern gas region**

The northern gas market is Australia's smallest producer. Its basins provide gas for export and also for domestic consumption in the Northern Territory.

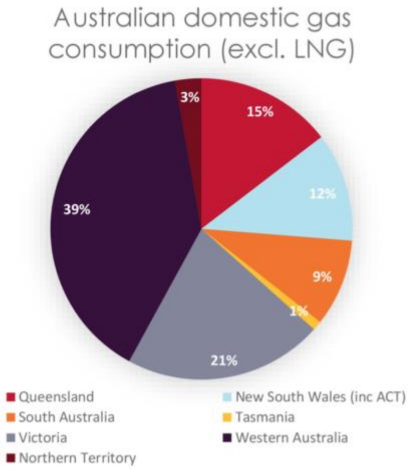


*Figure 3: Australian Gas Consumption*

*Table 3: Natural gas prices, Australia, 2013-2018*

| | AU$ per GJ Wholesale Price | | |
|---|---|---|---|
| Year ending | Adelaide | Brisbane | Sydney |
| September-13 | $5.01 | $5.78 | $4.42 |
| September-14 | $3.84 | $2.34 | $3.85 |
| September-15 | $5.67 | $4.23 | $5.07 |
| September-16 | $9.57 | $7.22 | $7.85 |
| September-17 | $8.25 | $6.72 | $9.03 |
| September-18 | $9.33 | $9.49 | $9.44 |
| Change 2013-2018 | 86.2% | 64.2% | 113.6% |

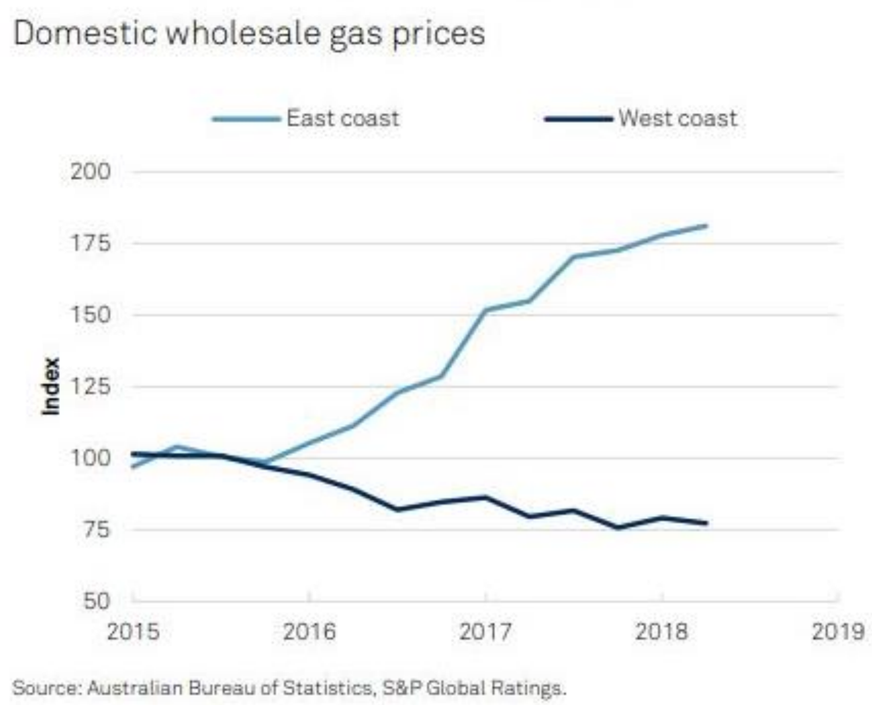


*Figure 4: Domestic wholesale gas prices*

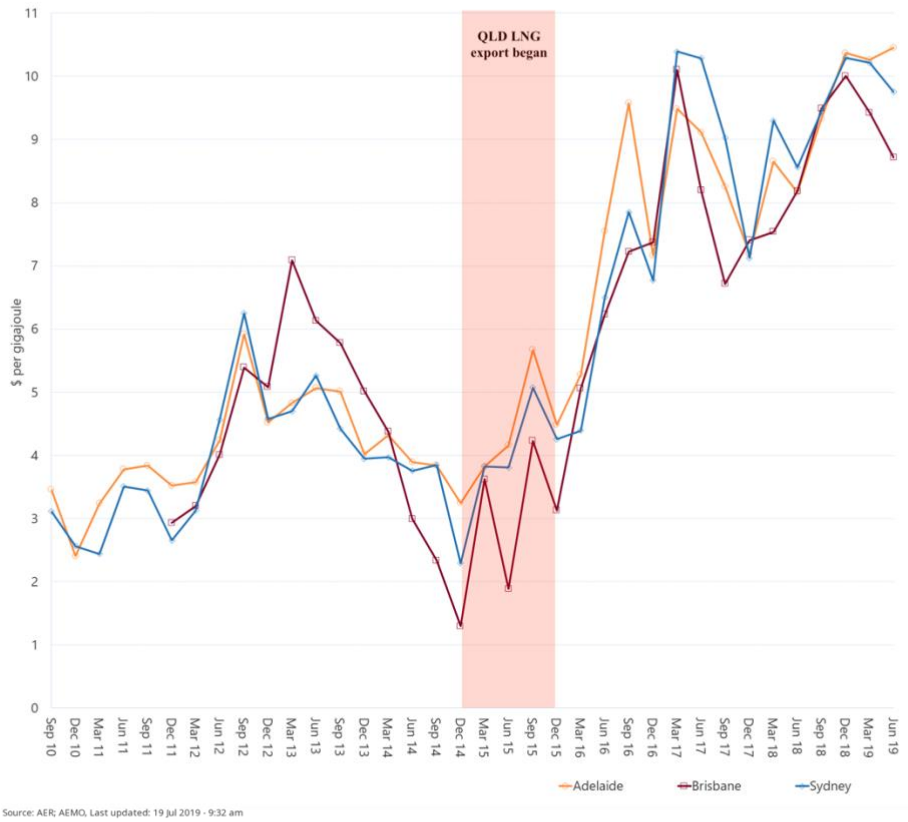


*Figure 5:Quarterly average 'short term trading market' natural gas prices ($/GJ) across the three eastern Australia wholesale gas markets since 2010. The three LNG Source: Australian Energy Regulator.*

# 4 STUDY PARAMETERS/METHODOLOGY

The methodology used to determine the selection of AMPC member locations as reference cases for the gathering of site-specific data was based on the application of modular CST and SG technologies and the environments that are suited for generation. Preferred locations for renewable adaptation were then cross referenced with AMPC member locations, areas of existing infrastructure and high population densities. Combining all data sets allowed the Study to identify and segregate into high to low potential regions and cross reference to member locations to identify the pros and cons of the technologies in each of the defined regions. Further aspects that affected this process included land availability for the adoption of modular CST systems, known geothermal hot spots and distances from gas networks.

## 4.1 Google Earth GIS Dataset

Google Earth was chosen as the GIS data set program to form a graphical presentation of site suitability and display for the Study. Google Earth, in contrast to ArcViwer and other GIS platforms, was selected due to its online availability to a wide range of organisations and its ability to be shared easily with other data sets. The data that was deemed essential for the Study included the following.

### 4.1.1 Solar Radiation

Solar radiation data was used to cross reference areas of high solar generation potential with abattoir locations to identify primary locations for modular CST technology. This data provides long-term averages of solar resources that determine solar generation potential. The data was sourced from SOLARGIS with three main sets of data shown on Google Earth;

1. *DNI –* *Direct Normal Irradiation*

   Solar radiation component that directly reaches the surface [kWh/m2]. It is relevant for concentrating solar thermal power plants (CSP) and photovoltaic concentrating technologies (CPV).

2. *GHI –* *Global Horizontal Irradiation*

   Sum of direct and diffuse components of solar radiation [kWh/m2]. It is considered as a climate reference as it enables comparing individual sites or regions.

3. *PVOUT –* *Photovoltaic Power Potential*

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Amount of energy converted by a PV system into electricity [kWh/kWp] that is expected to be generated according to the geographical conditions of a site and a configuration of the PV system.

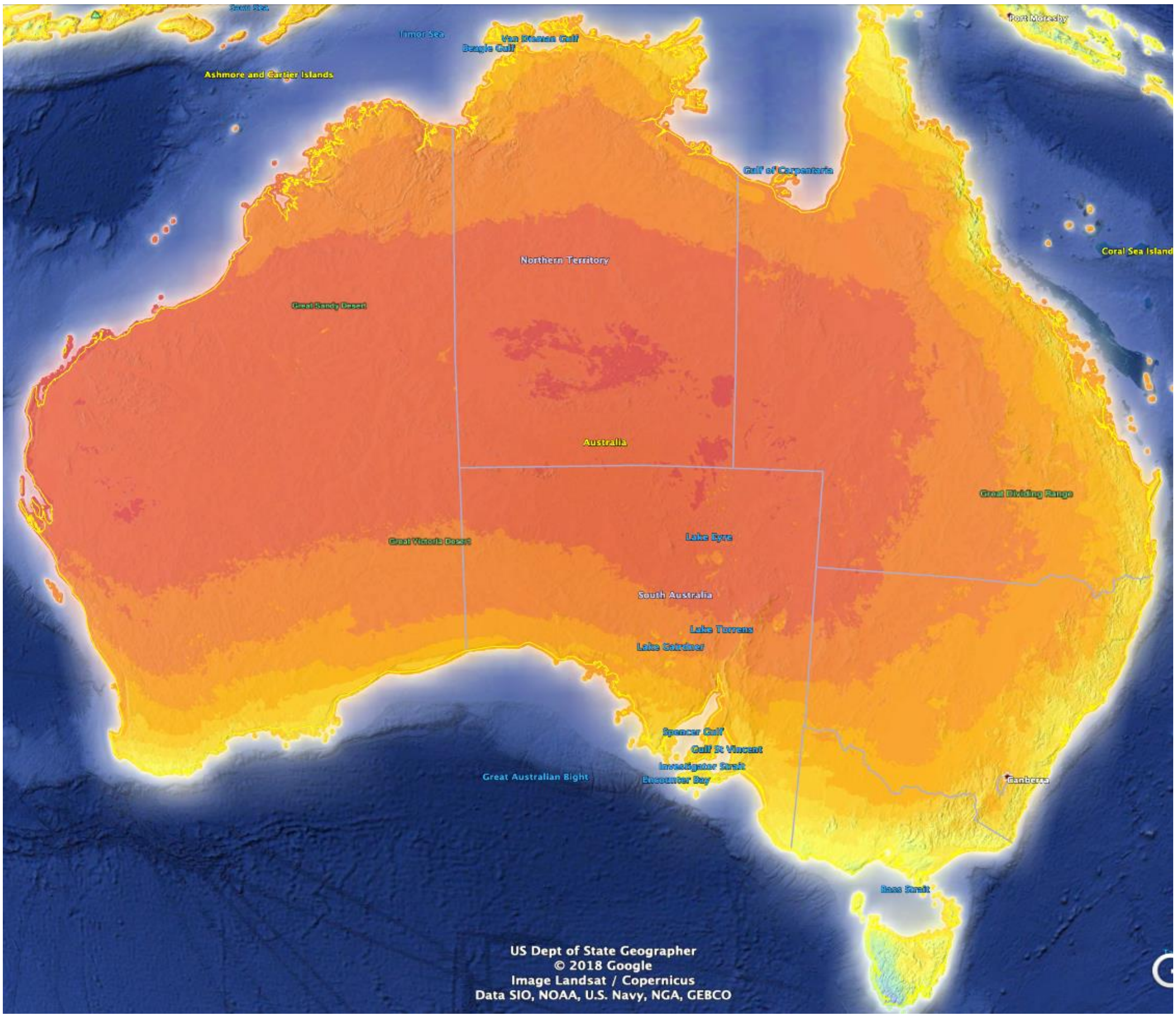

*Figure 6: Australian Solar Irradiation (RWA Google Earth Data Set)*

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### 4.1.2 Geothermal

Geothermal data was collected from the Commonwealth of Australia (Geoscience Australia). The OZTemp Interpreted Temperature was the first data set applied. It includes an interpretation of the crustal temperature at 5km depth based on the OZTemp bottom hole temperature database. The second data set applied was the well geothermal temperature and location, extracted from the OZTemp database. It currently contains 5,513 individual wells and 17,247 temperature or temperature gradient data records. Due to the range of sources of data, it is known to be of varying quality and reliability and should, therefore be used with discretion. However, the mapping represents the best available data compilation of its type as a basis for considering the abattoir locations that are potentially suitable for geothermal generation.

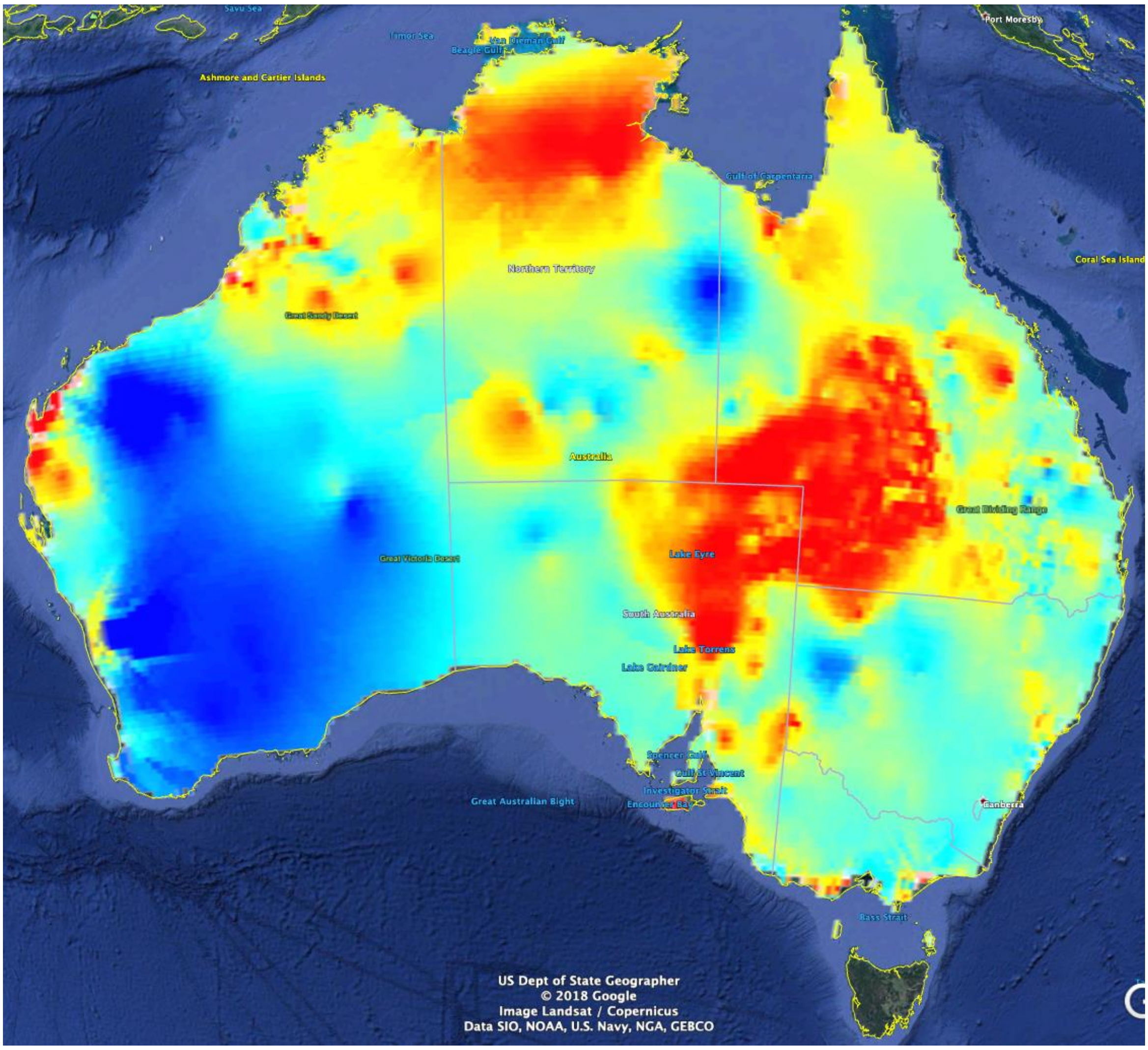


*Figure 7: Australian Geothermal Temperature at 5km Depth (RWA Google Earth Data Set)*

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### 4.1.3 Australian Abattoir Sites

Data for the locations of abattoirs in Australia were sourced from the Commonwealth of Australia database and imported into Google Earth. It consists of several layers of current and past locations, including possible future abattoir sites.

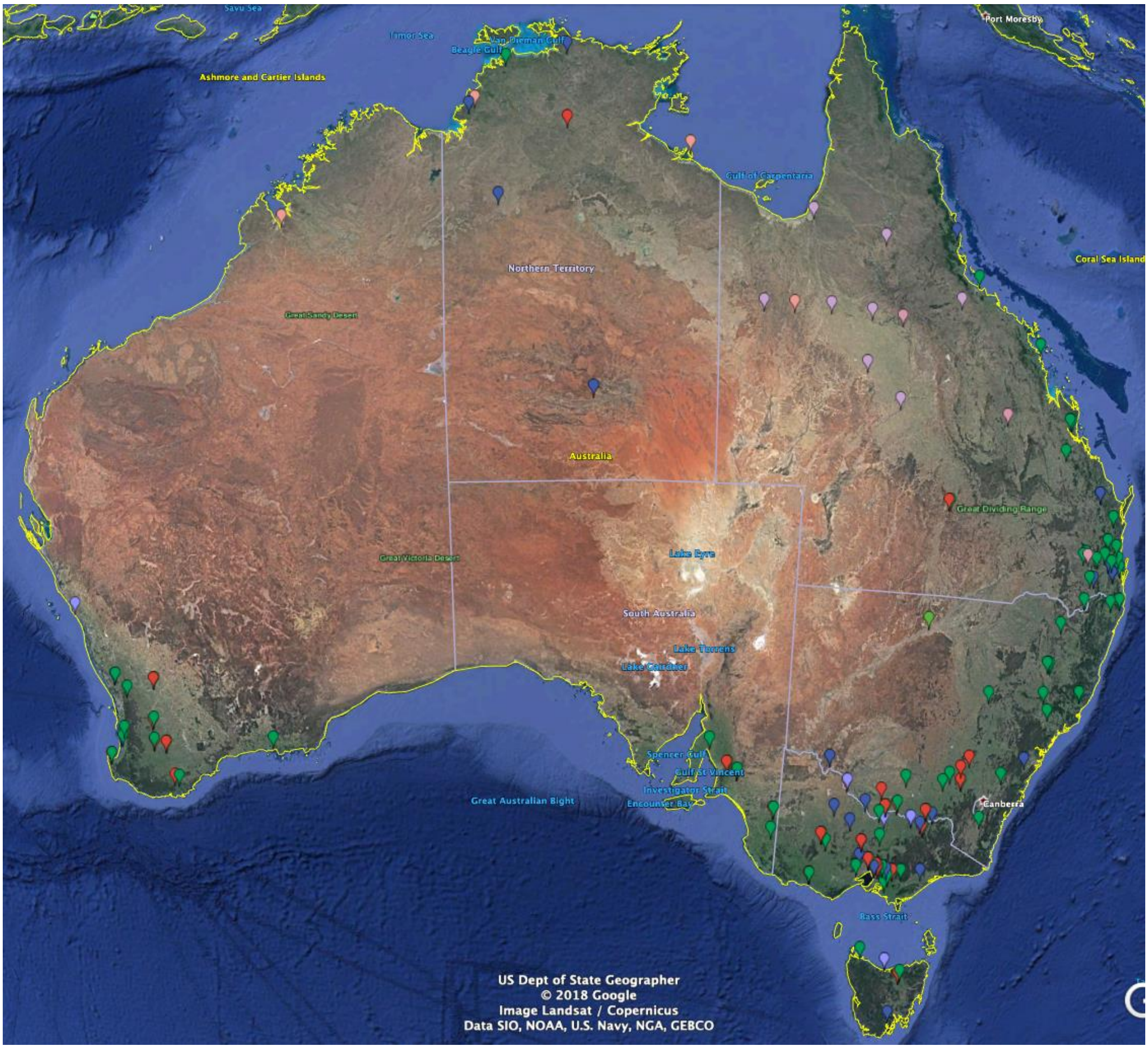


*Figure 8: Australian Abattoirs, Current & Future Sites (RWA Google Earth Data Set)*

### 4.1.4 Gas & Oil Pipelines

Data relating to gas networks was sourced from individual States and Territories, created by the Built Environment & Exposure Section, National Location Information Group, Geoscience Australia (GA).

This data presents all oil and gas infrastructure and presents the spatial locations of onshore oil and gas pipelines for the transmission of gas within mainland Australia.

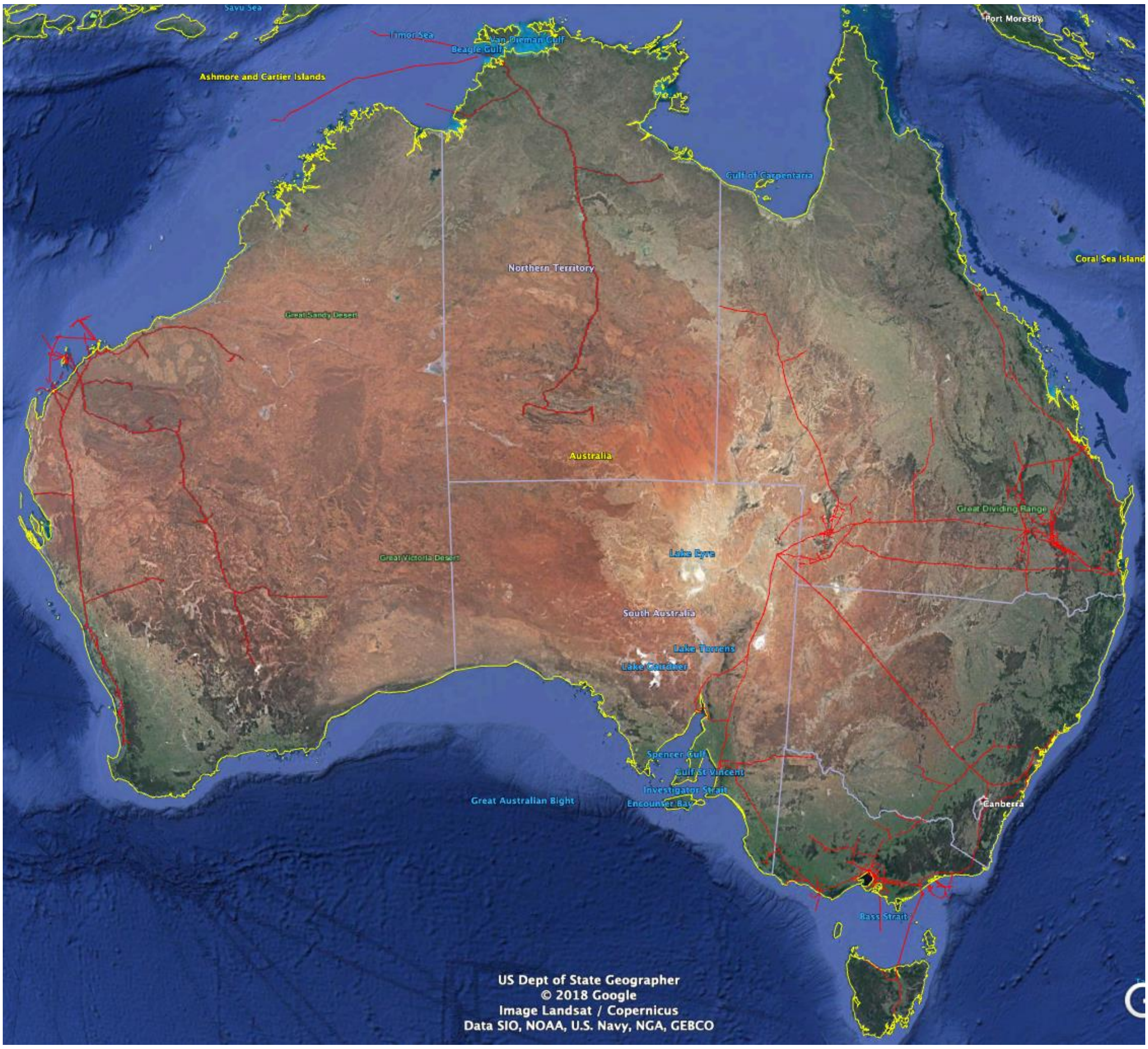


*Figure 9: Australian Gas & Oil Pipelines (RWA Google Earth Data Set)*

### 4.1.5 Population

Data for the estimated resident population is the official estimate of the Australian population, which links people to a place of usual residence within Australia. Estimates of the resident population are based on Census counts by place of usual residence (excluding short-term overseas visitors in Australia), with an allowance for Census net undercounts.

