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Australia — Country Update

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ABSTRACT

The six years from 2015 – 2020, inclusive, saw the focus of geothermal development in Australia continue to move from electrical power generation to direct-use and ground source heat pumps (GSHPs).

All geothermal power projects existing prior to 2015 were suspended or abandoned in the subsequent six-year period, including the high-profile Cooper Basin engineered geothermal systems project. Australia's longest-running geothermal power station, the 120 kWe plant at Birdsville (Queensland), was decommissioned in 2018 in favor of solar PV with battery storage. However, a new 310 kWe geothermal plant was commissioned at Winton (