The data was sourced from Geoscience Australia.

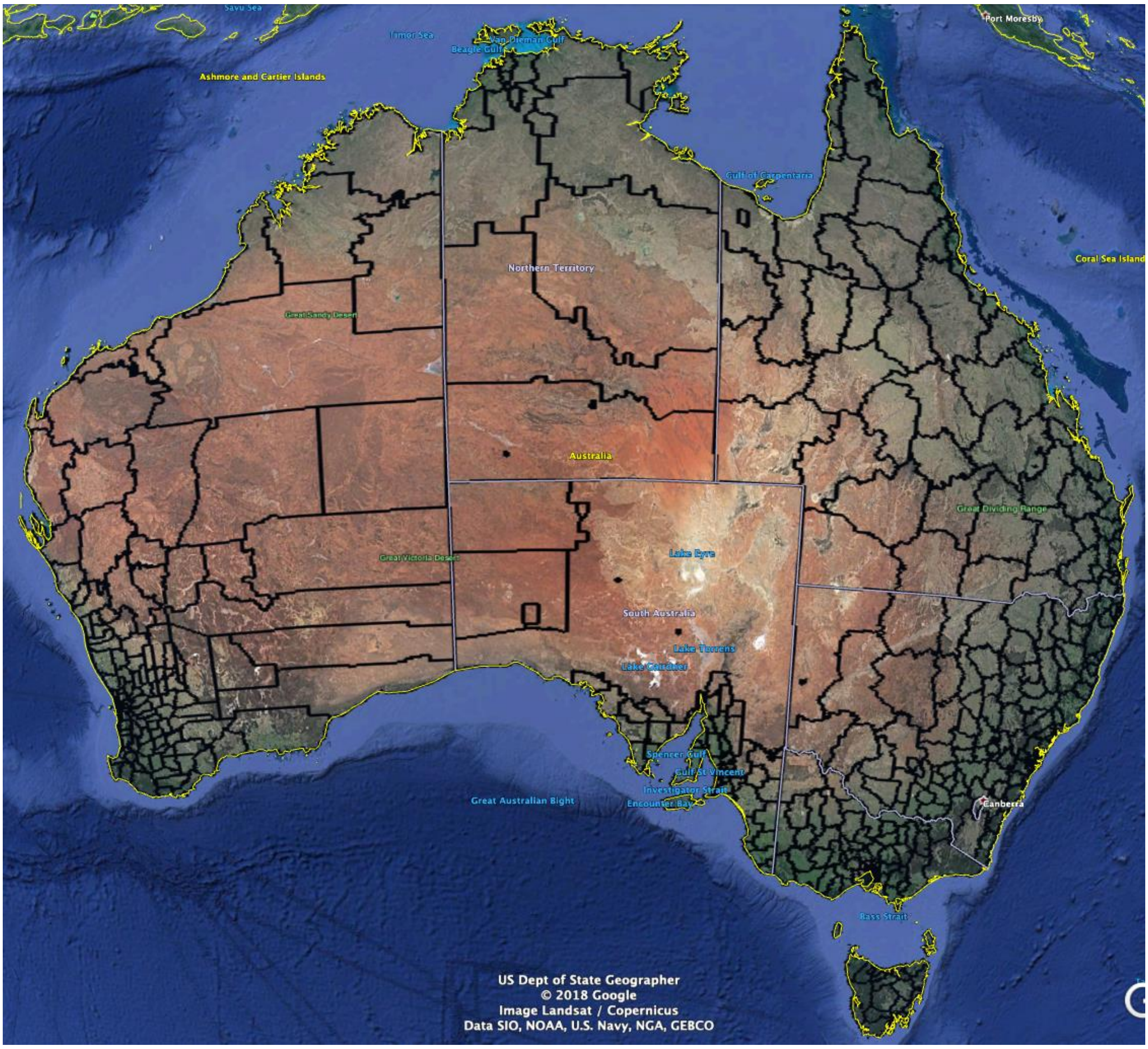


*Figure 10: Australian Population and Major Towns (RWA Google Earth Data Set)*

# 5 CONCENTRATED SOLAR THERMAL (CST)

Concentrating Solar Thermal systems collect solar energy using a large array of mirrors that reflect this energy into a high temperature receiver and pass this energy through to a receiver that then converts water into steam. The steam can then be used to drive generators or provide heat for industry uses. In the case of this Study, the application is focused on utilising CST to convert water to steam for direct use within the abattoirs

CST is an emerging technology within Australia and is being used increasingly around the world with over 5GW in operation today. This is due to an increased demand globally for dispatchable power generation in tandem with reductions in the emissions created from industry. As the major technical and economic advancements in CST continuing to mature the reductions in CAPEX and OPEX are also expected to continue, leading to further opportunities to exploit the viability of CST technologies in the Australian market and displace the use fossil fuels.

The majority of CST plants globally are used for electricity production incorporating between 3 and 15 hours of thermal energy storage. Until recently, CST installations have been constructed on a large (greater than 100MWe) grid supply scale, utilising enormous land areas, using exotic storage mediums (graphite/molten salt) and incurring high capital and operating costs generally beyond the reach of private industry. With recent advances in CST technology, this is no longer the case, with smaller modular systems requiring less land area, smaller capex and simpler operations.

CST does however have its limitations because of the required surface area footprint, even at small scale, and its reliance on high solar radiation. There are four main types of solar thermal systems used around the globe including Tower CST, Dish, Trough and Linear Fresnel:

### 5.1.1 Tower CST

Centralised reflective tower systems involve an array of heliostats (large mirrors with dual-axis sun-tracking) that concentrate sunlight onto a single fixed receiver point at the top of a tower.
This technology is favoured over others because it can achieve concentration ratios of up to 1,000 times, has excellent economies of scale, and can integrate thermal storage using molten salts, usually nitrates, as the heat transfer fluid, which enables them to generate electricity around the clock for grid supply purposes.

### 5.1.1.1 Solar Thermo-Electric Magaldi (STEM) (the subject of this study)

The principle of STEM is based on a solar tower layout utilising tracking reflective mirrors to concentrate sunlight onto a central receiver and then secondarily, into a chamber of silica sand. The sand is superheated to ~600+ °C with the sun's energy though which an array of pipework passes water through the sand to convert the water to steam. The steam can then be utilised directly or passed through a steam turbine the generate energy. The energy is able to be drawn on during both the day and night-time hours depending on the amount of energy drawn and (seasonal) sunlight energy available at the location.

STEM technology has been selected for this study due to the following factors;

- CST can be constructed on a small modular scale
- A relatively small land footprint of 7Ha per module
- Long operational life – 30 years+
- Robust technology that utilises low cost materials of concrete, glass and steel rather than exotic materials such as molten salt and nitrates
- Demonstration plant has been in operation since 2016
- Backed by the corporate and engineering strength of the Magaldi Group who specialise in thermal products for nearly 100 years.

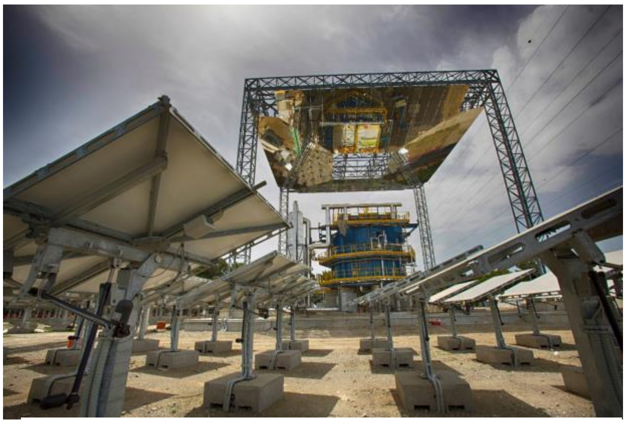

*Figure 12: STEM tower technology (Magaldi)*

*Figure 11: STEM tower technology (Magaldi)*

### 5.1.2 CST technologies not considered in this study

The following CST technology was not considered in this study, because they were addressed in another recent AMPC report on CST technology. The Magaldi STEM plant is a new and proven addition to the CST technology sector and therefore chosen to study the feasibility of implementation on AMPC member sites. The technologies not considered in the study are;

*Dish* – These are usually a paraboloidal dish reflector with two-axis tracking focusing sunlight to a point receiver located at the focal point of the dish. The dish structure must fully track the sun to reflect the beam into the thermal receiver. It can achieve temperatures in excess of 1500 °C.

*Trough* – A solar trough uses parabolic-trough-shaped mirrors that reflect the solar radiation onto a tube absorber located along the focal line of the trough, which then heats the fluid circulating through it.

*Linear Fresnel* – This system consists of long rows of narrow, flat or shallow-curved mirrors that move independently on one axis. These systems aim to offer lower overall costs, as compared with trough and dish concepts, by sharing a linear receiver between several mirrors.

### 5.1.3 STEM Pilot Plant, Messina Italy

The first Magaldi STEM technology was constructed and tested in San Filippo del Mela, Messina, Italy in 2016 with an industrial model pilot plant built to 2MW on 1.44 Hectares of land. The pilot plant has been running successfully for 3 years and has been generating superheated steam at approx. 550°C at over 50 bars, operating with a fluidised sand bed at temperatures around 600°C.

*Figure 13: Magaldi STEM Pilot Plant, Italy*

## 6 GEOTHERMAL

Geothermal energy is heat contained naturally within the earth. Natural hot water is a source of geothermal energy, as is the heat contained in solid rock. Tapping into natural geothermal aquifers is typically the cheapest way to access geothermal energy that can offset energy costs that might otherwise be incurred to heat water for industrial purposes. Heat, however, cannot be easily stored or transported, so the geothermal source must be located close to the site at which the heat is required.

When the International Geothermal Association last collated global geothermal energy statistics, it identified 163,300 gigawatt hours of heat ($GWh_t$) provided by geothermal energy for industrial purposes in 2015[1]. In contrast, geothermal sources were responsible for just 73,500 gigawatt hours of electricity generation ($GWh_e$) in that same year[2]. That is, direct use of geothermal heat accounted for more than two thirds of primary energy production from geothermal sources in 2015.

A recent census of geothermal energy installations in Australia[3] estimated total production of just 90 $GWh_t$ of geothermal heat for direct consumption in this country in 2019, or ~0.05% of the global total. It is clear that Australia remains far behind the rest of the world in its direct exploitation of geothermal heat. The primary reason for this is that energy prices in Australia were historically very low by global standards. This is illustrated by the doubling of east coast natural gas prices after Australia expanded its global liquified natural gas (LNG) market with the commissioning of three export facilities Queensland between December 2014 and December 2015 (Figure 14). The sustained rise in natural gas prices has stimulated interest in alternative sources of industrial heat over the past three years.

1 **Lund, J.W. and Boyd, T.L.** (2015). Direct utilization of geothermal energy 2015: Worldwide review. *Proceedings, World Geothermal Congress, Melbourne, Australia, 19–25 April 2015*.

2 **Bertani, R.** (2015). Geothermal power generation in the world, 2010–2014: Update report. *Proceedings, World Geothermal Congress, Melbourne, Australia, 19–25 April 2015*.

3 **Beardsmore, G., Davidson, C., Ricard, L., Pujol, M., Larking, A., and Bendall, B.** (2020). Current directions for geothermal energy development in Australia. *Proceedings, World Geothermal Congress, Reykjavik, Iceland, 26 April – 2 May 2020*.

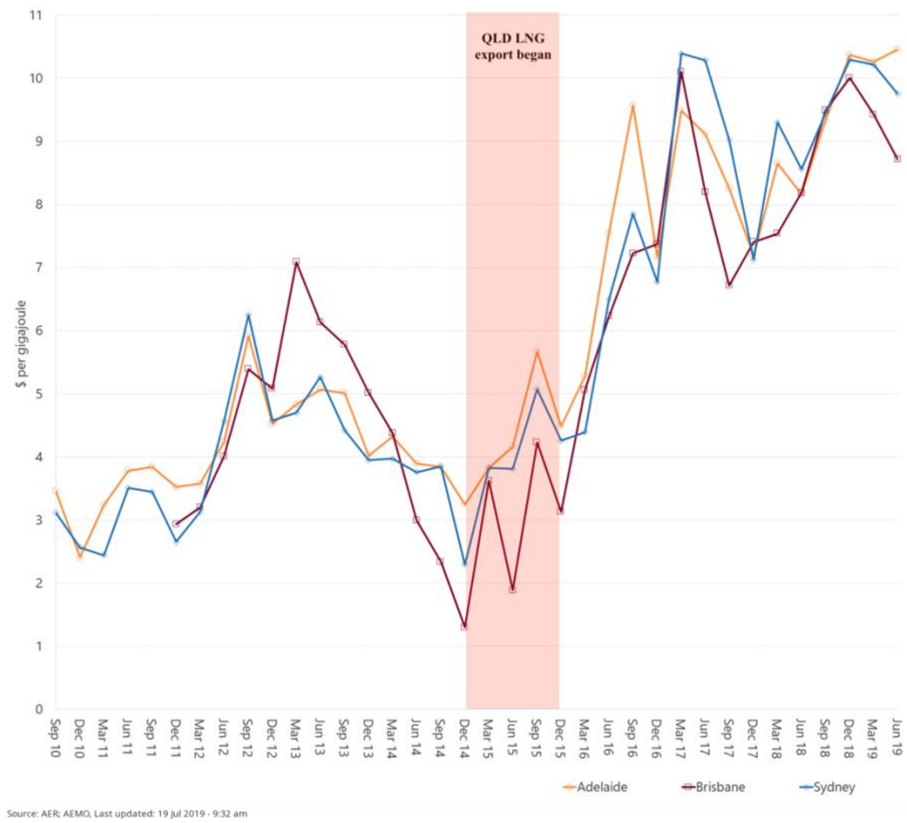


*Figure 14: Quarterly average 'short term trading market' natural gas prices ($/GJ) across the three eastern Australia wholesale gas markets since 2010. The three LNG Source: Australian Energy Regulator.*

## 6.1 Australian Geothermal Distribution

The map below shows the broad distribution of aquifers in Australia. In general, the dark blue and dark green areas with 'highly productive' aquifers are the most likely to host extractable geothermal resources at depth. The light green regions with 'low to moderate productivity' aquifers might be less prospective in general but could still host useful geothermal resources. In general, the brown areas are not expected to be prospective for natural sources of hot water. Four regions are highlighted below as examples of geothermal potential, but many other regions of the county might also be prospective.

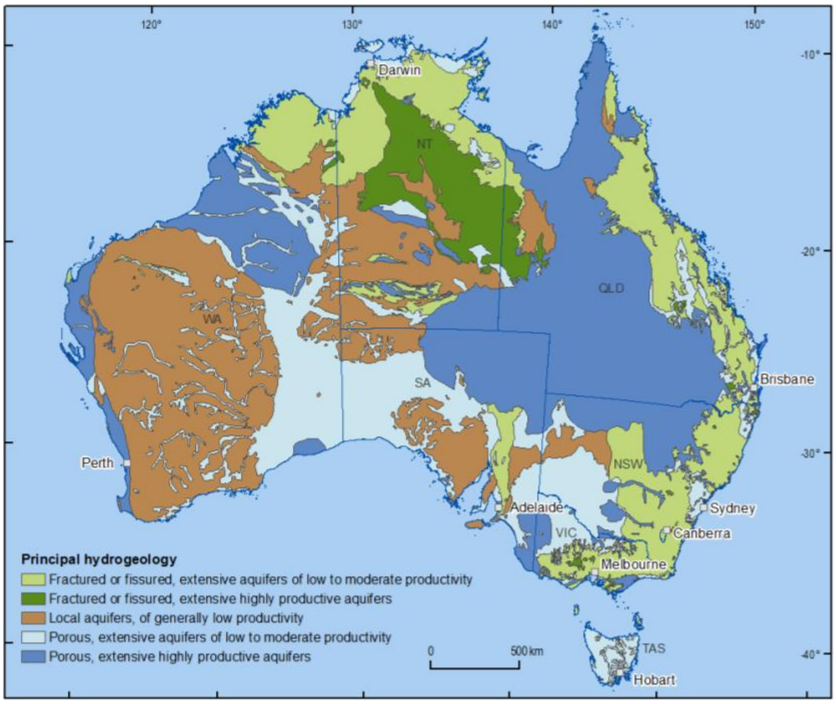


*Figure 15: Principal hydrogeology map of Australia. Source: Geoscience Australia*

### *6.1.1.1 Gippsland Basin—Victoria*

Local aquifer temperatures reach a maximum around Traralgon and further west, where thick coal seams provide thermal insulation and significantly boost the thermal gradient. Elsewhere, depth and temperatures of known aquifers generally increasing towards the coast.

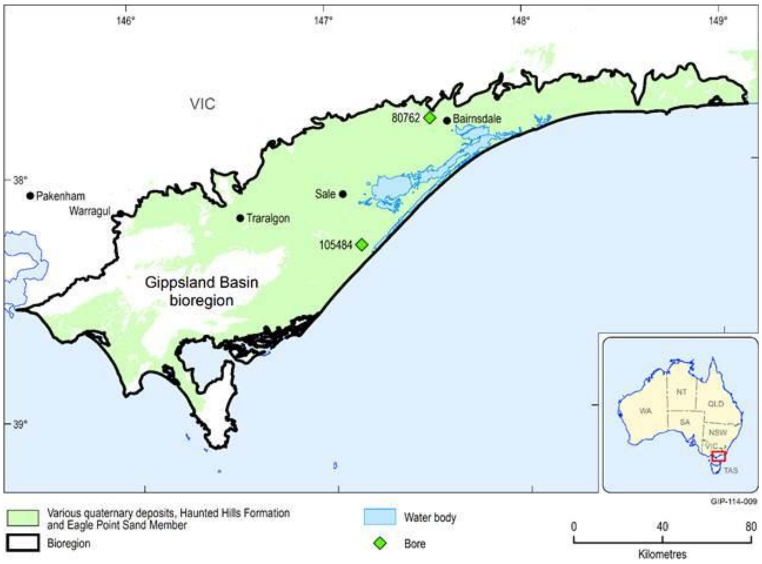


*Figure 16: Gippsland Basin temperature gradient*

AMPC

#### *6.1.1.2 Great Artesian Basin—SA, QLD, NT & NSW*

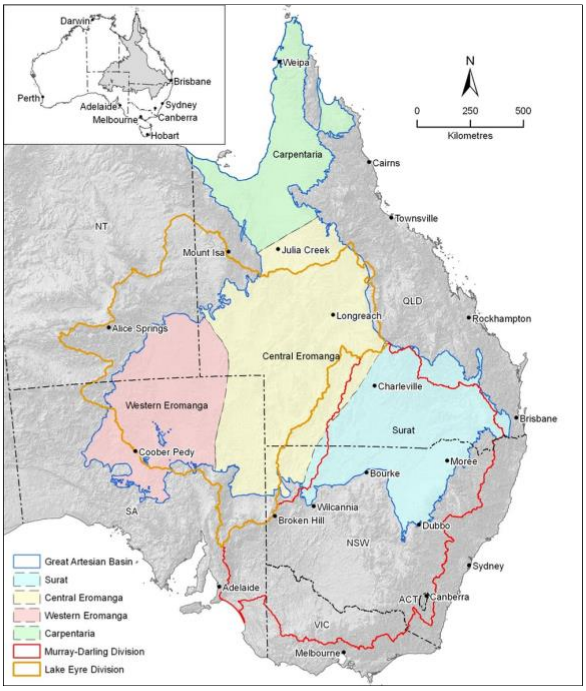


*Figure 17: Great Artesian Basin temperature gradients*

Aquifers in the Western Eromanga (pink), Central Eromanga (yellow), and Surat (blue) regions on the map above are already being utilized for their geothermal energy for bathing in a number of locations, and small-scale power generation in SW Queensland.

#### *6.1.1.3 Otway Basin—SA, Vic*

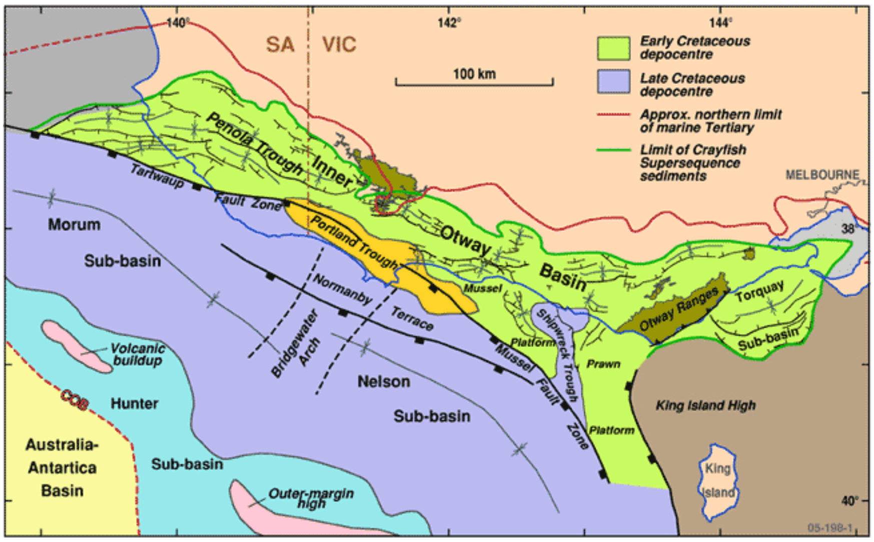


*Figure 18: Otway Basin geology*

Geothermal aquifers are known in the Otway Basin in the green and orange areas on the map presented in Figure 18. Although deeper than in the Gippsland Basin, these aquifers have historically been utilised to a greater extent, including the existing Deep Blue Hotel and Resort in Warrnambool (Vic), a barramundi farm at Robe (SA), formerly a district heating system in Portland (Vic), and an attempt at geothermal power production at Penola (SA).

#### *6.1.1.4 Perth Basin*


*Figure 19: Extent of the Perth Basin*

The Yarragadee Aquifer is already extensively exploited for geothermal heating of aquatic centres around Perth, for which economics favour geothermal heat over natural gas.

### 6.2 Industrial uses for Geothermal Heat

Geothermal sources can, in theory, provide heat for any industrial process that requires it. The amount of energy (joules) contained in hot liquid water is equal to the mass of the water (kilograms) times the specific heat capacity of water (4200 joules per kilogram per kelvin, J/kgK) times the temperature of the water relative to a base temperature to which the water can be effectively reduced. For example, relative to a base temperature of 20°C (typical ambient surface air temperature in southern Australia), 10 kg of 50°C water contains 10 x 4200 x (50 - 20) = 1.26 million joules of heat or 1.26 megawatts of thermal power ($MW_t$) that could theoretically be applied to an industrial process.

Industrial applications for the direct use of geothermal heat are limited only by the need for heat and the existence of a geothermal source. As well as a requirement for thermal power, however, most industrial processes also require heat to be delivered at a certain ‘grade’, or temperature. Figure 20 is a ‘Lindal diagram’ (after Lindal, 1973[4]) illustrating a selection of possible industrial applications for geothermal energy in different temperature ranges. Figure 20 is in no way an exhaustive list of possible applications, but merely a selection.

## 6.3 Historical uses in Eastern Australia

There has been recent steady growth in Australia in the use of geothermal water to offset the cost of industrial heating using natural gas. This has been especially evident in the exploitation of shallow geothermal heat for aquatic centres around Perth, and for a growing hot spring spa and bathing industry in Victoria. While these are two clear examples of shallow geothermal applications in Australia, they both represent relatively simple uses of natural hot water to provide hot water.

### 6.3.1 Australian Paper Manufacturer, Maryvale VIC

Burns *et al*. (1995)[5] reported that Australian Paper Manufacturer (APM) used natural 68°C water from two 600 m deep wells in its paper manufacturing process at Maryvale (near Morwell, Victoria) in the 1950s. The reason that APM abandoned the wells is unclear, but King *et al*. (1985)[6] put the decision down to “unspecified problems.” Paper Australia Pty Ltd still owns and operates the paper mill today.

4 **Lindal, B.** (1973). Industrial and other uses of geothermal energy. In: *Geothermal Energy, Paris, UNESCO, LC No. 7297*, 138, pp 135–148.

5 **Burns, K.L., Creelman, R.A., Buckingham, N.W. and Harrington, H.J.** (1995). Geothermal Development in Australia. *Proceedings, World Geothermal Congress, Florence, Italy, 18–31 May 1995.*

6 **King, R.L., Ford, A.J., Stanley, D.R., Kenley, P.R. and Cecil, M.K.** (1985). *Geothermal resources of Victoria — A preliminary study*. Department of Industry, Technology and Resources and the Victorian Solar Energy Council, Melbourne, 129 pp.

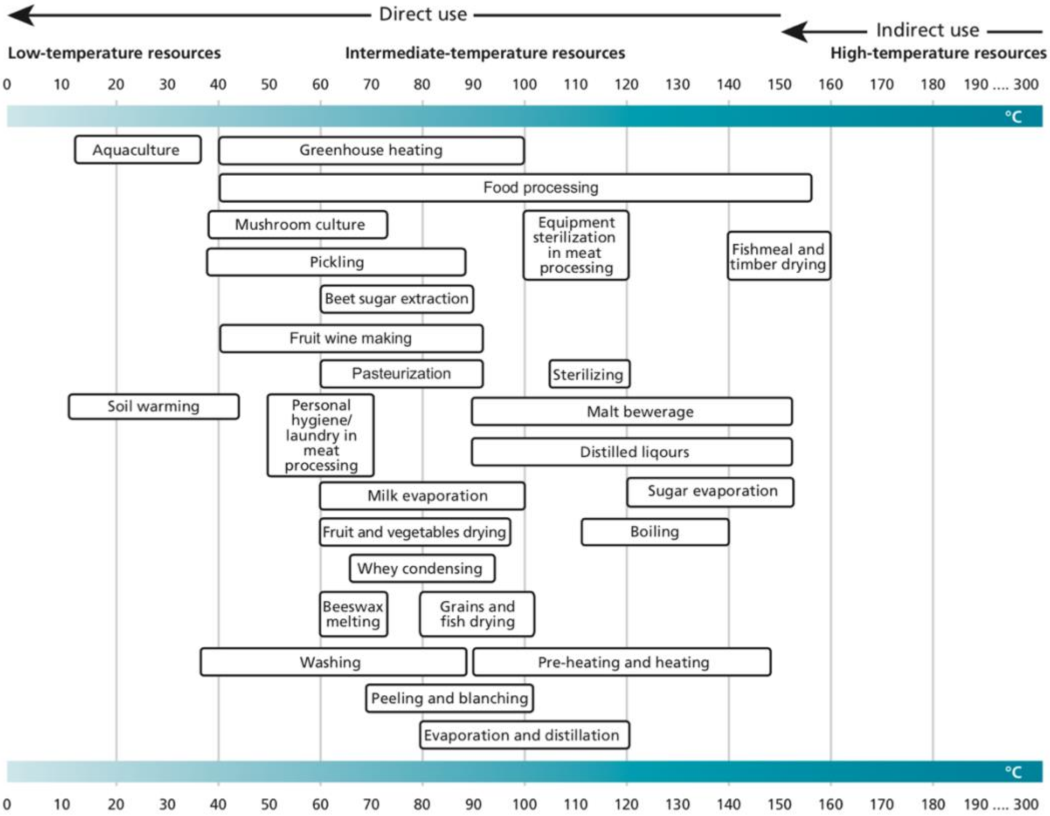


*Figure 20: 'Lindal diagram' showing possible industrial uses for geothermal sources at different temperatures. From van Nguyen et al. (2015).*

### 6.3.2 Mainstream Aquaculture, Werribee VIC

Mainstream Aquiculture (http://www.mainstreamaquaculture.com) runs a comparable barramundi farming operation at Werribee in Victoria, where the average annual air temperature is also 14.5°C. Mainstream directly uses 28°C fresh geothermal water at about 25 litres per second from several hundred metres depth, offsetting an average 1.4 $MW_t$ of process heat demand. The geothermal energy underpins Mainstream's business of spawning, hatching and growing fingerling and mature fish (Figure 21) for domestic and export markets.

*Figure 21: Mainstream Aquaculture operations at Werribee, Victoria*

### 6.3.3 Glenelg Shire Council, Portland VIC

A bore in southwest Victoria provided hot water for a reticulated hydronic heating system servicing about a dozen municipal buildings with a total area of 18,990 $m^2$ in Portland for 23 years. While the system was only used for space heating, it always held "prospects of expansion to manufacturing uses" (Burns *et al.*, 1995[5]). The bore produced water from between 1,250 and 1,420 m in the Dilwyn Aquifer at 56–59°C and up to 70 litres per second. With an average annual air temperature of 13.5°C, the bore provided more than 12 MWt of potential process heat (Chopra, 2005)[7].

### 6.3.4 Hazelwood Pondage, Churchill VIC

The Hazelwood Pondage was constructed in the 1960s to dissipate heat from steam condensers at the Hazelwood Power Plant (Figure 22), which kept the pond's temperature around 10°C warmer than nearby bodies of water year-round. Fisheries Victoria introduced barramundi into the Hazelwood Pondage in April 2016 and attracted 5,000 new visitors to the Latrobe Valley region over a four-month trial recreational fishing period spanning the 2016/17 summer.

*Figure 22: The Hazelwood Pondage in front of the now de-commissioned Hazelwood Power Plant, Churchill, Victoria*

[7] **Chopra, P.N.** (2005). Status of the geothermal industry in Australia, 2000–2005. *Proceedings, World Geothermal Congress, Antalya, Turkey, 24-29 April 2005*.

### 6.3.5 Deep Blue Resort, Warrnambool VIC

At the Quality Suites Deep Blue geothermal spa resort at Warrnambool, a 735 m bore produces 43°C water at a maximum of 50 litres per second. The bore provides heat to the domestic hot water and space heating systems of the resort's 80 rooms at an estimated 1.7 $MW_t$ of thermal power and over 30,000 $GJ_t$ of heat per year. The resort is currently undergoing a major expansion of its thermal bathing facilities.

## 6.4 Geothermal Sources, Aquifer vs 'Hot Rock'

Two main conditions must be met in order for there to be a commercially viable geothermal resource beneath any given location. The required temperature must exist at a depth that can be economically drilled, and there must be an aquifer at that depth from which the hot water can be produced at a sufficient rate to deliver the required thermal power. The geothermal energy content of the rocks is directly proportional to the rock temperature. The ability to *extract* that energy and bring it to the surface via a borehole is a function of the petrophysical properties of the aquifer such as porosity and permeability.

Temperature almost always increases with depth, but the rate of increase with depth (the 'geothermal gradient') can be different in different locations, controlled by geological factors. The geothermal gradient is the main control on the cost of drilling for geothermal energy, and hence the dominant factor influencing the financial viability of geothermal projects in any given location. Geothermal gradient cannot be artificially enhanced.

The petrophysical property of a rock formation that most directly affects its potential for geothermal production is its 'permeability-thickness' or 'transmissivity'. This is the cumulative permeability of the formation added over the full thickness of the target rocks. A thin, highly permeable aquifer can theoretically produce the same flow of hot water as a thicker, less permeable aquifer. If the natural transmissivity of the rock formation is initially insufficient to sustain commercial flow rates, its transmissivity can sometimes be enhanced by artificial methods. Such methods include chemical, physical or thermal stimulation, although these methods come with an added capital cost to the project.

Natural hot rocks with high transmissivity as the most attractive targets for geothermal energy. But hot rocks contain enormous amounts of heat even without significant natural permeability. 'Engineered geothermal systems' (EGS; Figure 23) aim to extract heat from such rocks. In an EGS system, a bore is drilled into a hot rock formation, and high-pressure water is injected to enhance the permeability of the rock. A second (and perhaps third) bore is then drilled to intersect the volume of enhanced permeability.

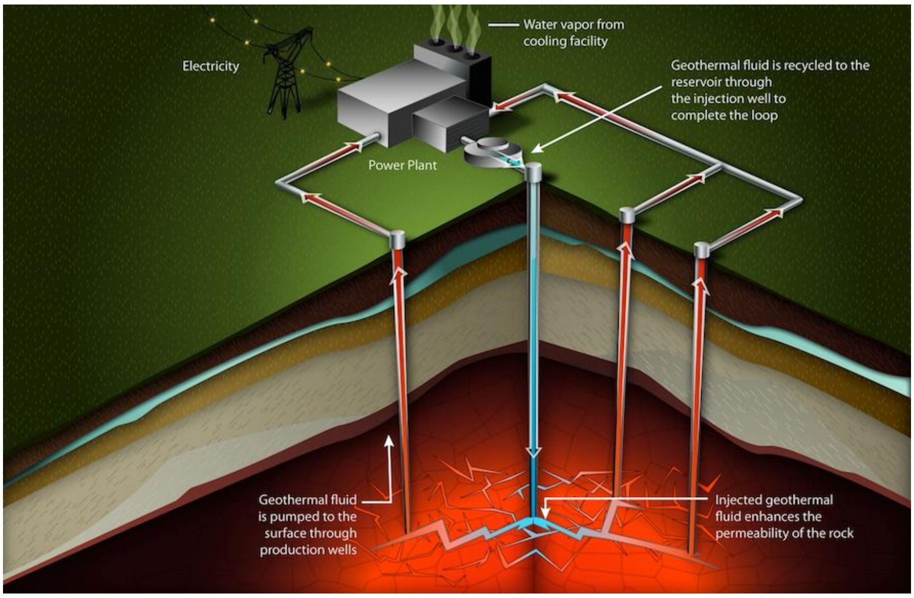


*Figure 23: Engineered geothermal systems' concept. Source: US Department of Energy*

A closed-loop circulation system established by pumping hot water from the production bore, extracting the heat from the water at the surface, then injecting the cooled water back into the reservoir where it permeates through the hot rock, reheating, before again being extracted from the production bore. EGS systems are capital-intensive and most suited to large industrial systems with constant heat demand. For example, an EGS project has been producing 24 $MW_t$ of industrial heat to dry starch at a bio-refinery plant at Rittershoffen in France since 2016[8]. The system produces geothermal fluid at 165°C and over 40 litres per second from a 680 m thickness of fractured sandstone and granite starting at 2,500 m depth, which was chemically and physically stimulated in 2014.

Geodynamics Ltd (GDY) operated a 1.0 $MW_e$ pilot electricity generation plant at its Habanero EGS project near Innamincka in South Australia for a 160-day period in 2013. Although it generated electrical power as a demonstration, GDY identified the most financially attractive option for developing the EGS project further was to partner with Beach Energy Ltd to provide power and

8 https://www.egec.org/a-world-first-for-geothermal-deep-egs-heat-plant-for-industrial-use-inaugurated/

process heat for a possible future shale gas development[9]. Unfortunately, a shale gas industry has not yet eventuated anywhere in Australia, and GDY abandoned the Habanero project in 2016.

Permeability enhancement techniques are useful if high natural permeability cannot be found where required. But there are likely to be locations in eastern Australia where warm productive aquifers are able to deliver reliable thermal power for industrial purposes without need for permeability enhancement. The technology for producing geothermal heat is proven and readily available. The next section describes the principal components of such a system.

[9] **Geodynamics Ltd**: *Geodynamics and Beach Sign Exclusivity Agreement*, release to ASX on 26 May (2014).

# 7 TECHNOLOGY

The technologies were selected based on their potential to address the energy challenges of the meat processing industry in an economically feasible manner utilising renewable energy to minimise operating costs. The CST and geothermal technologies are expanded on below;

## 7.1 Modular Concentrated Solar Thermal (CST)

### 7.1.1 Overview

The Magaldi STEM uses a heliostats field which concentrates sunlight onto a secondary reflector (beam down) and subsequently focuses the sunlight into a receiver, positioned at ground level. The receiver is based on a fluidized sand bed technology utilising 270 tons of fluidized sand.
level.

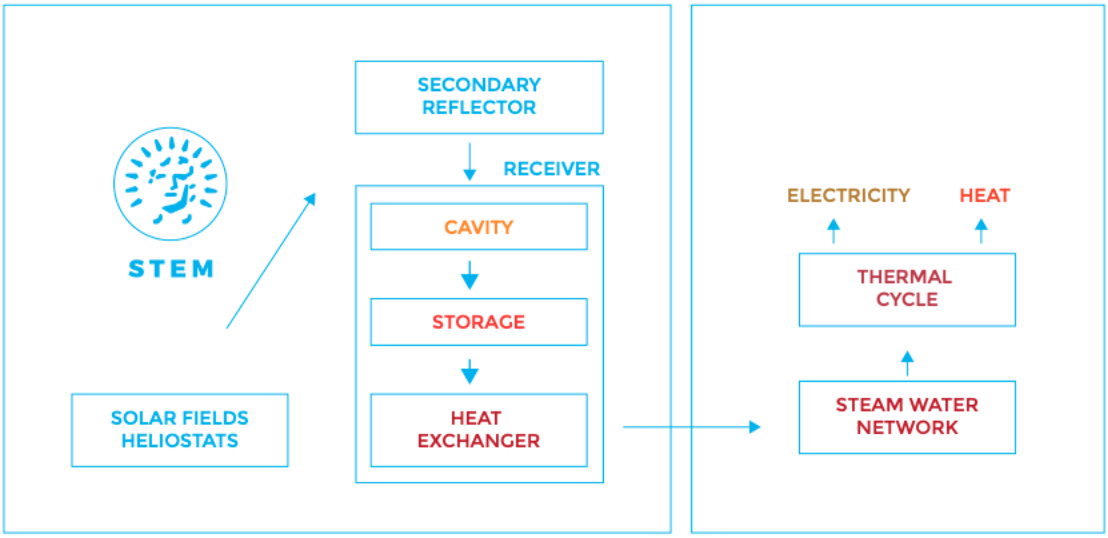


*Figure 24: Magaldi STEM configuration for steam and energy generation.*

### 7.1.2 Heliostats Field

Designing and characterizing solar concentrators for CST applications involves optimizing the concentration ratio of the radiation considering the collector cost and material limitations. A low concentration ratio implies low-temperature thermal energy and thus low exergy; a high concentration ratio implies large thermal losses from the solar receiver. In addition, heat losses at the solar receiver must be considered.

Choosing a concentrator (*i.e.,* reflector) type is one of the chief optimisation challenges. Magaldi uses a central receiver system with heliostats with each reflector having the ability to intercept and guide solar radiation to a thermal receiver that is engineered specifically for the heliostats and application.

In the present configuration of STEM module, the heliostats field includes 16,000 $m^2$ of total reflecting surface distributed into six subfields arranged in a circular shape, with the solar receiver located in the center.
Land occupation of each module is approx. 7.25 hectares and the maximum distance between receiver and farthest heliostat is approx. 150m.

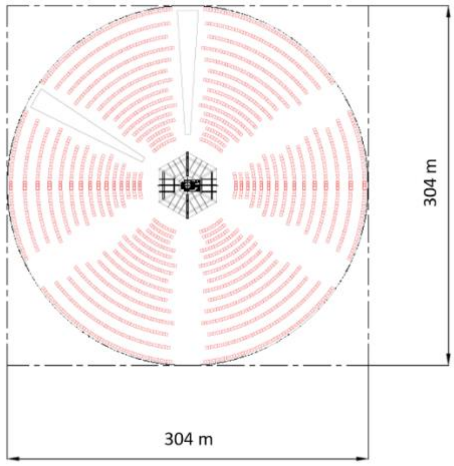


*Figure 25: STEM Module - Layout*

Each heliostat is moved by a double-tracking system. The main heliostats components are:

- Carbon steel supporting frame;
- No.2 spherical reflecting surfaces with reflective glass on a steel frame;
- Linear electric actuators for tilt and roll drive;
- Proprietary electronic mainboard.

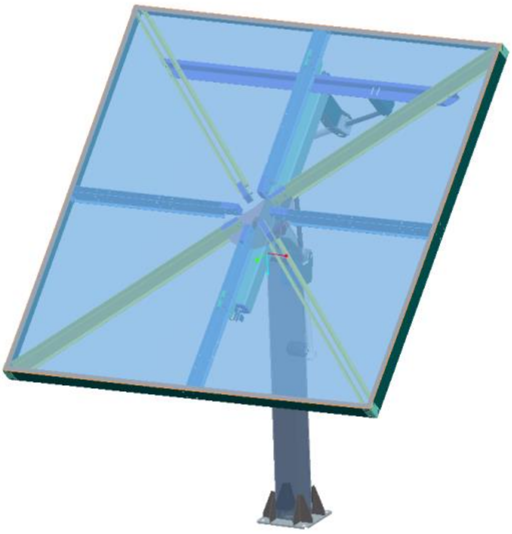

*Figure 26: Heliostat – 3D Assembly*

### 7.1.3 Secondary Reflector

The tower of the Magaldi system is comprised of a second set of solar reflectors that beam the solar rays down directly into the cavity comprising of fluidized sand.

The secondary reflector consists of six flat reflecting surfaces, one for each heliostat's subfield, suitably oriented to reflect the solar radiation down into the solar receiver opening. The reflecting surface is made of high reflecting aluminum sheets, glued on finned aluminum panels for temperature containment, totaling 1,900m2 reflecting area, supported by a steel structure approx. 35m tall, provided with six supporting columns.

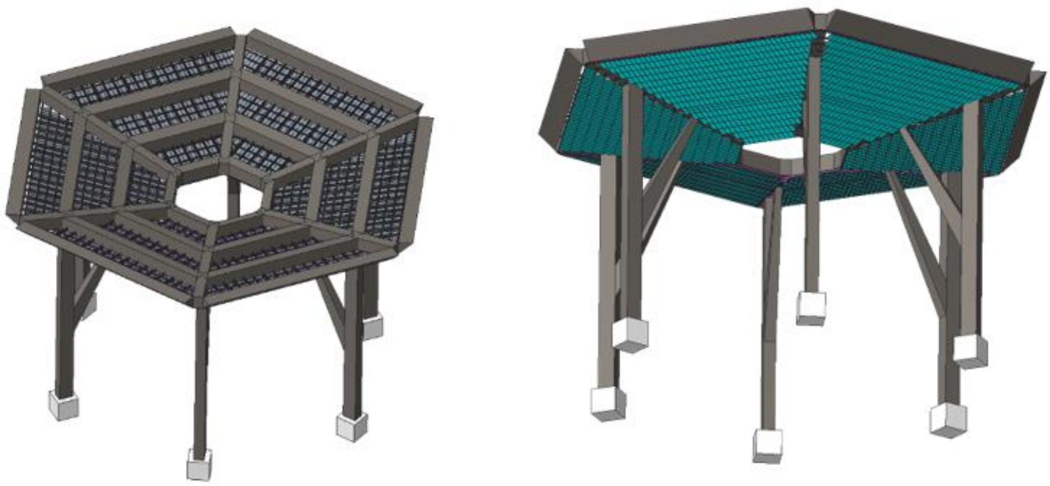

*Figure 27: Secondary Reflector Supporting Structure – 3D Assembly*

The supporting structure is designed in order to minimize environmental impact.

The main components of the secondary reflector are:

- Carbon steel supporting structure;
- High reflective aluminum sheets;
- IR camera to detect surface temperature of fluidised sand bed.

### 7.1.4 Receiver and Molten Sand

The integrated solar receiver is a fluidised bed boiler, made of a cylindrical body, internally insulated and refractory lined, provided with an aperture on the top side, to allow the inlet of solar radiation reflected by the beam-down tower.

The solar flux directly irradiates the fluidised sand bed which allows an effective absorption and transfer of solar energy to the entire bed inventory. Solar energy is stored in the bed inventory as sensible heat and can be transferred, when requested, to the heat exchangers suitably immersed into the sand bed for superheated steam generation.

A set of air injection manifolds is installed on the entire bottom of the integrated solar receiver, to activate the fluidisation of sand bed during the phases, that can be either simultaneous or not, of solar energy absorption into the sand and of heat transfer from the sand to the steam heat exchangers.

During the thermal energy storing time, in absence of solar energy absorption and steam generation, the sand bed is not fluidised and the top aperture is closed by means of a slide gate valve.

Air manifolds are divided into two main lines that can be operated with different fluidisation air velocities: one fluidisation airline is dedicated to serve the steam heat exchangers, the other is dedicated to the remaining area used for thermal energy storage.

Hot fluidising air, exiting from the top surface of the bed, is drafted through dedicated suction hoods, located in the freeboard area, by means of an external fan.

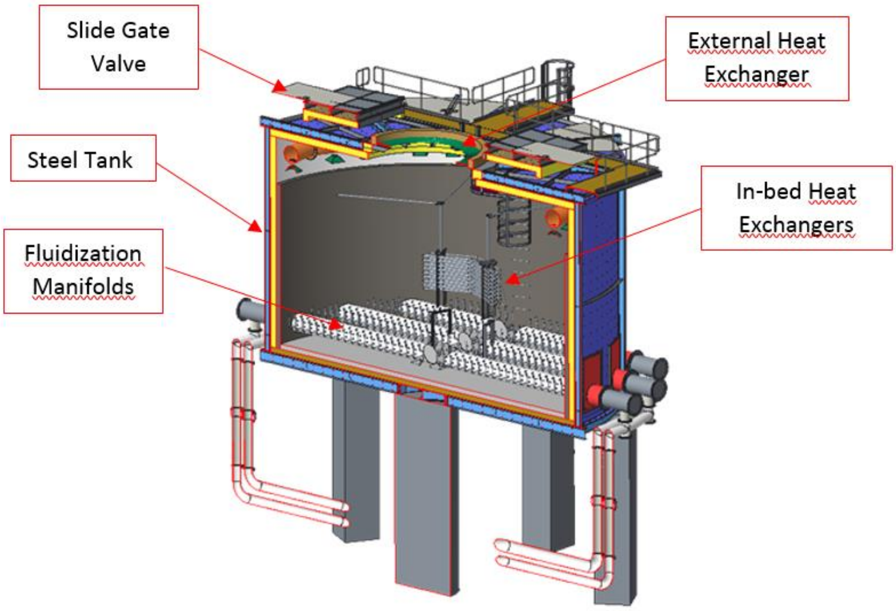


*Figure 28: Integrated Solar Receiver – 3D Section*

Around the integrated solar receiver top aperture, an additional steam heat exchanger is installed to collect the solar energy spillages out of the aperture. Main components of the solar receiver are:

- Carbon steel tank, internally lined with thermal insulation panels and casting refractory wall, with manhole for inspection and set of ladders and platforms;
- Stainless steel fluidisation manifolds for heat storage area;
- Solid particles bed inventory for heat storage;
- Stainless steel heat exchangers for superheated steam generation;
- Slide gate valve, thermally insulated, equipped with electric drives;
- Set of instruments (thermocouples, pressure transmitters) to detect process parameters;
- Suction hoods for drafting hot air from the receiver freeboard to the air pre-heater;
- Concrete pedestals for steel tank support (to be included in the civil work package);

The choice of particle material for the receiver is based on the material's poor aptitude for abrasion and fragmentation, in response to the need to minimise the phenomenon of bed particles elutriation, to limit the production and transportation of fines in the fluidisation air. Based on these considerations, a preferred configuration of the material is of granular particles that are inert to oxidation, e.g. silicon carbide or quartz and has a regular shape, preferably spherical and/or preferably having the size of the order of 50 to 500 microns.

Based on the preferred choice of particle material the Magaldi CST plant uses 270 tons of fluidized sand, at an operating temperature of 550-650°c. This fluidizable sand bed can carry out the dual function of storing the heat transferred from the walls and transferring the heat to further heat exchanging elements, through pipes being immersed within the bed. The receiver provides two independently fluidisable zones, the first portion of the bed is in contact with the receiving cavity, which storages the thermal energy and the second portion, which is used to effectively transfer and store the solar thermal energy of up to 8.2 MWh, which acts as a heat exchanger with the pipe network to create the required superheated steam.

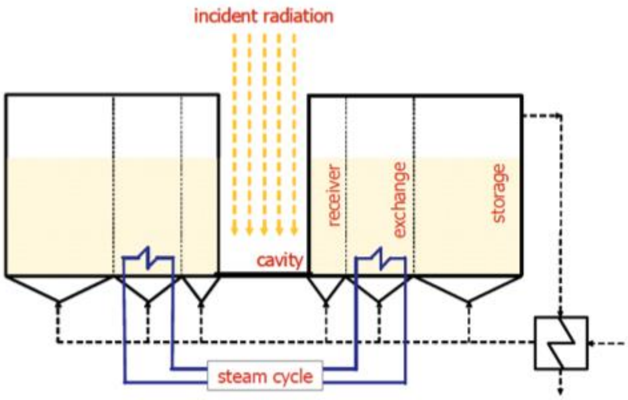


*Figure 29: Magaldi receiver configuration for thermal storage.*

### 7.1.5 Fluidising Air System

Fluidising air system is composed by two sub-systems: the first for fluidising air introduced into the receiver, the second for hot air drafting from the solar receiver to the pre-heater, dust filter and released to the environment.

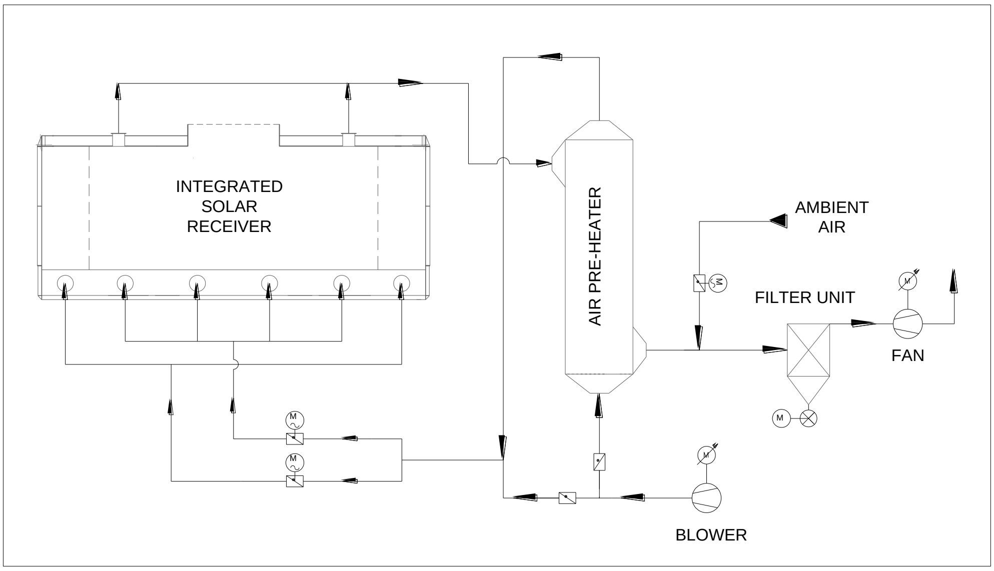


*Figure 30: Fluidising Air System – Schematic Diagram*

A blower is used to introduce ambient air into the receiver manifolds, after pre-heating, at any time the fluidising bed is operated, namely during sun operation to capture the solar energy and to generate steam.

A fan is used to draft hot exhaust air from the receiver freeboard, which passes sequentially into the pre-heater (to heat up the cold ambient air entering into receiver) and then into a filtering unit to collect airborne fines before releasing air to the environment.

Main components of the fluidising air system are:

- Blower, for air injection into the receiver;
- Set of air pipeline, expansion joints, shut-off valves to and from the receiver;
- Pre-heater, for air to air heat exchange;
- Bag filter;
- Fan, for air draft from the receiver freeboard;
- Set of instruments (thermocouples, pressure transmitters) to detect process parameters;
- Thermal insulation of the entire fluidising air system;

### 7.1.6 Automation and Control System

The Automation and Control system of a STEM module includes two different blocks: the first controls the module heliostats field, while the second controls the Solar Receiver process.

The supervision system of an entire STEM Plant coordinates the logics of all modules.

The MIR control allows, by a PLC, to perform the following main functions:

- interface to the STEM® and Power Block supervision system, to produce the steam flow rate (at controlled temperature and pressure) required to the STEM® module
- controlling the fluidising air system, and solar aperture slide gate valve, to capture and store solar energy;
- controlling the steam heat exchangers, to allow for steam generation
- monitoring, through a SCADA, all process parameters recording operational data, for historical analysis and monitoring;
- calculating the efficiency of the plant.

Magaldi has designed and developed a dedicated software program to control the heliostats fields: Magaldi Heliostats Control System – MHC.

Each heliostat is provided with an electronic control board communicating by private protocol on serial bus. The electronic control board drives the heliostat actuators, setting the relative position and decoding the encoder signal obtained from the current position.
MHC algorithm calculates, with the astronomical equation, each heliostat position along the day in order to guarantee the correct aiming on the secondary reflector focus.

An autocorrection system, based on artificial vision (BCS: Beam Characterization System) is incorporated in the logics, in order to calculate possible aiming error of each heliostat and accordingly correct its position.
Each heliostat periodically points on the BCS target, a camera acquires the solar spot image on the target and a PC, using image detection algorithm, measures the offsets between the solar spot centroid and the target. A correction is calculated and then sent in real time to the heliostat and stored in a data file.

The algorithm works like an expert system: it uses the data stored (experience) to implement new and more accurate aiming trajectories, in order to compensate for possible misalignment occurring during the plant lifetime, due to any reason (heliostats foundations positioning and stability inaccuracy, small deformations of heliostats frames, etc).

## 7.2 Geothermal

### 7.2.1 Overview of Technology

Geothermal energy is brought to the surface for direct-use applications via groundwater. Therefore, a bore for producing 'low grade' geothermal energy is effectively a water bore designed with allowances for; water temperature, required flow rate, durability and chemistry. A borehole pump is usually installed to ensure reliable and controllable delivery of heat. Once above ground, the geothermal water can be passed through a heat exchanger to transfer its heat at approximately the same temperature, or a heat pump to boost the heat to a higher temperature, without consuming the water itself. In most circumstances, sustainability and/or regulatory considerations require the geothermal source water to be reinjected back into the aquifer after heat extraction.
A geothermal production system, therefore, requires most or all of the following pieces of plant: production bore, borehole pump, heat exchanger, heat pump and reinjection bore.

### 7.2.2 Production Bore

All sources of geothermal energy are, by definition, underground and require a ‘production bore’ to access them. Drilling and completing a production bore requires time and takes up land area at the surface, so the process can impose temporary disruptions on a business. A drilling rig will usually be on site for between one and two weeks to complete a geothermal bore. Good advanced geological knowledge, experience and planning can minimise the disruptions.

The components of a production bore include casing, screen, cement, wellhead and surface works (Figure 31). After drilling, casing and screen are cemented in place, surface works completed, and a pump installed. These activities are described below in more detail.

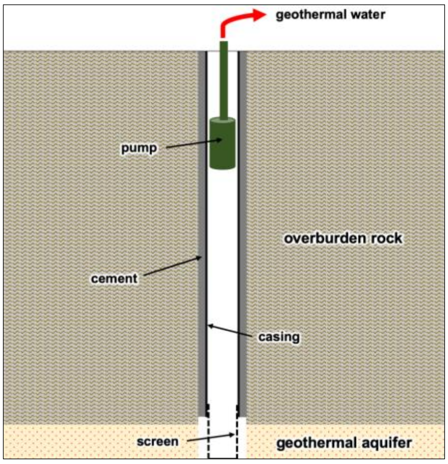


*Figure 31: Generic subsurface components of a geothermal bore*

#### *7.2.2.1 Drilling*

In general, geothermal bores tend to be deeper than regular water bores to access higher temperature water at greater depths. For example, bores accessing the Yarragadee aquifer for geothermal heating around Perth are between 750 m and 1150 m deep[10]. The main production bore at Peninsula Hot Springs south of Melbourne is 650 m deep. Such bores can typically be drilled using truck-mounted ‘rotary mud rigs’ (e.g. Figure 32) which require a relatively small operating footprint. These rigs grind the rock with a drill bit (normally ‘tri-cone’) on the end of an assembly of solid drilling rods rotated by a motor at the surface, while circulating a thick muddy slurry through the hole to cool the drill bit and lift the rock chips to the surface. Drilling usually continues around the clock until reaching the target depth, so as not to allow the mud to settle and

10 **Pujol, M., Ricard, L.P., and Bolton, G.** (2015). 20 years of exploitation of the Yarragadee aquifer in the Perth Basin of Western Australia for direct-use of geothermal heat. *Geothermics*, 57, 39–55.

harden in the hole. Continual access is required to water and mud holding tanks, which can also be truck mounted.

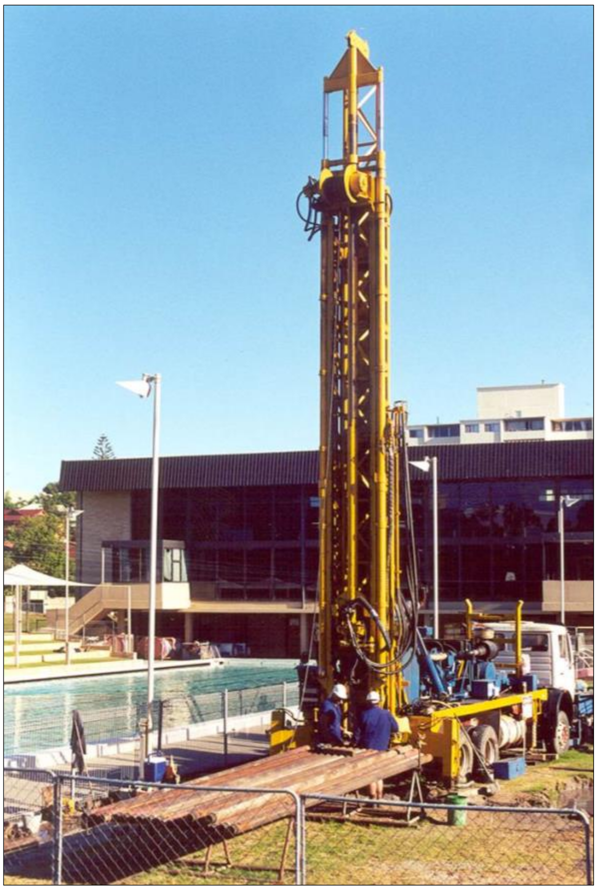

*Figure 32: A rotary mud rig drilling at the Christ Church Grammar School geothermal project, Western Australia, 2001. Source: Rockwater Pty Ltd.*

There are local commercial drilling companies with appropriate equipment in most parts of Australia, although only a few have experience drilling geothermal bores. DrillTec in Victoria (www.drilltec.com.au/) and JSW Australia in Western Australia (https://jswaustralia.com/) are two examples of Australian drilling companies with geothermal experience.

#### *7.2.2.2 Casing*

'Casing' is a hollow sleeve of cylindrical pipe (Figure 33) installed permanently into the bore immediately after drilling, from the surface to a depth usually just above the geothermal aquifer zone. The primary purpose of casing is to stop the walls of the bore from collapsing. Casing can be made from various grades of steel, fibre glass, polyvinyl chloride (PVC), Teflon or other materials, with more durable materials coming at greater cost. The design lifetime of a bore is primarily a function of the casing material. While it is possible to design and case a bore to last much longer than 50 years, cheaper initial casings can also be relined with narrower casing at the end of their initial life.

*Figure 33: Lengths of casing ready to be emplaced in a geothermal bore in Turkey, 2005*

When choosing a casing material for a geothermal bore, it is important to consider factors such as the required lifetime of the bore, the expected temperature and chemical composition of the water, and the nature of the connection to the screen at the base of the bore (see below). Hot, corrosive geothermal fluid can destroy mild steel casing and cause bore failure much faster than the notional design life of the same bore producing benign fluids.

The most common cause of failure within bores is rupturing of the weld between different materials at the casing–screen connection. The potential for rupture can be mitigated for mild steel casing (10-year life) by using extra heavy wall steel and a special connection to the stainless-steel screens. This option would typically add <5% to the cost of a bore but could extend bore life to 25-years.

#### *7.2.2.3 Screen*

'Screen' is a special section of casing emplaced within the geothermal aquifer. Screens are similar in many respects to normal casing but are 'slotted' or perforated to drain groundwater from the geothermal aquifer into the bore cavity. While screens can technically be made from any of the same materials as casing, geothermal bores in practice usually employ stainless steel screens (Figured 34). The slots have a small aperture to allow water to seep into the bore, but to exclude most mineral grains. As noted above, the point at which the screen is welded onto the overlying casing can be a weak point in bore construction if not properly considered during both design and implementation.

*Figure 34: Lengths of slotted stainless-steel screen to be installed in a geothermal bore in Western Australia in 2017. Source: Rockwater Pty Ltd.*

### *7.2.2.4 Cement*

Permanent casing is generally cemented in place for a geothermal bore. The cement is injected from either the top or (via a tube) the bottom of the bore into the 'anulus'—the gap between the wall of the bore and the outside of the casing. The cement holds the casing in place and isolates and protects any shallower aquifers from contamination or cross-flow. Like the casing material, cement properties should be designed for the specific temperature and chemistry of the rocks and groundwater, and design lifetime of the project.

### *7.2.2.5 Head and Surface Works*

The headworks complete the bore once it has been drilled, cased and cemented. The headworks attach directly to the top of the casing and typically include various valves and flanges to allow a pump motor or other equipment to be mounted on top, and to direct the flow of geothermal water into surface pipes (Figure 35). The design of the headwork should also consider bore security, effective sealing, future access into the bore interior for monitoring or maintenance purposes, pressure control for artesian wells, any gas that might need venting, temperature differentials during operations, compatibility with water composition, and other matters.

*Figure 35: The headworks of a geothermal bore in Turkey, capped with a line-shaft pump motor, 2005*

### 7.2.3 Borehole Pump

All geothermal systems require pumps, even if the bore is naturally artesian. Pumps are essential to control the rate of water flow, which controls the thermal power delivered by the bore, and to maintain pressure and flow through the above-ground plant. There are two main categories of borehole pumps, 'line-shaft' and 'submersible'. Both are typically 'turbine' pumps, which use rotational force to push water into pipes that discharge to the surface. The main difference between the two is line-shaft pumps have a motor installed above ground, while submersible pumps have a motor in a waterproof housing at the bottom of the pump and operate entirely submerged in the bore.

Line-shaft pumps can be driven by many different size and orientations of motor. Having the motor above ground significantly reduces installation, maintenance and replacement costs relative to pulling a submersible motor back to the surface for servicing and maintenance.

Submersible pump motors can also be as much as six percentage points less efficient than line-shaft motors (88% vs 94%[11]) because of their smaller diameter and because they usually operate in an oil medium. On the other hand, being fully submerged in the borehole, submersible pumps are generally silent, while an above-ground motor running a line-shaft pump can produce a substantial amount of noise.

The range of pump products is such that it is generally possible to find one to precisely suit the requirements of any given project, although it is wise to consider pump options at the same time as the rest of the borehole design. Pump choice depends on the required flow rates, natural reservoir pressure, bore diameter, hydraulic resistance of surface pipes and plant, water chemical composition, maintenance schedules, life cycle cost, and other factors.

Pumps are readily available from many Australian manufacturers and suppliers. Davey Water Products (https://davey.com.au/) and Dynapumps (https://www.dynapumps.com.au/) are two examples of local firms manufacturing and retailing their own lines of stainless-steel submersible pumps. Other retailers include Industrial Pumping (http://www.pumping.com.au/), Pump Solutions Australasia (https://pumpsolutions.com.au/), All Pumps (https://allpumps.com.au/) and Water Bore Pump Warehouse (https://www.waterborepump.com.au/). There are many others.

Pumping consumes electricity so represents an operational expense for the system. For example, Davey Water Products' largest six-inch submersible pump fitted with its largest motor (Figure 36) could lift 60 $m^3$/hr (16.7 L $s^{-1}$) of 45°C water with a 200 m head. This would potentially provide about 350 $kW_t$ of thermal power at the expense of about 35 $kW_e$ of electrical power.

11 https://www.waterworld.com/municipal/technologies/pumps/article/16191770/submersible-vs-lineshaft-vertical-turbine-pumps-advantages-and-limitations

| Operating Limits | |
|---|---|
| Nominal flows | 18, 27, 45, 60 m3/hr |
| Maximum flow | 77 m3/hr |
| Heads | 500 metres |
| Motors | 5.5kW to 37kW |
| Water Temperature Range | 10°C to 50°C |

*Figure 36: Images, operating limits and other specifications for the range of six-inch submersible pumps from Davey Water Products. From https://davey.com.au/*

### 7.2.4 Heat Exchanger

Geothermal water is not directly used in most industrial applications, but the geothermal heat is transferred to a secondary fluid (liquid or gas) via a heat exchanger. The maximum temperature of the secondary fluid exiting the heat exchanger is always less than the inlet temperature of the geothermal fluid, although the temperature difference can be as low as 1°C in a well-designed system.

The two main categories of heat exchanger are 'shell-and-tube' and 'plate' heat exchangers. In practice, most geothermal applications use plate heat exchangers because they are generally more compact, scalable, easier to maintain, and cheaper than the shell-and-tube variety.

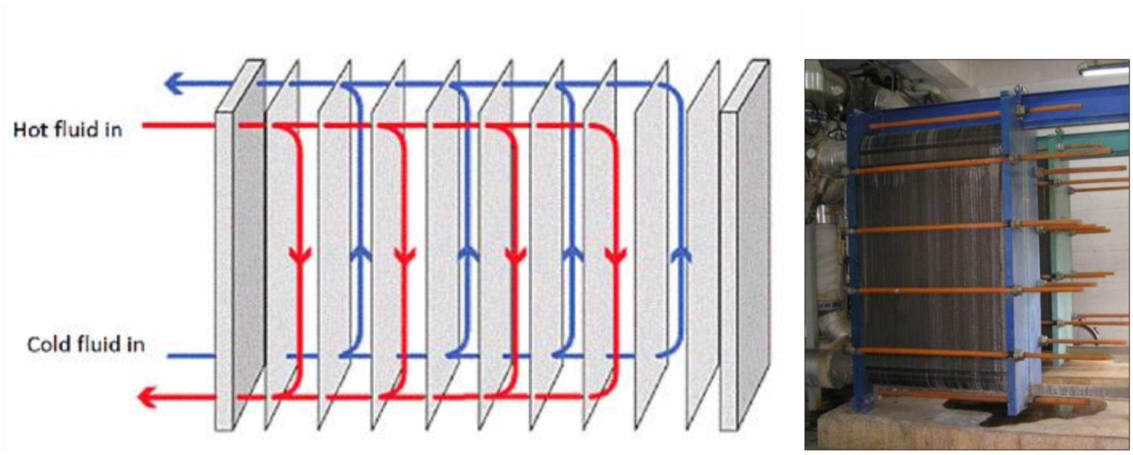


*Figure 37: (Left) Counterflow of geothermal and secondary fluids through a plate hear exchanger, like that shown at (right) for a district heating system in Turkey. Left hand figure from http://www.ipieca.org.*

Plate heat exchangers rely on the primary and secondary fluids moving turbulently through narrow planar spaces separated by thin, thermally conductive walls. They have relatively high hydraulic resistance so require pumps on both the primary and secondary circuits to generate pressure differentials to sustain the required flow rates.

An appropriate heat exchanger is chosen after considering the fluid chemistry, heat exchange rates, and fluid flow rates. Australian manufacturers include Sepak Industries Pty Ltd (https://www.sepak.com.au) and Sondex Australia (http://www.sondexaustralia.com.au/). Many other companies retail and service international brands of plate heat exchanger.

### 7.2.5 Heat Pump

Heat pumps can heat ambient water to almost boiling point with high efficiency by extracting heat from geothermal sources above ~30°C. Working fluids within heat pumps vaporise (boil) through indirect contact with a heat source such as geothermal water. The temperature and pressure of the vapour are then significantly increased using a compressor running on electricity. The high temperature vapour heats the ambient stream of water as the vapour condenses back to it liquid state before returning back through the cycle to collect more geothermal energy. By replacing a natural gas boiler with a high-efficiency geothermal heat pump, energy costs are transferred from natural gas to substantially lower electricity usage. While the economics of heat pump systems must be assessed on an individual basis, under the right conditions they can offer cost effective and low emission solutions for industrial supplies of hot water.

Heat pumps can use many different types of working fluids, each with different thermodynamic properties. This allows heat pump systems to be specifically designed for optimal performance for any given geothermal source temperature and required water process temperature. Working fluids include a range of synthetic hydrocarbon compounds and supercritical $CO_2$. Note that the working fluids circulate in a closed loop and are neither consumed nor released to the atmosphere under normal operating conditions.

The efficiency of a heat pump is referred to as it 'coefficient of performance' (COP). COP is the amount of heat produced by a heat pump for each unit of electrical energy consumed. Figure 38 shows indicative COPs (vertical axis) for optimised heat pump systems depending on geothermal water temperature (horizontal axis) and process water temperature (coloured lines). For example, a heat pump drawing on >40°C geothermal water could produce 70°C process water

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(green line) with a COP = 8. In simple terms, this means 1 MJ of electricity (0.28 kWh) could replace >8 MJ of natural gas.

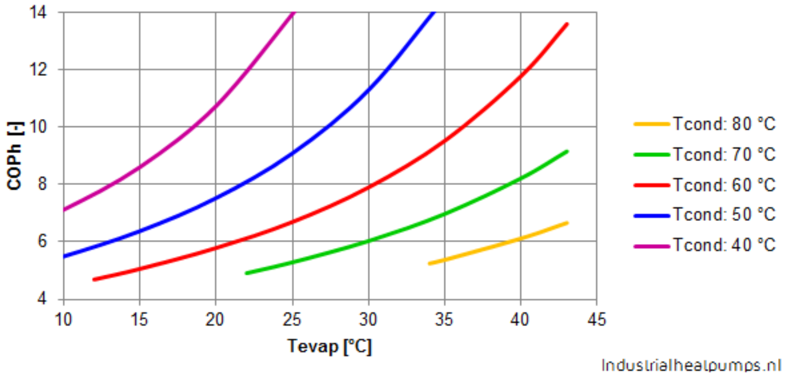


*Figure 38: Indicative heat pump COPs for approximate input temperatures (Tevap [°C]) and output temperatures (Tcond [°C]). Source: www.industrialheatpumps.nl*

### 7.2.6 Reinjection Bore

The primary value of geothermal water is in its heat, so the water itself is often a 'waste' product requiring disposal. While surface disposal is usually the cheapest and easiest solution, there are often technical and/or regulatory reasons to reinject the cooled water back into the source aquifer. This requires a 'reinjection' bore. The main technical reason for reinjection is to maintain the aquifer pressure. There are many international examples where unrestricted production of geothermal water has led to long term declines in aquifer pressure. Declining aquifer pressure results directly in either declining borehole flow rates (less thermal power) or increased pumping requirements (greater operational expense).

Reinjection might also be imposed by a state regulator as a condition for access to the geothermal water.

Reinjection of cooled geothermal water into sedimentary aquifers is still a relatively under-researched topic. There is often a period of 'trial and error' to optimise the geothermal system in terms of minimising and stabilising the pump power required to reinject the water. Technical risks associated with reinjection include 'thermal breakthrough', fouling (clogging) of the screens, and damage to the reservoir itself.

Thermal breakthrough is when the cool, reinjected water migrates through the aquifer to the production bore, with resulting rapid cooling of the production water. This risk is best managed by careful hydrogeological modelling before selecting the reinjection site, with a typical aim to locate the reinjection bore a significant distance down-flow from the production bore.

Screens at the aquifer level in reinjection bores can foul due to biological growths, chemical precipitation, or physical motion of particles. The result is an increase in required pump power and/or an increase in maintenance costs. While these effects sometimes become apparent only during operation, the risks should be carefully assessed and mitigated as much as possible during the design phase. Ungemach (2003)[12] and Siebt & Kellner (2003)[13] provide two of the best reviews of reinjection of cooled geothermal water into sandstone aquifers. The geological and geochemical conditions in the aquifer are critical parameters for successful planning, construction and operation of geothermal systems. It is good practice to include geological and hydro chemical studies as an interim step between drilling a production bore and planning a reinjection bore, and to consult an experienced hydrogeologist.

### 7.2.7 Summary

The components of a geothermal system include most or all of a production bore, borehole pump, heat exchanger, heat pump and reinjection bore. The design and implementation of each component should be considered with reference to each other and the characteristics of the overall (including subsurface) system. Critical characteristics to consider include (but are not limited to) the depth, thickness, temperature and composition of the host rocks for the aquifer; the temperature and chemical composition of the geothermal water; how the water and rock composition might change with a change of temperature; how the water composition might impact the borehole and surface plant; the flow rate necessary to produce the required thermal power; the expected lifetime of the project; water disposal; maintenance schedules and others. The technical performance of a geothermal system is generally optimised if it is properly designed and planned at the outset.

[12] **Ungemach, P.** (2003). Reinjection of cooled geothermal brines into sandstone reservoirs. *Geothermics*, 32(4–6), 743–761. DOI: 10.1016/S0375-6505(03)00074-9.

[13] **Seibt, P. and Kellner, T.** (2003). Practical experience in the reinjection of cooled thermal waters back into sandstone reservoirs. *Geothermics*, 32(4–6), 733–741. DOI: 10.1016/S0375-6505(03)00071-3.

# 8 AUSTRALIAN CLIMATE ZONES

The sites chosen for detailed assessment in Stage 2 were selected based on their operating characteristics, location alignment and suitability for detailed assessment. The environmental climate data was assessed around Australia of known mainland geothermal aquifers and solar radiation latitudinal and climatic range and referenced between AMPC Meat Processor sites for their relative potential for alternative energy solutions. The zone's benefits and site locations are explained below.

## 8.1 Solar Thermal Zones

Solar irradiance is the power per unit area received from the sun in the form of electromagnetic radiation. Direct irradiance is equal to the extraterrestrial irradiance above the atmosphere minus the atmospheric losses due to absorption and scattering. Therefore, it is important to understand the distribution of clouds and aerosols to help define the expected performance of the CST plant in the chosen location.

CST plants rely on Direct Normal Irradiance (DNI) that can be concentrated into the receivers and stored within the chosen medium, therefore for the purpose of this Study, Australia's solar irradiance has been split into 4 zones to justify CST's performance for abattoirs falling within these zones. As seen in figure 39 and table 4 the zones are split by highest DNI, zone 1, to lowest DNI, zone 4, to show the viability of implementing the Magaldi STEM system in this current financial market.

*Table 4: Solar Zone Irradiance per Magaldi Unit*

| Zone | Average DNI | Productivity | Surface Area | Gas Offset/Unit (±10%) | CAPEX | Cost Savings/Unit |
|---|---|---|---|---|---|---|
| Zone 1 | 2,922 + | High | 7ha | ~105,000 GJ | $13.5M | $1.26M |
| Zone 2 | 2,774 | Medium/High | 7ha | ~97,000 GJ | $13.5M | $1.16M |
| Zone 3 | 2,373 | Medium | 7ha | ~78,000 GJ | $13.5M | $936k |
| Zone 4 | 1,826 | Low/Medium | 7ha | ~64,000 GJ | $13.5M | $768k |

Table 4 shows each zones average DNI number and the displacement of gas possible per Magaldi unit and the land area needed. Because the Magaldi units can be modularised, more then one can be built depending on land area available and amount of gas offset needed.

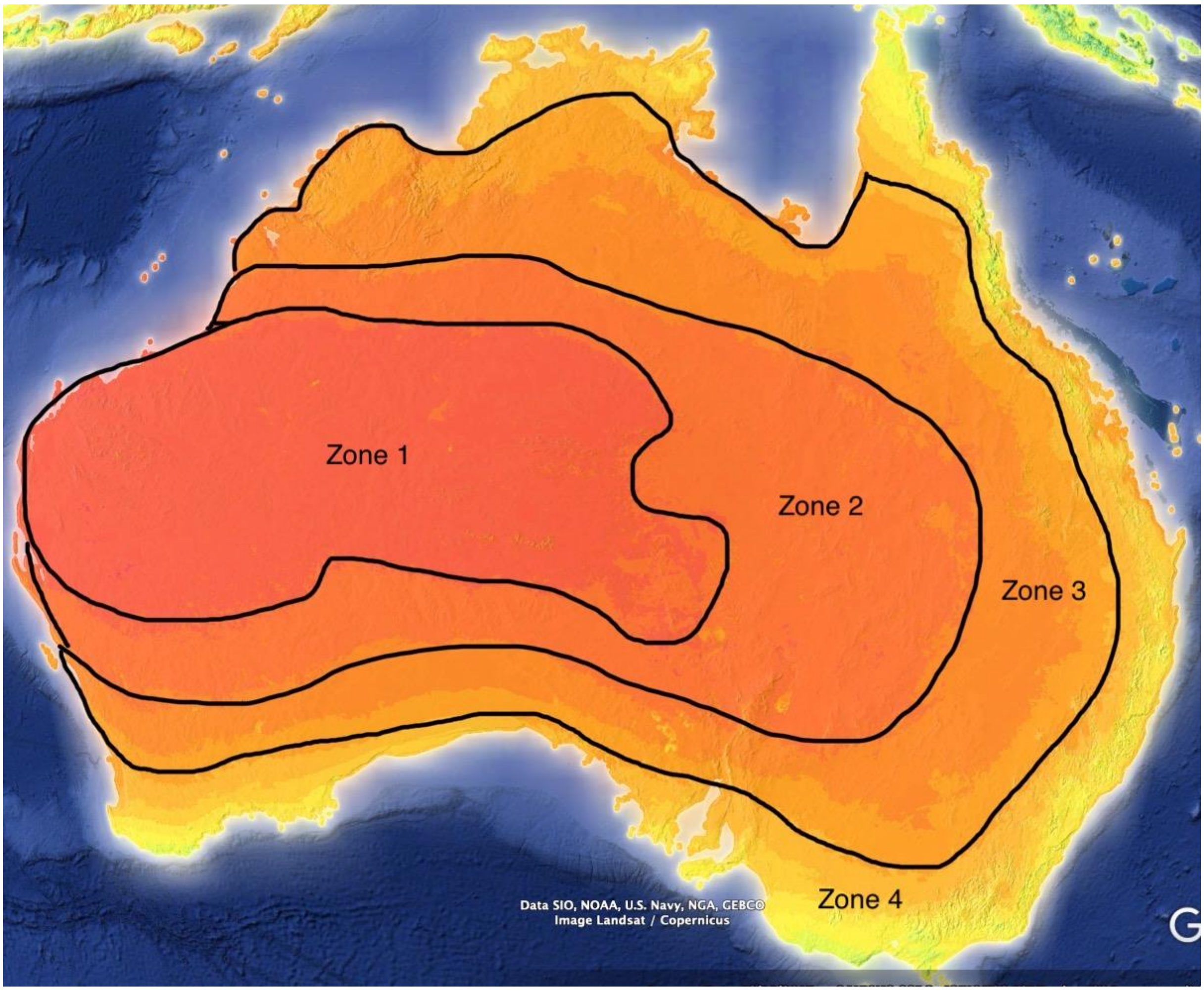


*Figure 39: Australian Solar DNI Zones*

Within each State the listed meat processing facilities have been segregated according to their alignment to the DNI zones. This details which facilities fall within the high potential Zone 2 and 3 areas (given that no sites exist at this point within Zone 1) and are well positioned to take advantage of modular CST technology.

*Table 5: Ideal Suburbs for Solar Summary*

| | Zone 2 | Zone 3 | | | |
|---|---|---|---|---|---|
| **Suburbs** | Charleville, 4470<br>Rudds Gully, 6530 | Bunbury, 6230<br>Cobram, 3644<br>Cowra, 2794<br>Dubbo, 2830<br>Gundagai, 2722<br>Harvey, 6220<br>Inverell, 2360 | Katanning, 6317<br>Nathalia, 3638<br>Narrogin, 6312<br>Oakey, 4401<br>Picton, 6231<br>Swan Hill, 3585<br>Tallangatta, 3700 | Tatura, 3197<br>Tamsworth, 2340<br>Two Wells, 5501<br>Wagga Wagga, 2650<br>Wangaratta, 3197<br>Wodonga, 3689<br>Yanco, 2703 | Young, 2594 |

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### 8.1.1 Queensland

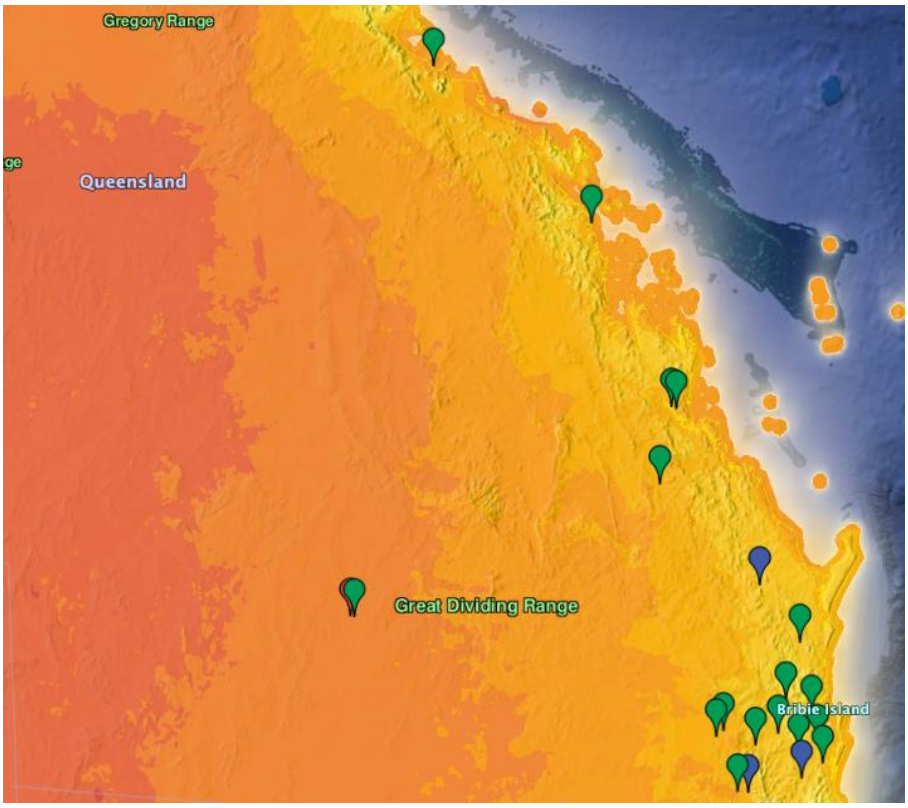


*Figure 40: Queensland Solar Radiation*

*Table 6: Queensland AMPC Member Solar Zones*

| | Zone 2 | Zone 3 | Zone 4 |
|---|---|---|---|
| **Suburbs** | Charleville, 4470 | Oakey, 4401 | Dakenba, 4715<br>Gleneagle, 4285<br>Grantham, 4343<br>Holmview, 4207<br>Kilcoy, 4515<br>Mackay, 4740<br>Nerimbera, 4700<br>North Rockhamton, 4701<br>Riverview, 4304<br>Stuart, 4814<br>Warwick, 4370<br>Yangan, 4371 |

### 8.1.2 New South Wales

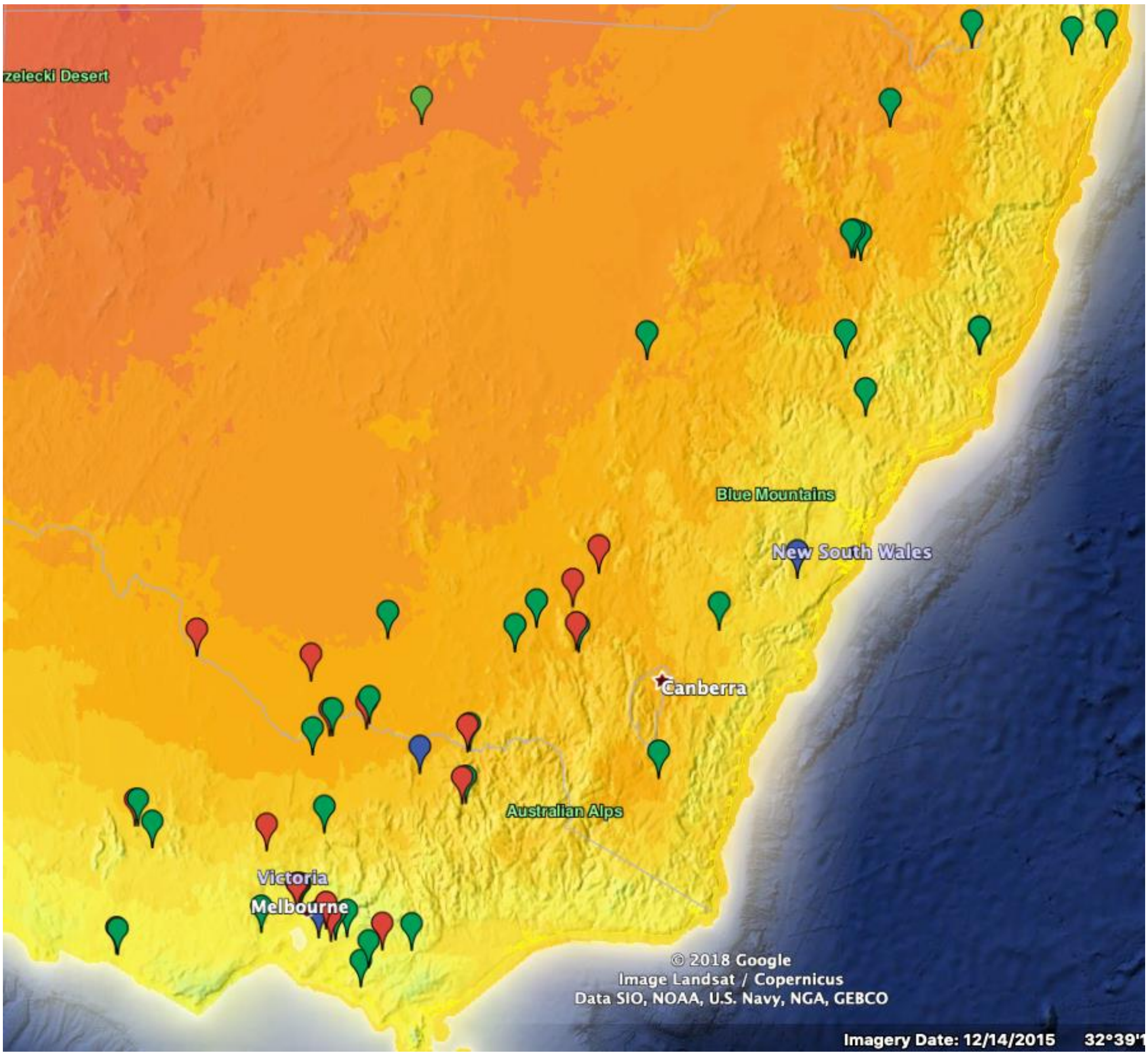


*Figure 41: New South Wales Solar Radiation*

*Table 7: New South Wales AMPC Member Solar Zones*

| | Zone 3 | Zone 4 |
|---|---|---|
| **Suburbs** | Cowra, 2794 | Casino, 2470 |
| | Dubbo, 2830 | Cooma, 2630 |
| | Inverell, 2360 | Goulburn, 2580 |
| | South Gundagai, 2722 | Heddon Greta, 2327 |
| | Tamsworth, 2340 | Junee, 2663 |
| | Wagga Wagga, 2650 | Scone, 2337 |
| | Yanco, 2703 | Whittingham, 2330 |
| | Young, 2594 | Wingham, 2429 |

### 8.1.3 Victoria


*Figure 42: Victoria Solar Radiation*

*Table 8: Victoria AMPC Member Solar Zones*

| | Zone 3 | Zone 4 |
|---|---|---|
| **Suburbs** | Cobram, 3644 | Ararat, 3377 |
| | Nathalia, 3638 | Bacchus Marsh, 3340 |
| | Swan Hill, 3585 | Brooklyn, 3025 |
| | Tallangatta, 3700 | Colac, 3250 |
| | Tatura, 3197 | Corio, 3215 |
| | Wangaratta, 3197 | Cranbourne |
| | Wodonga, 3689 | East, 3977 |
| | | Eurobin, 3739 |
| | | Kyneton, 3444 |
| | | Pakenham, 3810 |
| | | Patterson Lakes, 3197 |
| | | Lance Creek, 3995 |
| | | Seymour, 3025 |
| | | Stawell, 3380 |
| | | Tanjil South, 3825 |
| | | Tongala, 3621 |
| | | Warnambool, 3280 |
| | | Warragul, 3820 |

### 8.1.4 South Australia


*Figure 43: South Australia Solar Radiation.*

*Table 9: South Australia AMPC Member Solar Zones*

| | Zone 3 | Zone 4 |
|---|---|---|
| **Suburbs** | Two Wells, 5501 | Boardertown, 5268<br>Hynam, 5271<br>Lobethal, 5241<br>Murray Bridge, 5253<br>Normanville, 5203<br>Strathalbyn, 5255 |

### 8.1.5 Western Australia

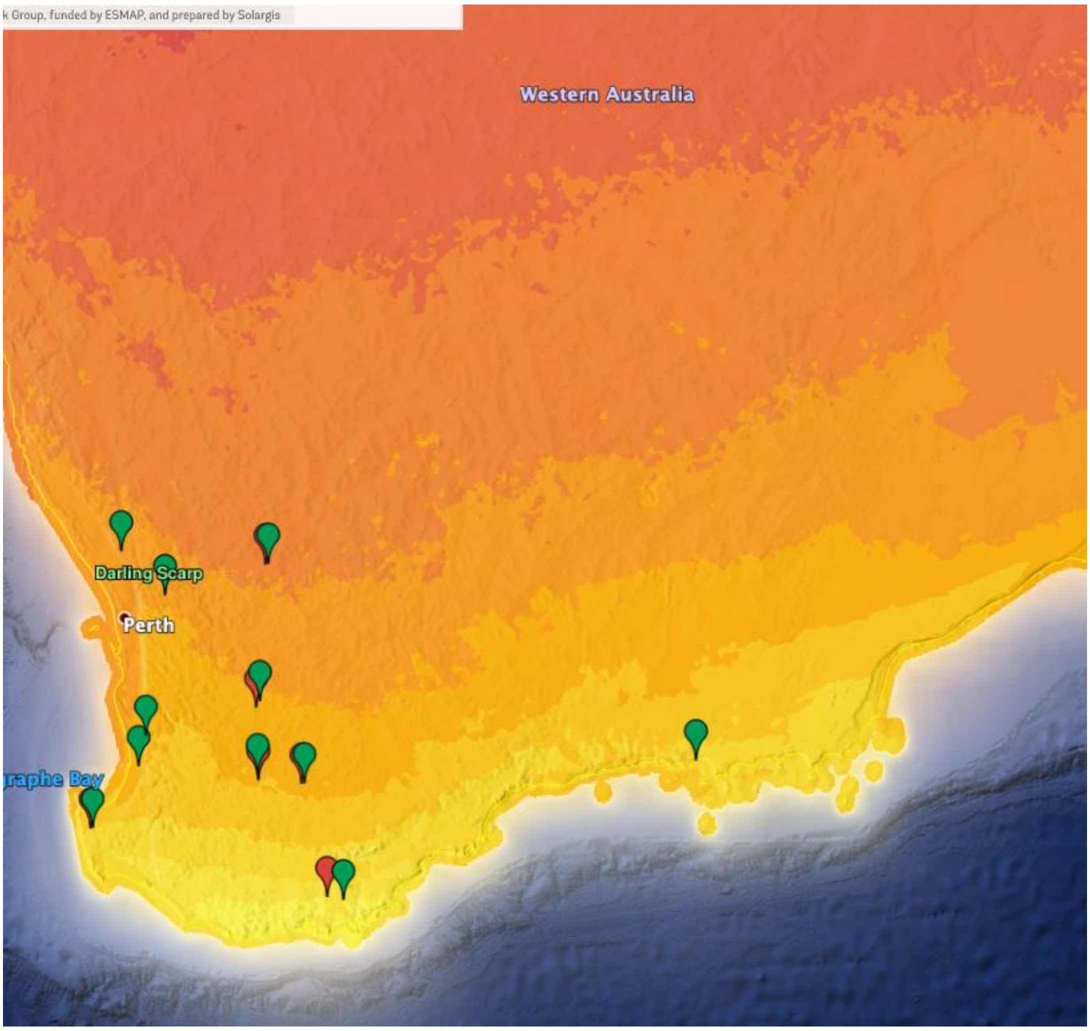


*Figure 44: Western Australia Solar Radiation*

*Table 10: Western Australia AMPC Member Solar Zones*

| | Zone 2 | Zone 3 | Zone 4 |
|---|---|---|---|
| **Suburbs** | Rudds Gully, 6530 | Bunbury, 6230<br>Harvey, 6220<br>Katanning, 6317<br>Picton, 6231<br>Narrogin, 6312 | Esperance, 6821<br>Narrikup, 6331 |

## 8.2 Geothermal Potential Zones

The Principal Hydrogeology Map of Australia published by Geoscience Australia provides a description of the high potential regions in Australia. All of the listed blue and green regions are potentially prospective for geothermal energy.

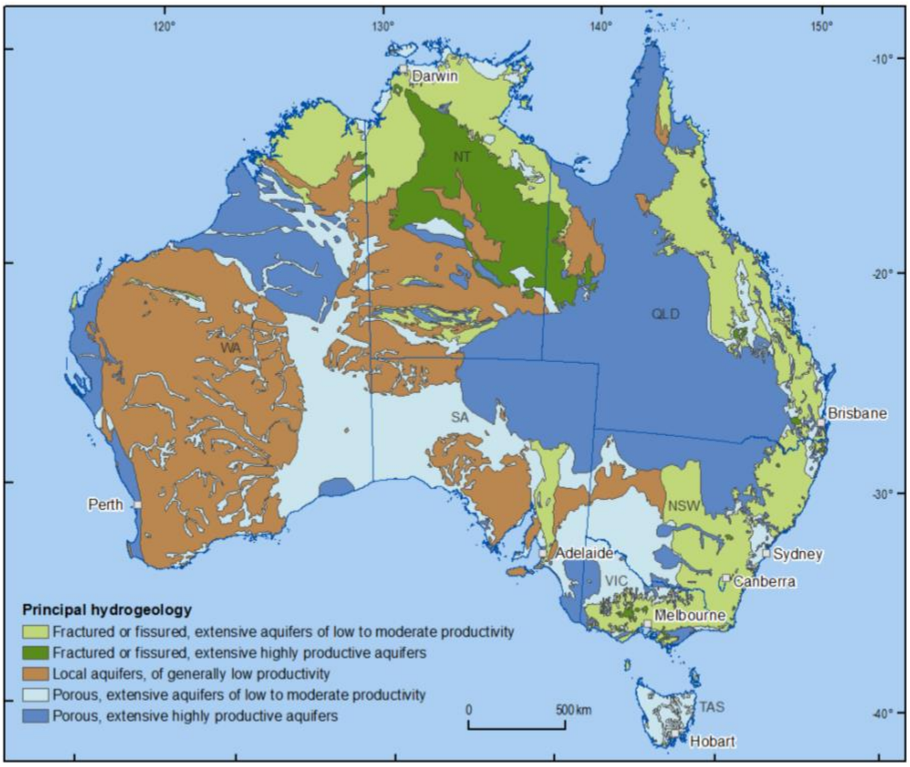


*Figure 45: Principal Hydrology map of Australia.*

### 8.2.1 Temperature

While there is no central database of aquifer temperature across Australia, other datasets can provide a first pass indication of geothermal favourability with respect to temperature. A recent study commissioned by IRENA generated a global map of estimated ground temperature at 1,000 m depth. Subtracting surface temperature (also collated by IRENA) from this map and multiplying by the specific heat capacity of water (4.172 kJ/kgK) provides an estimate of the maximum geothermal energy (in kJ/kg) potentially available in each kilogram of water in an aquifer at 1,000 m depth, relative to ambient surface temperature. Figure 45 shows the derived map at the 10' x 10' resolution of the IRENA products. To estimate the maximum potential geothermal power deliverable by a bore intersecting an aquifer at any given location, multiply the energy content shown on the map at that location by the predicted productivity of the bore (kg/s), and by the depth of the aquifer in kilometres.

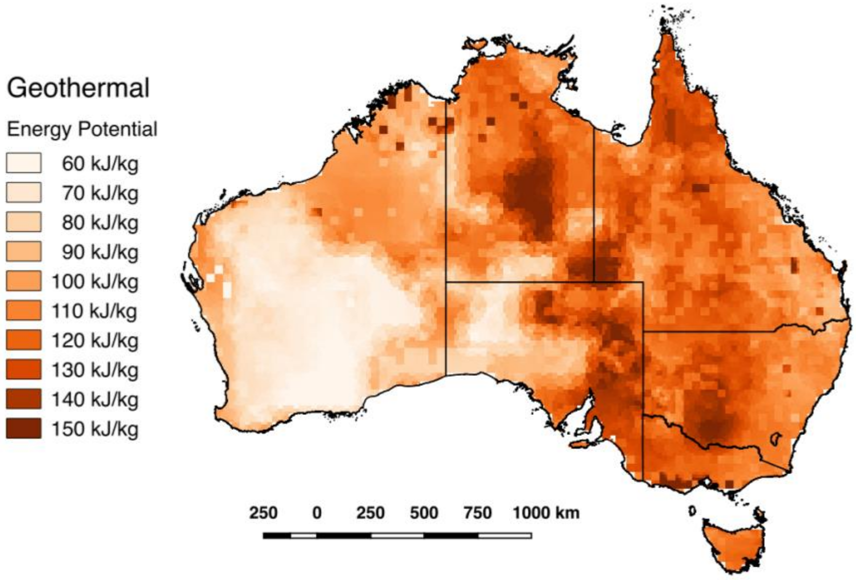


*Figure 46: Inferred Geothermal Energy Potential per Kilogram of Water at 1km depth*

### 8.2.2 Depth and Thickness

Aquifer depths and thicknesses are mapped for some parts of the country, but the datasets are piecemeal and not consolidated into a single national compilation. Part of the reason is that aquifers are distributed in the subsurface in three dimensions. A single map cannot legibly represent the depths and thicknesses of several aquifers stacked vertically one above another. It is best to seek local information on aquifer depths and thicknesses once approximate locations are known. The state governments are the custodians of groundwater information, including borehole records and aggregated datasets.

### 8.2.3 Favourability and Zones

The 'productivity' and 'temperature' assessments from previous sections were combined into a 'geothermal favourability' map of the country. The values on Figure 46 were multiplied by weighting factors derived from Figure 45, where 'highly productive' aquifers were assigned a weighting of 2.0, 'low to moderate productivity' aquifers a weighting of 1.0, and 'generally low productivity' areas a weighting of 0.5. The resulting range of potential geothermal power (temperature x productivity) was divided into 10 categories numbered from 1 (least favourable) to 10 (most favourable) and displayed on Figure 47.

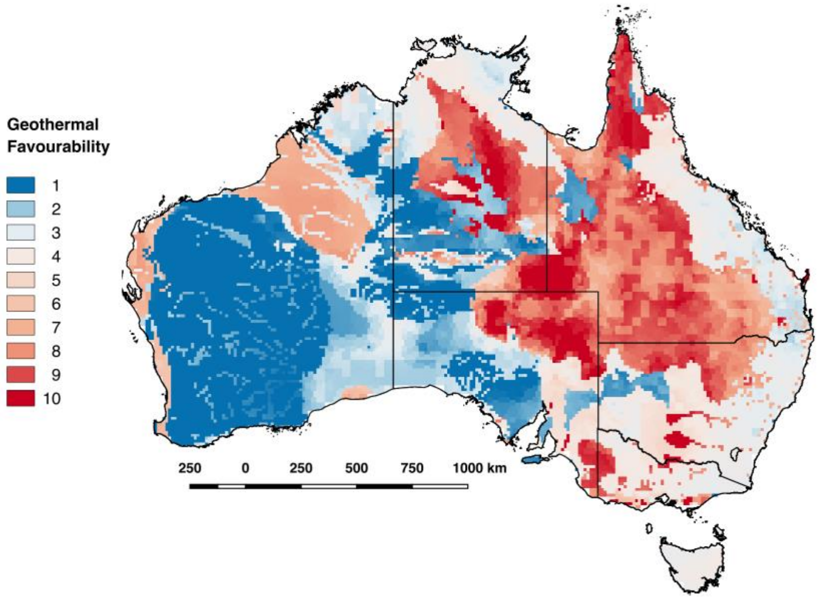


*Figure 47: Relative Favorability for Geothermal Energy Potential*

The Principal Hydrogeology map (Figure 45) provides a basis for dividing Australia into broad zones for discussion of geothermal potential at reference sites. The assessments presented in Section 10 below refer to Zones A, B, C, D and E as presented in Figure 48.

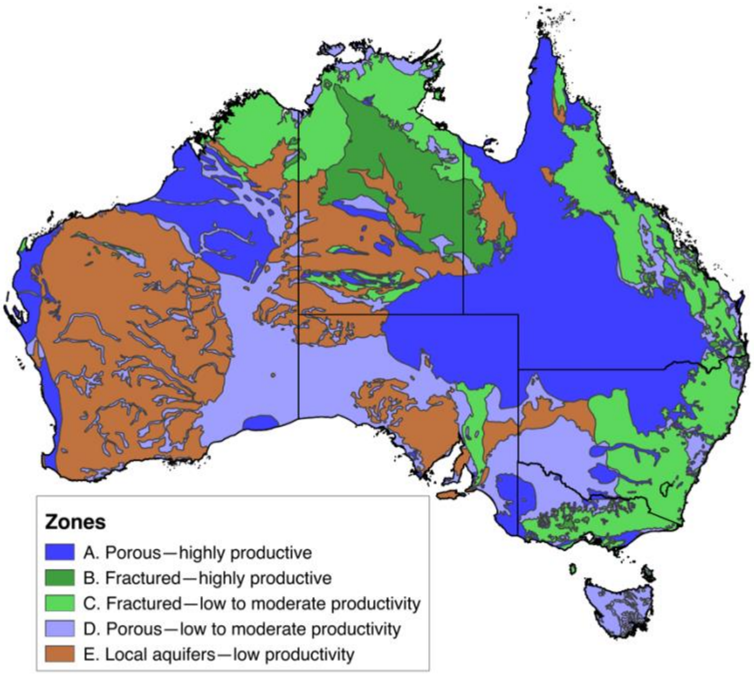


*Figure 48: Definition of Australian Aquifer Zones A – E*

### 8.2.4 Queensland

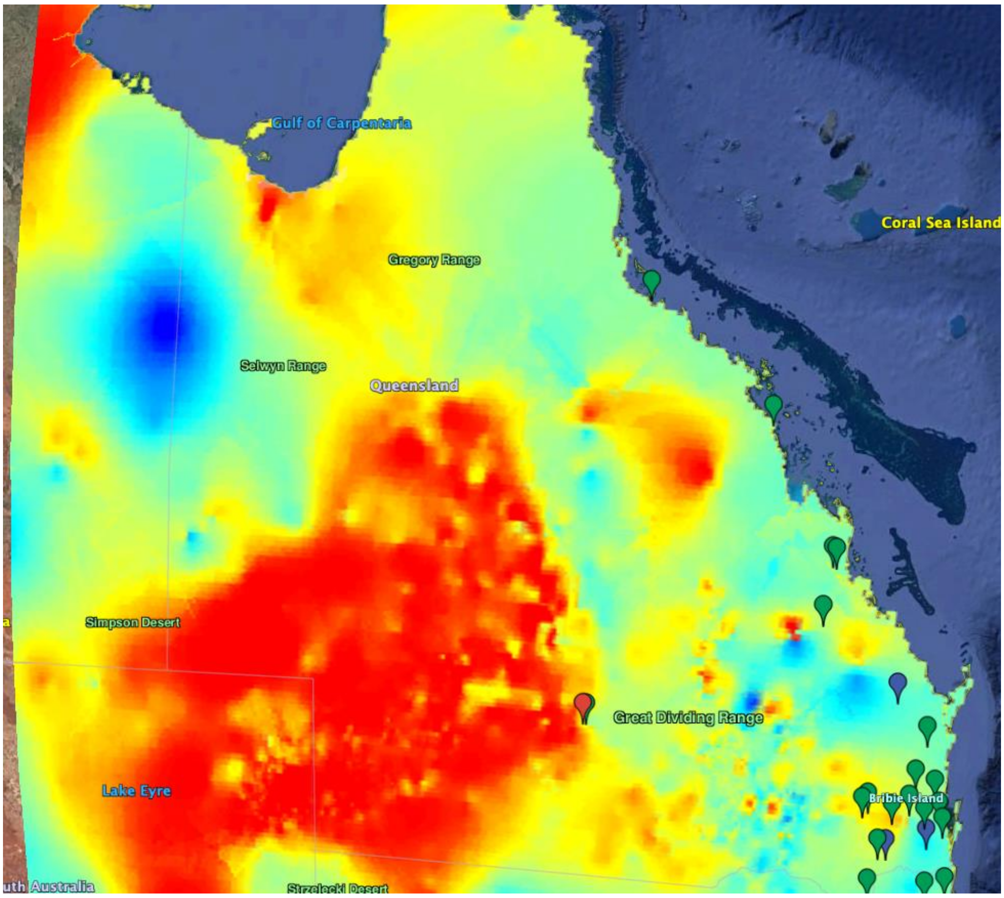


*Figure 49: Queensland geothermal zones from Google Earth data map.*

*Table 11: Queensland AMPC Members Aquifer Zones*

| | Zone A | Zone B | Zone C | Zone D |
|---|---|---|---|---|
| **Suburbs** | Charleville, 4470<br>Grantham, 4343<br>Holmview, 4207<br>Mackay, 4740 | Stuart, 4814<br>Oakey, 4401 | Dakenba, 4715<br>Gleneagle, 4285<br>Kilcoy, 4515<br>Nerimbera, 4700<br>North Rockhamton, 4701<br>Riverview, 4304<br>Warwick, 4370<br>Yangan, 4371 | Caboolture, 4510<br>Cannon Hill, 4170<br>East Deep Creek, 4570<br>Purrawunda, 4350 |

### 8.2.5 New South Wales

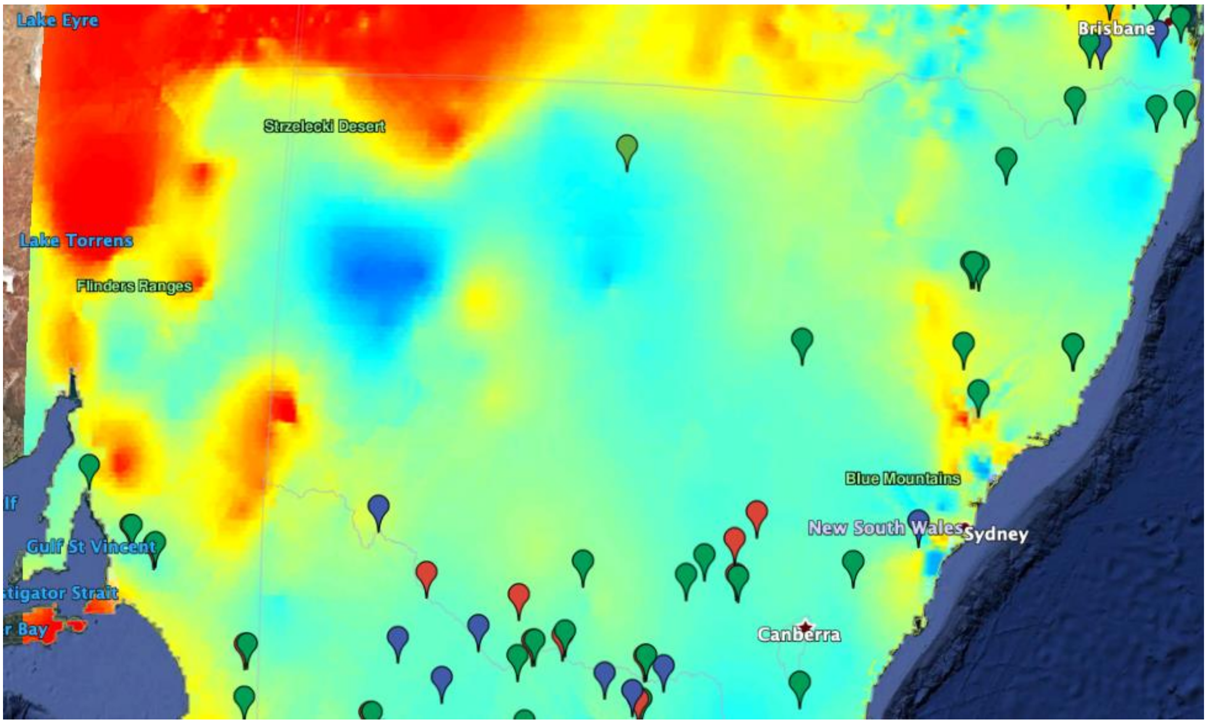


*Figure 50: New South Wales geothermal zones*

*Table 12: New South Wales AMPC Member Aquifer Zones*

| | Zone A | Zone B | Zone C | Zone D |
|---|---|---|---|---|
| **Suburbs** | Casino, 2470 | Inverell, 2360 | Cooma, 2630 | Frederickton, 2440 |
| | Cowra, 2794 | | Goulburn, 2580 | Milton, 2538 |
| | Dubbo, 2830 | | Heddon Greta, 2327 | Moruya, 2537 |
| | Scone, 2337 | | Junee, 2663 | Picton, 2571 |
| | South Gundagai, 2722 | | Wingham, 2429 | Wilberforce, 2756 |
| | Tamsworth, 2340 | | Yanco, 2703 | |
| | Waga Waga, 2650 | | Young, 2594 | |
| | Whittingham, 2330 | | | |

### 8.2.6 Victoria

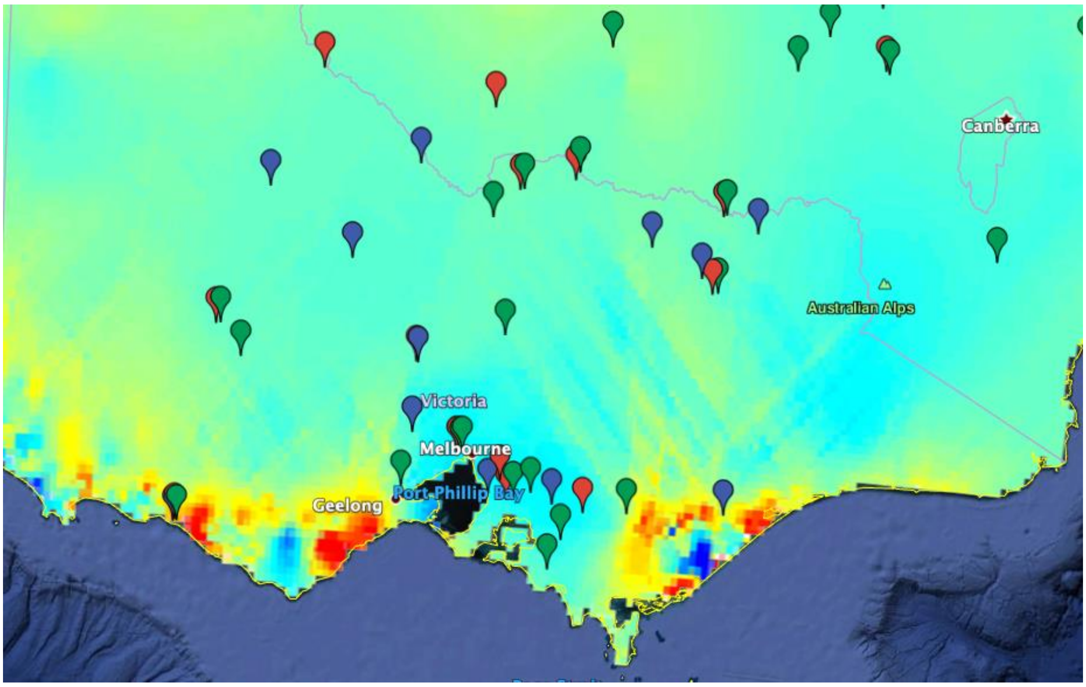


*Figure 51: Victoria geothermal zones*

*Table 13: Victoria AMPC Member Aquifer Zones*

| | Zone A | Zone B | Zone C | Zone D |
|---|---|---|---|---|
| **Suburbs** | Cobram, 3644<br>Colac, 3250<br>Nathalia, 3638<br>Tanjil South, 3825<br>Tatura, 3197<br>Tongala, 3621<br>Warnambool, 3280 | Warragul, 3820 | Ararat, 3377<br>Bacchus Marsh, 3340<br>Brooklyn, 3025<br>Corio, 3215<br>Cranbourne East, 3977<br>Eurobin, 3739<br>Kyneton, 3444<br>Lance Creek, 3995<br>Pakenham, 3810<br>Tallangatta, 3700<br>Seymour, 3025<br>Stawell, 3380<br>Wodonga, 3689 | Patterson Lakes, 3197<br>Swan Hill, 3585<br>Wangaratta, 3197 |

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### 8.2.7 South Australia

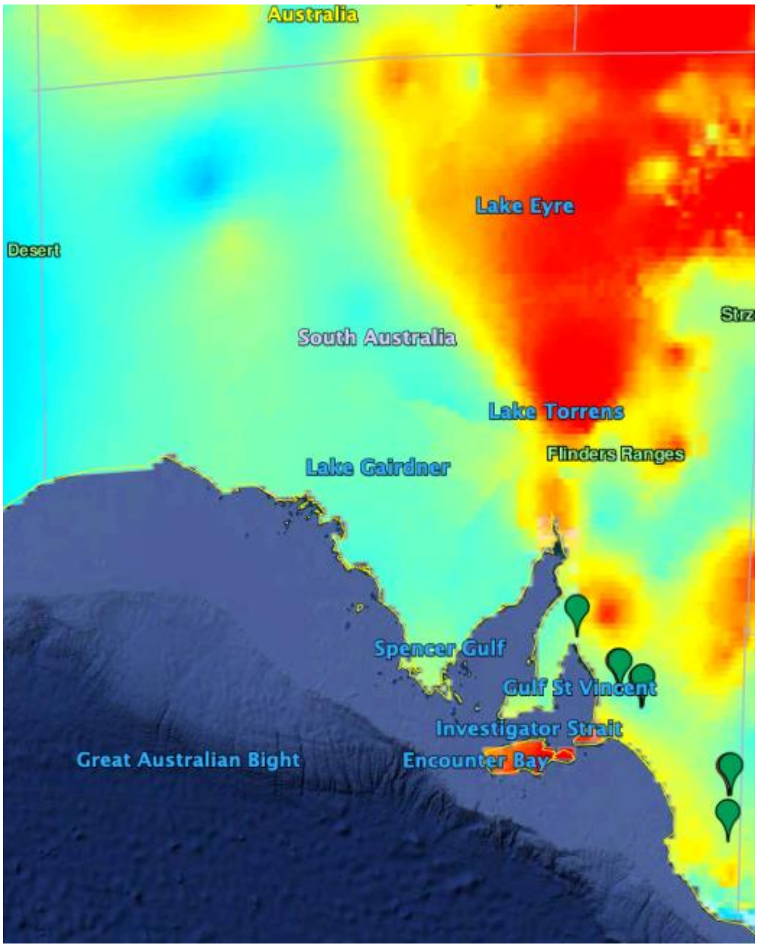


*Figure 52: South Australia geothermal zones*

*Table 14: South Australia AMPC Member Aquifer Zones*

| | Zone A | Zone D | Zone E |
|---|---|---|---|
| **Suburbs** | Boardertown, 5268<br>Hynam, 5271<br>Lobethal, 5241 | Murray Bridge, 5253<br>Strathalbyn, 5255<br>Two Wells, 5501 | Normanville, 5203 |

### 8.2.8 Western Australia

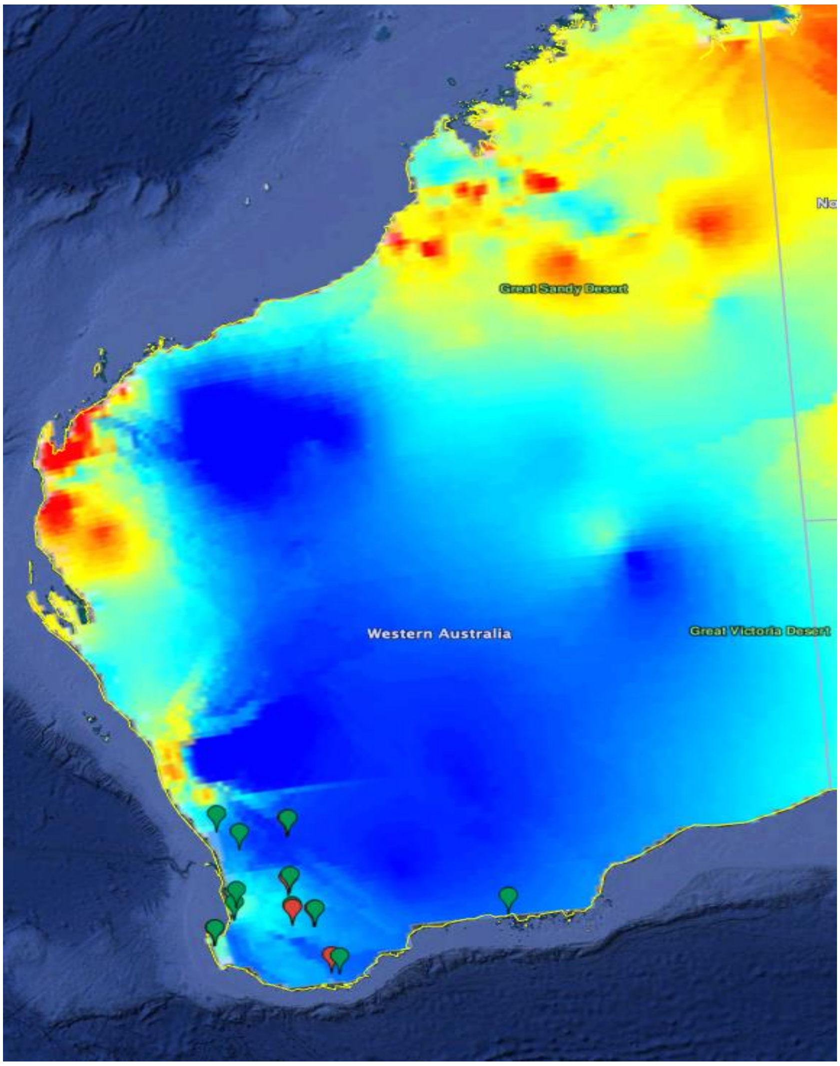


*Figure 53: Western Australia geothermal zones*

*Table 15: Western Australia AMPC Members Aquifer Zones*

| | Zone A | Zone D | Zone E |
|---|---|---|---|
| **Suburbs** | Bunbury, 6230<br>Harvey Beef, 6220<br>Picton, 6231<br>Rudds Gully, 6530 | Esperance, 6821 | Katanning, 6317<br>Narrikup, 6331<br>Narrogin, 6312 |

# 9 PRIMA FACIE GEOTHERMAL POTENTIAL AT REFERENCE MEAT PROCESSOR SITES

A few meat processing sites were selected to provide a more detailed review of the potential for geothermal sources to provide thermal steam for their operations. In addition, a current abattoir site has provided valuable geothermal use reference data presented in Section 9.4, which can be compared against *prima facie* geothermal favourability. Supplementary examples of geothermal potential are also considered for other locations in Victoria and Queensland.

## 9.1 Reference Site 1, zone A/E, Southwest Western Australia

Reference Site 1 lies directly on a boundary between highly productive Zone A aquifers to the west and a low-productivity Zone E region to the east. On the 'Geothermal Favourability' map (Figure 54), the site straddles a region of lowest favourability (favourability = 1) and moderate favourability (favourability 5–6). There is potential, therefore, for the plant to access productive aquifers, and its actual location suggests geothermal energy potential of 87 kJ/kg of water at 1 km depth.

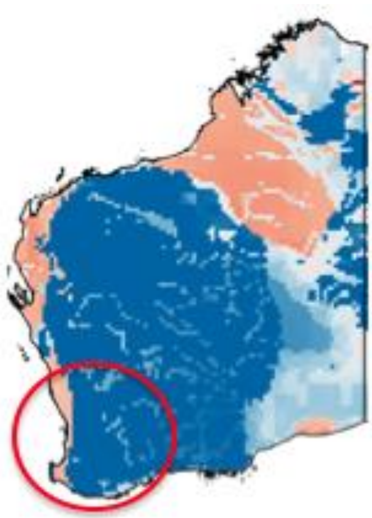

*Figure 54: Location of Reference Site 1 on the 'Geothermal Favorability' Map*

While a full feasibility study of the geothermal potential of Reference Site 1 would require a detailed review of local groundwater data, information published by CSIRO (2009)[14] indicates that three aquifers underly the area. The deepest (and likely hottest) of the three, comprises up to 2,000 m of interbedded sandstone and siltstone. The water is reportedly saline, suggesting it

[14] **CSIRO** (2009). Groundwater yields in south-west Western Australia. A report to the Australian Government from the CSIRO South-West Western Australia Sustainable Yields Project. *CSIRO Water for a Healthy Country Flagship*, Australia.

would require desalination for direct use, or that its heat could be exploited indirectly through heat exchangers. The aquifer's thickness indicates that depths greater than 1,000 m could be targeted, yielding energy greater than 100 kJ/kg on production. Furthermore, the region's high reported aquifer productivity suggests that a bore could deliver > 25 kg/s, potentially providing in excess of 2.5 $MW_t$ of thermal power, worth up to $400,000 per annum by offsetting natural gas usage at an average historical Western Australian price of $5/GJ.

## 9.2 Reference Site 2, zone C, Southeast Queensland

Similar to Reference Site 1, Reference Site 2 also lies on a boundary between a region of low favourability (favourability = 2) and high favourability (favourability = 9) on the 'Geothermal Favourability' map (Figure 55). The plant's actual location is in Zone C, only 2–3 km to the north of a Zone B region of 'high productivity' fractured rocks. There is potential for the plant to access productive aquifers with geothermal energy potential of 90 kJ/kg of water per kilometre of depth, with potential exceeding 130 kJ/kg per kilometre of depth from the high productivity zone 2–3 km to the south.

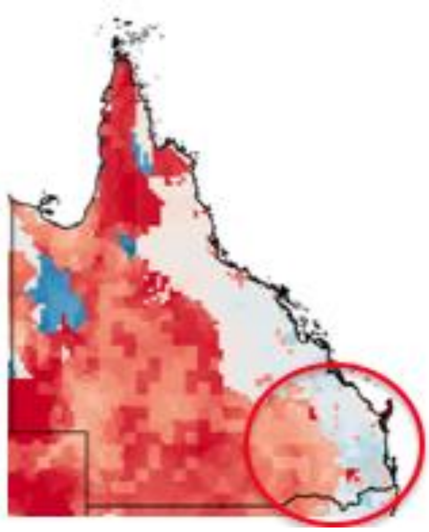

*Figure 55: Location of Reference Site 2 on the 'Geothermal Favorability' Map*

While a full feasibility study of the geothermal potential of Reference Site 2 would require a detailed review of local groundwater and geological data, preliminary information sourced through the Queensland Globe web portal (https://qldglobe.information.qld.gov.au/) indicates that the 'high productivity' aquifers identified on Figure 45 probably correspond to very shallow (< 25 m) fractured basalts that are unlikely to produce water much above ambient temperature. However, geological data sourced through the Queensland Globe also indicate that the plant is potentially underlain by hundreds of metres of coal measures. Coal measures generally boost thermal gradients because of their thermal insulation properties, and their existence at this location probably accounts for the elevated geothermal favourability just south of the site. Should the coal measures produce water from a depth of 300 m, that water could contain about 30 kJ/kg of thermal energy. If production rate was a low to moderate 15 kg/s, the thermal power would equate to 0.45 $MW_t$.

According to Reference Site 2 plant's own data for a recent six-week period during winter, the peak water volume delivered to its boilers was 199 kL (average 2.30 kg/s), with a median rate of 63 kL/day (average 0.73 kg/s). Assuming the water was heated from ambient temperature (12°C in August[15]) to steam at 175°C, that implies a median heating rate of about 0.55 $MW_t$, with a peak of 1.75 $MW_t$[16]. Geothermal energy could, therefore, potentially offset a large proportion of the boiler energy requirements either through direct preheating or heat pumps, but the production rate of bore water to deliver the necessary thermal power would far exceed the rate at which the plant consumes water.

## 9.3 Reference Site 3, Zone C, Southern Victoria

Reference Site 3 lies in a region of moderately low ranking (favourability = 3) on the 'Geothermal Favourability' map (Figure 56). The fractured rock aquifer reported for the site probably relates to surficial layers of basalt. While bores in close vicinity to the site are only tens of metres deep, the 'Visualising Victorian Groundwater' web portal (https://www.vvg.org.au) discloses several bores deeper than 150 m within a five-kilometre radius of the site. These are mostly legacy bores drilled about fifty years ago, suggesting the presence of extractable groundwater at that depth.

Similar to that of References Sites 1 and 2 discussed above, a full feasibility study of the geothermal potential of Reference Site 3 would require a detailed review of local groundwater and geological data. Its location, however, suggests geothermal energy potential exceeding 110 kJ/kg of water per kilometre of depth. If an aquifer was intersected between 150–200 m depth, then it might provide 20 kJ/kg of thermal energy, which at a 'low to moderate productivity' of 15 kg/s could deliver 9,500 GJ of heat per year, offsetting up to $95,000 of natural gas at $10/GJ.

15 Bureau of Meteorology, http://www.bom.gov.au/climate/averages/tables/cw_041359.shtml
16 Assuming boiler thermal efficiency of 90%

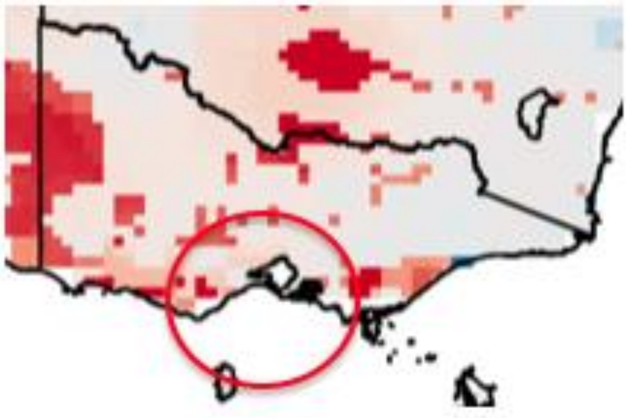

Figure 56: Location of Reference Site 3 on the 'Geothermal Favorability' Map

## 9.4 A Case Study of an Abattoir with Existing Geothermal Zone A, Warrnambool Victoria

This current abattoir processing plant presented provides an objective case against which the validity of the assumptions and calculations in Sections 9.1 to 9.3 can be judged. Following the same process as above, the current abattoirs plant location corresponds with an area of high ranking (favourability = 7–10) on the 'Geothermal Favourability' map (Figure 57), reflecting the existence of 'highly productive' porous aquifers and geothermal energy potential exceeding 150 kJ/kg of water per kilometre of depth (Figure 45).

Although the aquifer accessed by the 800 m deep bore is potentially 'highly productive', the bore only produces 10 kg/s for 5,760 hours per year, due to the period and rate at which the plant's sterilisation unit consumes water. With those production parameters, Figure 46 predicts geothermal energy potential of about 25 TJ per year. Given that close to 40% of the bore's produced thermal energy is lost from the system (10°C of cooling from an initial 26°C above ambient) before the water reaches the co-gen pre-heater, this is in remarkably close agreement with the current abattoir's actual geothermal energy utilisation of about 15 TJ per year (64 GJ/day, 240 days/year). The close agreement with the current abattoir's practical experience provides confidence in the assessment methodology applied to other reference sites.

## 9.5 Supplementary Example 1, Zone D, Southern Victoria

A specific location in southern Victoria has a moderate ranking (favourability = 4) on the 'Geothermal Favourability' map (Figure 57) due to 'low to moderate productivity' porous aquifers (Figure 48) and geothermal energy potential of about 125 kJ/kg of water per kilometre of depth (Figure 46).

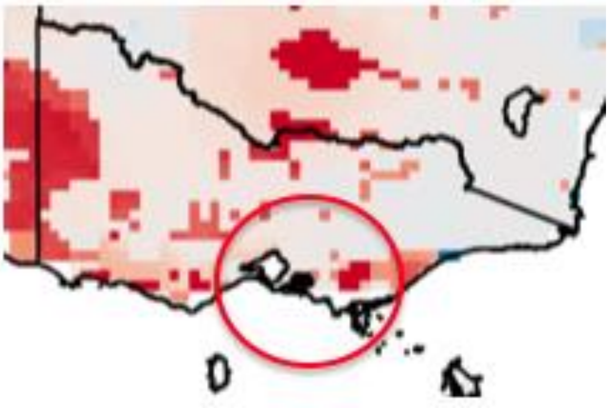

*Figure 57: Location of Supplementary Example 1 on the 'Geothermal Favorability' Map*

According to the 'Visualising Victorian Groundwater' web portal (https://www.vvg.org.au), no bore penetrates much deeper than 100 m within five kilometres of the specific site, although a bore 10 km to the east is reported as 500 m deep. Should an aquifer be located beneath the site able to produce groundwater at a 'low to moderate' 15 kg/s from 500 m depth, it could provide 0.9 $MW_t$ of thermal power, potentially offsetting almost $200,000 per annum of natural gas consumption at $10/GJ (assuming operations run 5 days/week, 48 weeks/year).

## 9.6 Supplementary Example 2, Zone A, South Central Queensland

A specific location in south central Queensland has a high ranking (favourability = 9) on the 'Geothermal Favourability' map (Figure 58) due to 'highly productive' porous aquifers (Figure 48) and geothermal energy potential of about 133 kJ/kg of water per kilometre of depth (Figure 46). The site lies above the Great Artesian Basin with known production from 600 m depth. Should the aquifer produce groundwater at 28 kg/s (as did a geothermal bore at Birdsville further west), it could provide 2.2 $MW_t$ of thermal power, potentially offsetting more than $450,000 per annum of natural gas consumption at $10/GJ (assuming operations run 5 days/week, 48 weeks/year).

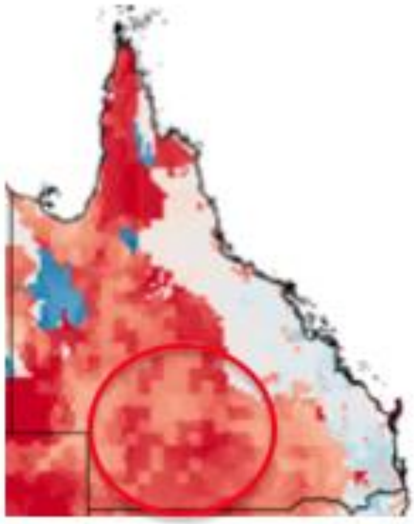

*Figure 58: Location of Supplementary Example 2 on the 'Geothermal Favorability' Map*

## 9.7 Summary

The *prima facie* considerations of geothermal potential presented above are based on regional data sets of ground temperature averaged over relatively broad regions. Critically, they lack information about the depths of likely productive groundwater aquifers, a parameter with first order importance with respect to water temperature, energy content and capital cost. Notwithstanding those limitations, however, the evidence suggests technical potential for geothermal energy to offset natural gas consumption for water heating at each of the sites examined. The financial viability of geothermal energy would be site-specific and depend on the total energy demand of each plant, the cost of accessing the geothermal energy (ie drilling) at each location, the cost of producing (ie pumping) and disposing of the groundwater, and the capital and operational costs of the heat exchangers and/or heat pumps required to harvest the thermal energy from the groundwater.

# 10 FINANCIAL MODELLING

## 10.1 Financial Modelling

The financial model was created to show the economic viability of the modular CST and SG technologies when compared to the traditional and existing methods. Upon receiving the requested data from selected representative abattoir operations, the structure of the financial model was developed to assess the economic viability of the chosen technologies when compared to the representative operations existing steam generation methods. The requested data included:

- Gas Usage (GJ)
- Gas Price ($/GJ)
- Steam Requirement (Cubic meters)
- Steam Temperature (Degrees Celsius)
- Water usage (ML)
- Operation profile (Hours & days/week)

The key focus of the model was to analyse the amount of gas in gigajoules (GJ) that would be offset by the inclusion of a Magaldi CST (STEM) or SG solution and compare this to the cost data for the technologies to determine the viability across the defined zones. The financial model consists of the selected STEM and SG technology and defines the capital costs (CAPEX), operational costs (OPEX), Net Present Value (NPV) and Internal Rate of Return (IRR). Some of the key data inputs in the financial model are based off assumptions provided by geothermal specialists from Rockwater Hydrogeological and Environmental Consultants to define the likely geothermal resource available in the selected zones.

The financial modelling has been structured and is driven by the aquifer basins and associated surface water temperatures. This is based on factoring the energy requirements to increase ambient surface water temperatures to create steam. Consequently, the model has been structured to compare the technologies against the ambient water temperature in order to understand the amount of energy needed to create steam and the cost economics of the technologies against the base case. It should be noted that a standardized rate of 365M liters of water usage was assumed across each zone/region. For further in depth review an individual may input their locations specific water usage requirements. The aquifers included as part of the modelling were the Great Artesian Basin (QLD), the Perth Basin (WA) and the Otway Basin (VIC).

For SG technology, the model is further influenced by the required bore hole depth across each of the basins. Based on these inputs the outputs of the model will vary, providing an accurate representation of zones/regions where each respective technology may or may not be viable.

## 10.2 STEM

In order to get accurate financial model outputs, a specific set of assumptions were compiled and established to model the expected costs and gas offset by a STEM module. These assumptions included:

- STEM development costs
- STEM operating and variable costs
- STEM module size (MW)
- Region DNI

The assumptions were formed on the back of conversations with Italian based STEM module experts and consultants, Magaldi. While the structure and setup of each STEM module will differ on a case by case basis, for the purpose of the model we have assumed a standard 6.4MW size facility that will offset 66% of an operations gas requirements. Due to the similar nature of the respondent abattoir locations, the model is able to use the same STEM setup across each basin region. However, due to the differences in average ambient water temperatures from region to region, the gas requirements change and in turn so do the cost benefits of the STEM technology.

## 10.3 Geothermal

In order to get accurate financial model outputs a specific set of assumptions were compiled and established to model the expected gas input costs saved following the implementation of a geothermal system. These assumptions included:

- Geothermal development costs
- Geothermal operating and variable costs
- Surface and bore water temperatures
- Bore depths
- Levelized costs of heat (LCOH)

## 10.4 Overall Project Inputs

The financial model includes an "Inputs" section sheet that outlines several additional project finance specific assumptions. These assumptions were generated on typical current industry standards. They include:

- Debt/Equity funding ratios
- Interest rates
- Cost and price escalation
- WACC/CAPM rates
- Gas prices

Assumptions for energy prices and requirements were formed on the basis of an analysis of respondent information. The information provided was standardized and enabled the model to consider "best fit" data.

As an addition to the model, a "project feasibility" calculator has been included. The calculator looks to provide an insight into whether a project may be positioned geographically to benefit from the use of STEM or SG technology as a guidance function.

### 10.4.1 GEOTHERMAL

*Table 16: Geothermal Outputs from Financial Model*

| | Great Artesian Basin (1km) | Great Artesian Basin (1.5km) | Perth Basin (1km) | Perth Basin (1.5km) | Otway Basin (1km) | Otway Basin (1.5km) |
|---|---|---|---|---|---|---|
| **GEOTHERMAL SIZE** | 2.31 MW | 3.60 MW | 1.24MW | 1.88 MW | 1.93 MW | 3.01MW |
| **CAPEX** | $2.92M | $5.28M | $2.33M | $4.33M | $2.71M | $4.96M |
| **OPEX p.a** | $0.19M | $0.26M | $0.25M | $0.22M | $0.18M | $0.26M |
| **PROJECT NPV** | $9.00M | $13.74M | -$3.24M | -$3.02M | $2.23M | $2.96M |
| **PROJECT IRR** | 23.92% | 21.58% | NA | 0% | 11.57% | 10.21% |
| **PROJECT SAVINGS (30 Years)** | $30.77M | $49.13M | -$1.67M | $4.18M | $13.10M | $21.02M |

Table 16 provides an overview of the SG modelling analysis, establishing regions that present a potential for SG technology implementation. The table has been colour coded to illustrate the regions that are the most feasible (green) to the feasible (red). After detailed analysis, it was concluded that due to low current gas prices in Western Australia and colder bore water temperatures, the return on investment is insufficient in this region for the implementation of SG technology as an alternative to gas based steam generation. In particular, the operating costs were much greater due to a higher Levelised Cost of Heat (LCOH) that was provided by Rockwater. The

Great Artesian Basin returns were more attractive due to the higher bore water temperatures and increased cost of gas due to differing industry supply policies.

### 10.4.2 STEM

*Table 17: STEM Outputs from Financial Model*

| | Great Artesian Basin | Perth Basin | Otway Basin |
|---|---|---|---|
| STEM SIZE | 6.4 MW | 6.4 MW | 6.4 MW |
| CAPEX | $27M | $27M | $27M |
| OPEX p.a | $1.11M | $1.11M | $1.11M |
| PROJECT NPV | -$15.75M | -$32.54M | -$25.24M |
| PROJECT IRR | 0% | NA | 0% |
| PROJECT SAVINGS (30 Years) | $33.23M | -$10.58M | $8.47M |

Similar to the summary results for Shallow Geothermal, the above table illustrates the projects from most viable locations (orange) and the least viable project locations (red). The results within the financial model overlay the Solar Zones based on the generating capacity of a STEM module and cross referencing with the aquifer basins. The results are structured into the three basins as per the Shallow Geothermal results due to the need to assess the energy requirements to heat the ambient surface water to steam.

None of the regions within the Study provide optimal parameters for the implementation of STEM technology. The Great Artesian Basin presents a region that may be considered for further detailed investigation. The Perth Basin and Otway Basin are not viable due to a combination of low gas prices and low solar radiation capacities.

## 10.5 Financial Model Overview

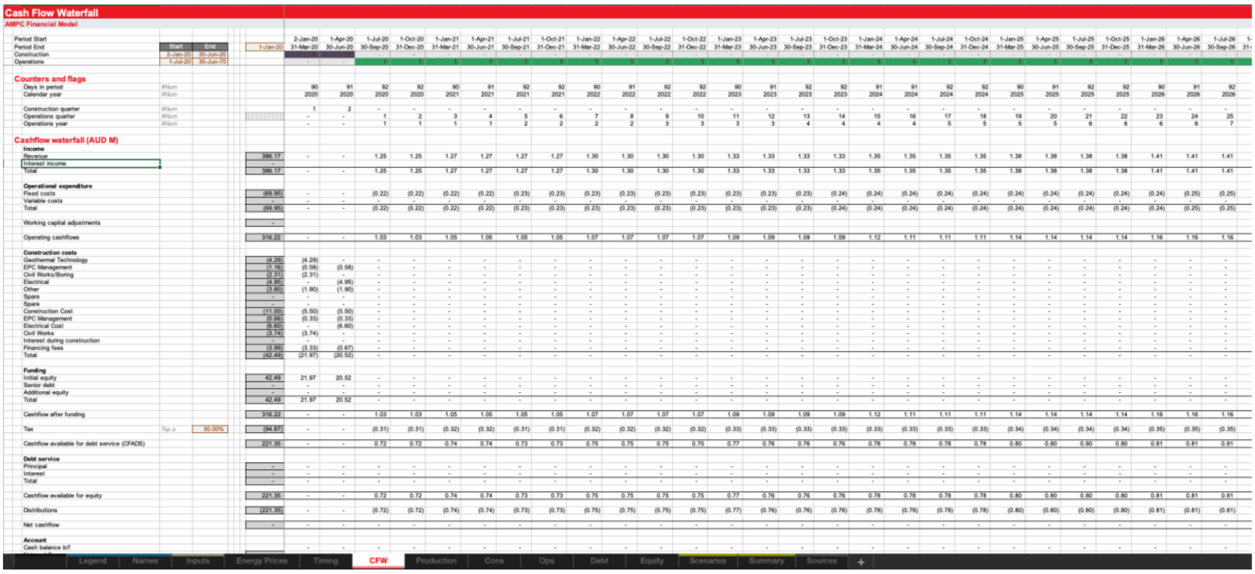


*Figure 59: AMPC Study Financial Model (Snapshot)*

# 11 REGULATORY CONSIDERATIONS

## 11.1 Federal

At the international level, Australia's commitment under the 'Paris Agreement' of 2015 is to reduce greenhouse gas emissions by 26–28 per cent below 2005 levels by 2030.

The federal government's primary mechanism for reducing non-energy sector emissions is an 'Emissions Reduction Fund' (ERF) of $4.55 billion. Projects that reduce emissions earn 'Australian carbon credit units' (ACCUs) that can be sold to the Australian Government or to other businesses seeking to offset their emissions. According to RepuTex Energy (Figure 59)[17], the spot price for ACCUs between May 2018 and May 2019 averaged around $15.50 per tonne of $CO_2$ (or equivalent) stored or avoided by a project. The ninth ERF auction took place 24–25 July 2019, with an average auction price of $14.17/tonne-$CO_2$ announced on 1 August 2019[18]. That represented a 2.5% increase on the eighth auction in December 2018, and a 5% increase on the seventh auction of July 2018. This points to a trend of steadily increasing ACCU prices.

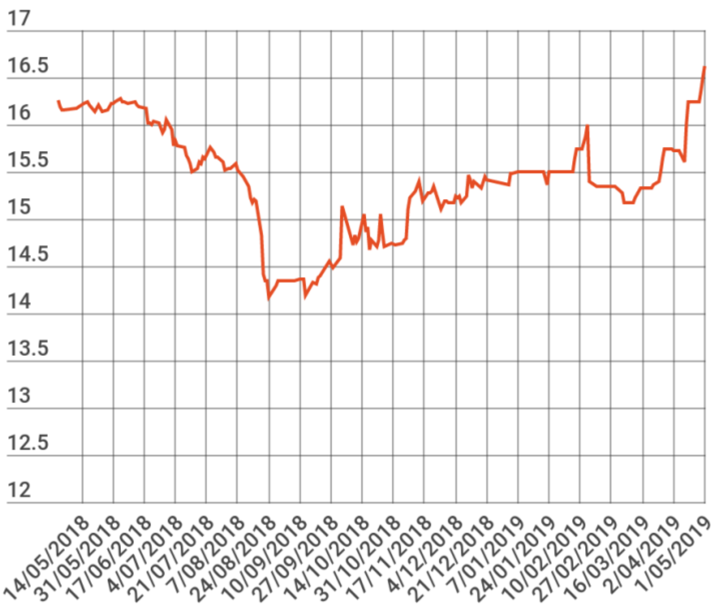


*Figure 60: Spot prices for Australian carbon credit units, May 2018 to May 2019. Source: RepuTex Energy.*

The spot price on secondary markets for an ACCU on 13 August 2019 was $15.25 per tonne $CO_2$[19].

[17] https://www.reputex.com/blog/insights-what-is-the-current-australian-carbon-spot-price/

[18] http://www.cleanenergyregulator.gov.au/ERF/Auctions-results/july-2019

[19] http://www.demandmanager.com.au/certificate-prices/

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## 11.2 States

Different states have enacted individual pieces of legislation to control the exploration and development of geothermal energy. In most cases, the legislation specifically targets deep drilling for power generation. The production of geothermal energy for direct use is explicitly excluded from geothermal legislation in most states, regulated instead under existing frameworks for groundwater management.

- South Australia - the Petroleum and Geothermal Act 2000 (as amended in 2018) allows 'over the counter' applications for geothermal licenses.
- Queensland - the Geothermal Energy Act 2010 (as amended in 2016) controls the exploration and development of 'large-scale' geothermal energy extraction. The Act defines geothermal energy as "heat energy derived from the earth's natural (subsurface) heat." The Act allows 'over the counter' applications.
- New South Wales - exploration and production of geothermal energy is governed by the Mining Act 1992 (No 29, as amended in 2018.) The Act allows 'over the counter' applications for geothermal licenses. The Mining Regulations 2016 (as amended in 2018) define geothermal energy as "the heat energy contained or stored in rock, geothermal water or any other material occurring naturally within the earth."
- Victoria - the Geothermal Energy Resources Act 2005 governs exploration for geothermal resources in the state. The Bill allows the state government to release blocks of land across the entire state for open tender.
- Tasmania - Geothermal resources are classified as 'Category 6' minerals under the Mineral Resources Development Act 1995 (as amended in 2017. The Act allows 'over the counter' applications for licenses.

All eastern Australian states have also introduced their own emission reduction targets, namely: Tasmania (zero net emissions by 2050), Australian Capital Territory (zero net emissions by 2045), South Australia (zero net emissions by 2050), Victoria (zero net emissions by 2050), Queensland (zero net emissions by 2050), and New South Wales (zero net emissions by 2050).

# 12 RISKS

As with the implementation of any new technology, the integration of geothermal & STEM energy into meat processing systems would carry some risks. The risks are relatively low and manageable if recognised and considered from the initial stages of pre-feasibility. They can be divided into technical and non-technical risks. While the list of risks below might appear long, each risk factor on its own is quite low and manageable. The greatest risk lies in failing to recognise and manage the risks.

## 12.1 Technical risks

### 12.1.1 STEM

#### *12.1.1.1 Transit Risk*

With the technology from Magaldi being manufactured in Europe, there is a substantial logistical challenge involved in transporting parts and equipment to Australia. Transporting key components across long distances, often overseas, can result in equipment getting damaged, broken, or misplaced in transit. Furthermore, if equipment is mishandled, or damages occur during the loading or unloading stages, this can have a wide range of impacts on the project as a whole, as developers are forced to wait for repairs to be completed, or replacement parts brought in.

#### *12.1.1.2 Construction Risk*

As with all projects of a certain scale, there are also construction risks involved in the development of CSP plants, which may lead to project delays in the short-term, and, in the long term, site performance issues. To ensure a CSP plant are built correctly, contractors with a proven track record, and solid understanding of the region, should be employed to handle the construction of a project.

#### *12.1.1.3 Operational Risk*

CST plants uses the Sun's energy to heat oil, salt or sand to boiling temperatures, and therefore the risk of fire can be high. On-site fires can often be attributed to overheating equipment, but a power block or welding work can also cause problems.

The lack of adequately experienced operators and local support staff could also hinder the operations of the CST plant due to the lack of training and CST adaption within Australia.

### 12.1.2 Geothermal

#### *12.1.2.1 Exploration risk*

The subsurface is inherently unknown. Its properties must be inferred from geoscience data prior to drilling. But even the most comprehensive geoscience data sets cannot give an exact image of subsurface properties. There is always an uncertainty range over characteristics such as depth, thickness, temperature, permeability, and extent of inferred aquifers. Once it has been drilled and tested, however, the aquifer properties are much more precisely known. Exploration risk, therefore is only significant at the stage of drilling the first well into an inferred, but otherwise unknown, aquifer. Exploration risk can be mitigated to some extent by applying best practice in geoscience data collection and interpretation to select optimal drilling sites.

#### *12.1.2.2 Drilling risk*

Geothermal reservoir productivity, or the ability to sustainably extract geothermal water from a buried rock unit, requires good hydraulic connection between the reservoir and the bore. The drilling process itself can have a serious negative impact on the productivity of a reservoir by inflicting 'reservoir damage.' This mostly relates to inadvertent injection of fine-grained material from the drilling fluid into the pore spaces near the bore, effectively plugging the rock and impeding the flow of geothermal water into the bore. Drilling risk can be mitigated by clearly discussing the purpose of the bore with the driller and requesting a drilling plan that explicitly addresses the risk of reservoir damage.

#### *12.1.2.3 Sustainability risk*

Sustained production from a geothermal aquifer can affect and alter the original 'natural state' properties of the aquifer, which can result in a long-term decrease in production rate. Mechanisms by which this could occur include the physical mobilisation of fine-grained material in the rock matrix, which can lodge in 'pore throats' and effectively choke the permeability of the aquifer. They also include dissolution or precipitation of minerals due to changes in fluid temperature, pressure and salinity, which could be especially relevant for geothermal systems that inject 'used' geothermal water back into the aquifer. Sustainability risk can be managed by enlisting the services of an experienced hydrogeologist to build an early understanding of the reservoir and fluid properties and predict any adverse effects that might eventuate under a production scenario.

#### *12.1.2.4 Fluid property risk*

The chemical composition of geothermal water might not be as predicted. Issues such as especially high salinity might require additional capex or opex expenditure to manage. For example, unexpectedly high salinity might lead to salt scale or corrosion on the inside of surface plant (heat exchangers, pumps etc), requiring a regular maintenance schedule at an O&M cost over and above original financial projections. Fluid property risk can be managed by factoring contingency treatment or maintenance processes into financial feasibility models.

##### *12.1.2.5 Injection risk*

Some jurisdictions might impose a condition of reinjection on a groundwater licence. This is more likely to be the case for a heavily exploited groundwater reservoir where a licence might be granted to extract heat from the geothermal water only on the condition that the water itself is placed back into the aquifer after the heat is removed. Injection carries technical risk of clogging in the injection bore by chemical, biological and/or physical factors. Significant additional O&M costs can be incurred for regular removal and cleaning or replacement of screens. Injection is a relatively new activity in the hydrogeological sector. Risk remains moderately high because of a relatively low level of scientific knowledge about the mechanisms that adversely impact injection efficiency. Injection risk can be managed, although not altogether eliminated, by consulting a hydrogeologist with specific experience in injection.

## 12.2 Non-technical risks

### 12.2.1 STEM

#### *12.2.1.1 Geographical Risk*

Depending on the location of the CST plant, different weather phenomena’s can undermine its production levels. In some regions, projects can be susceptible to windstorms, tornados, cyclones, hurricanes and dust storms, experienced through El Nino events.

Drainage systems, flood canals, dykes and water pumps can be used to minimize the risk of water damage, and the automatic stowing of mirrors can help protect plants from the risk of strong winds.

Climate change in areas are an issue that can affect the production of the plant over the lifetime as the weather conditions change in the region. CST plants have an average life span of 30 years, making the risk of weather conditions a large factor in future predictions.

### 12.2.2 Geothermal

#### *12.2.2.1 Reduction of aquifer temperature due to proximal users*

Most Australian jurisdictions are yet to impose regulations to protect the thermal energy in an aquifer. For this reason, there is a low, but non-zero, risk in many jurisdictions that a geothermal project on a neighbouring property could reduce the temperature of the geothermal aquifer, and hence the amount of useful energy it contains, by injecting cold water into the aquifer upstream of the production bore. This risk is best managed through remaining vigilant for activities on neighbouring properties that might have an adverse impact on geothermal aquifer properties.

*12.2.2.2 Declining water levels due to externalities*

Long term decline in groundwater recharge, or large-scale regional extraction, can result in a continuous decline in groundwater levels. This observed, for example, in the Gippsland Basins, where onshore mine dewatering and offshore petroleum production have combined to lower the groundwater level in some aquifers by as much as one metre per year since at least the early 1980s. The result is a gradual increase in pump running costs to maintain constant production rates, plus possible regular replacement of pump.

*12.2.2.3 Social license*

While geothermal energy is a relatively benign energy source, any new technology or new competition for a groundwater resource can trigger social opposition. The Australian geothermal sector already experienced this when local residents organised protests against a proposed geothermal power development near Gherang in Victoria in 2010. The protestors identified no fewer than 14 concerns about the health and safety of local residents should the geothermal project proceed. While local concerns were eventually assuaged, it was not without significant time and effort on the part of the company. Social licence risk can be managed through an appropriate stakeholder engagement program if deemed appropriate.

*12.2.2.4 Borehole liability*

Owning and operating a bore comes with responsibilities and liabilities. Responsibility for production reporting, maintaining, and ultimately decommissioning the bore lies with the bore owner. The costs involved should be factored into any financial models at pre-feasibility and feasibility stage.

# 13 FUNDING OPTIONS

There are a large number of funding options available when looking at renewable energy projects across different industries. Within the large amount of funding mix for capital investment, many businesses neglect to examine potential government funding and financing options that exist to help industry achieve various policy outcomes. These can include:

- Infrastructure and capital projects
- Export-related activities
- Regional development
- Advanced manufacturing or value-add processing
- Renewable energy

AMPC and its clients' may be able to align with a number of these outcomes across both Federal and State Government. Undertaking a strategic exercise in identifying how members can be mapped to access various funding opportunities will position AMPC and its members with the information to examine how the government can play a role in securing finance for these renewable energy opportunities. Critically, this may enhance the economic viability of these technologies, particularly where multiple sites are located in close proximity or where the economic viability is "on the border".

This following briefly outlines the currently available government programs AMPC and/or its members may wish to consider accessing for support for their renewable energy opportunities.

*Table 18: Overview of Funding and Grant Options*

| Program | Project | Funding Available | Timing | Notes | More Information |
|---|---|---|---|---|---|
| Northern Australia Infrastructure Facility (NAIF) | Geothermal<br><br>CST | Debt finance | Ongoing / immediate | Has to be above the tropic of Capricorn to be considered for this finance.<br><br>Has to have indigenous community engagement. | Section 14.1 |
| Building Better Regions Fund (BBRF) | Geothermal<br><br>CST | Grants of up to $10M<br>At least 1:1 ratio | Imminent (next round Nov/Dec 2019) | Needs to be led by local council or other not-for- profit.<br><br>This will be a grant opportunity for new build abattoirs. | Section 14.2 |
| State Government Market-Led Proposal (MLP) | Geothermal<br><br>CST | Grants, loans (untested to date) | Ongoing / immediate | This is a policy rather than a discrete program. As such it only sets out the framework by which MLPs would be assessed and treated by Government. | Section 14.4 |
| Australian Renewable Energy Agency (ARENA) | CST | Grants | Ongoing | Feasibility study funding. | Section 14.3 |
| Export Finance Australia | Geothermal<br><br>CST | Debt finance Guarantees | Ongoing / immediate | Exporting or with a presence in international markets.<br><br>Part of an export supply-chain<br><br>Commencing exporting or selling to overseas customers. | Section 14.6 |

Further detail on each of these programs, along with a brief overview on the suitability of the programs for investment is included in the following sections.

## 13.1 Northern Australia Infrastructure Facility (NAIF)

NAIF is a $5 billion Federal Government concessional loan scheme that commenced on 1 July 2016 for five years. The aim of NAIF is to encourage private sector investment in new multi-beneficiary economic infrastructure in northern Australia. Northern Australia is generally defined as the geographic areas north of the Tropic of Capricorn and the entirety of the Northern Territory.
NAIF funding was announced in the 2015-16 Federal budget, and it officially commenced on 1 July 2016. NAIF aims to encourage private sector investment in infrastructure that would otherwise not be built and can include renewable energy infrastructure. NAIF provides loan support with the following concessions applicable:

- Longer term tenor than commercial loans
- Lower interest rates than offered by commercial financiers
- Extended period of capitalisation of interest

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- Deferral of loan repayments, or other tailored repayment schedules
- Lower or different fee structures than those offered by commercial lenders
- Lower ranking than commercial financiers for security.

Proponents need to demonstrate need for the requested concessions, in addition to compliance with various criteria which includes demonstrating public benefit, indigenous engagement, and the creation of economic infrastructure, as examples.

### 13.2 Building Better Regions Fund (BBRF)

The Federal Government's Building Better Regions Fund (BBRF) seeks to drive economic growth and build stronger regional communities into the future. The last funding round had $200 million available and up to $45 million specifically for tourism related infrastructure projects. The Federal Budget provided additional funding to the Program for a further round, expected to open in the second half of 2019.

To apply for funding, private businesses must partner with an eligible local government authority or not for profit organisation, in a consortium.
Claims for funding can be made for projects that identify significant multi-user or public benefit, through two streams:

- Infrastructure - grant amounts from a minimum of $20,000 and up to a maximum of $10 million for the construction of new infrastructure, or the upgrade of existing infrastructure outside capital cities (excluding Hobart and Darwin) with strong community benefits
- Community - grant amounts from a minimum of $5,000 and up to a maximum of $10 million for new or expanded local events, strategic regional plans or leadership and capability strengthening activities. Given the nature of eligible projects, it is expected most grants will be under $100,000.

Funding is usually available for up to 50% of eligible costs (up to a maximum grant of $10 million) across both streams, unless a project is in a region defined as remote or very remote. The Southern Argyle and Kalgoorlie Projects are located in regions classified as "very remote" which previously indicated that up to 75% of eligible costs can be covered by grant funding (up to the maximum of $10 million).

BBRF aims to achieve the following outcomes in regional and remote communities:

- Create jobs
- Have a positive impact on economic activity, including Indigenous economic participation
- through employment and supplier-use outcomes
- Enhance community facilities
- Enhance leadership capacity
- Encourage community cohesion and sense of identity.
-

Projects will be assessed against others of similar value across three ranges:

- Under $1 million
- $1 million to $5 million
- Over $5 million.

## 13.3 Australian Renewable Energy Agency (ARENA)

ARENA was established by the Federal Government on 1 July 2012 and is funded until 2022.
The aim of the ARENA is to accelerate Australia's shift to secure, affordable and reliable renewable energy. The following investment priorities have been established by ARENA:

- Deliver secure and reliable electricity
- Accelerate solar PV innovation
- Improve energy productivity
- Export renewable energy

Currently ARENA has not funded any modular CST projects or shallow geothermal projects that aim to displace gas in regional industries. ARENA is increasingly focusing its investment of grant money into Australia's manufacturing and processing industries so it is an ideal avenue for AMPC and its members.

## 13.4 State Government: Market -Led Proposal

Government has developed a Market-Led Proposals policy to guide consideration of proposals from the private sector.
Projects considered by Government under this policy initiative would involve:

- Building and/or financing infrastructure

- Providing goods and services
- Purchasing a government owned asset.

Projects would include a commercial proposition for government, for example accessing land, assets, information and networks, developing public infrastructure or providing a good or service on behalf of government.

The policy is intended as a framework and provides a mechanism for Government in assessing the merits of specific projects that might not be accommodated through other funding avenues.

### 13.5 Clean Energy Finance Corporation (CEFC)

The CEFC provides market rate and concessional support for renewable energy, low emissions and energy efficiency projects. Originally established with $10 billion of funding, the CEFC generally provides loans across two funding streams – a proven technology stream, and a Clean Energy Innovation Fund (CEIF) stream for new and innovative clean energy technologies.

Examples of CEFC projects include waste to energy and bioenergy plants, solar systems and farms, wind farms, energy efficiency equipment upgrades in manufacturing, remote solar and storage, tidal, energy efficiency in buildings, production of inputs to renewable energy technology, and on-site generation in agricultural sector.

The proven technologies stream seeks to fill gaps in the private sector finance market for mature technology projects. An overview of the types of terms that could be offered are:

- Interest rate of around 5 – 7%
- Longer borrowing and repayment terms (over conventional market loans)
- Need evidence of an offtake agreement.

Historically, projects seeking around $20 million worth of finance are received favourably by the CEFC for funding under this stream.

Funding through the CEIF is specifically for projects which are having difficulty in attracting private sector investment. The CEFC seeks guidance from ARENA on whether the proposal is supported for funding, technical and commercial feasibility of the technology, and competitive environment of businesses seeking to deploy technology. Loans through the CEIF have similar flexibility in loan structure.

### 13.6 Export Finance Australia (EFA)

EFA is the Australian Government's export credit agency. It provides Australian businesses with export finance solutions by:

- Working with banks and other financial institutions to provide supplementary financing support for export businesses
- Providing export finance solutions when the private market cannot
- Collaborating with Government agencies.

EFA operates on a commercial basis. Its range of export loans, guarantees, bonds and insurance products help Australian businesses:

- Secure export-related contracts in new markets
- Expand internationally
- Win export supply chain contracts
- Deliver on large offshore corporate or sovereign projects with significant Australian
- content.

EFA provides support to small, medium and large businesses across a range of industries that are:

- Exporting or with a presence in international markets
- Part of an export supply-chain
- Commencing exporting or selling to overseas customers.

It is important to note that EFA only provides loans and other products at market rates, given its role as a market gap financier.

## 14 CONCLUSION

The meat processing industry has a high demand for heat energy in order to produce both hot water for sterilization and steam for rendering. This heat is typically produced from domestic gas supplies either directly to a boiler or via various sources of cogeneration adequately covered in previous studies.

Applying renewable sources of energy to an industrial process is only able to provide a certain level of fossil fuel displacement according to the particular technical process and operational hours. The fossil fuel connection is maintained for the balance of energy needs and backup reliability. By default, existing sites are seeking a financial return through the fuel saving while a new greenfield site with the knowledge of renewable options has the flexibility to adapt operations production schedules to maximise the benefit of the renewable power source.

Evidence provided in this study suggests the technical potential for geothermal and CST energy to provide a significant portion of water heating requirements to the meat processing industry at each of the considered reference plant sites is there, though there are technical and commercial considerations to produce the optimal solution.

The first, is that smaller scale CST technology is still a maturing technology, which is at the beginning of the production efficiency cost curve, hence the high capital cost requires assistance in order to increase the long term energy cost saving potential. CST is also limited by the amount of land area available for uptake and needs a high, Zone 1 & 2, year-round sunlight index to be considered viable in the first instance. Though this makes regional applications of greater interest due to more available space.

CST can be broadly divided into lower cost instantaneous solutions and those with a means of energy storage considered important to buffer any daytime intermittency and extend working time and reliability but with additional cost. Though as with solar PV, as time moves forward with technology uptake the capital cost of CST will lower and thus making it an attractable solution for a wider range of applications then its current market. In conclusion, if capital costs reduce with time or if an interim funding mechanism was awarded to test and study the Magaldi STEM solution then the LCOH will be competitive enough for uptake of the technology in abattoirs.

Geothermal is a well understood, proven and technically robust source of renewable energy already used in industries and local communities, with a small site footprint and low O&M costs. The geothermal water is usually returned to the aquifer but in some locations can be extracted as a heat and water source.

In Western Australia, the populated area north and south of Perth sits over the Perth Basin, which has been drilled to supply heating water for almost all large private and council owned aquatic centres. Geothermal is therefore limited to areas that are known to have access to suitable exploitable aquifers, though has the advantage of being a 24/7 reliable energy supply capable also of producing electrical energy as well as thermal heat given commercially available technologies. This experience and consistency of energy supply allows for a more robust economic argument to be made for geothermal applications.

The next steps in the appraisal of geothermal potential for AMPC member sites looking to uptake the technology, should be to identify and collate local data for all parameters relevant to a pre-feasibility financial assessment. Relevant parameters include:

- Depth, temperature, water quality, and likely productivity of target aquifers (drilling on site);
- Plant water and heat consumption curves;
- Local gas and electricity price, and predicted 'business as usual' costs;
- Supply characteristics of current process water;
- Land area constraints for new construction;
- Local drilling and well completion costs;
- Local earthwork costs;
- Licence conditions for groundwater production and disposal;
- Type, capacity and cost of water pumps;
- Type, capacity and cost of surface thermal plant (e.g. heat exchangers, heat pumps);

Relevant local data might usually be sourced from the plant operators, state government geoscience data repositories, local drilling and earthwork contractors, and equipment manufactures / retailers. With those data, preliminary financial modelling could indicate if, and under what design criteria, geothermal energy could provide a net benefit to each operation.

In summary, any trial for CST or geothermal will be a close collaboration between a highly qualified site with a renewable energy agency such as ARENA and a proven technology partner to develop an industry pilot plant to optimize and demonstrate these technologies for the broader industry.

## Disclaimer

Due to the variances within data received as part of the Study, ResourcesWA note that figures within in the financial model are predominantly based upon a “best fit” basis. In order to get a more accurate understanding of project viability at a site specific level, it is recommended that further studies be done on individual prospects. The goal of the financial model is to provide a “best fit” insight into the potential opportunities available under specific conditions within the Study. The financial model does not aim to provide analysis on a project by project basis. ResourcesWA have relied upon the information provided by AMPC members and does not hold any responsibility for the accuracy of said information. ResourcesWA have relied upon assumptions and calculations provided by Rockwater Hydrogeological and Environmental Consultants and does not hold responsibility for the accuracy of said information. ResourcesWA have relied upon assumptions and calculations provided by STEM technology experts, Magaldi, and does not hold responsibility for the accuracy of said information. ResourcesWA advises that further in-depth detailed studies be conducted before making any financial investment decisions.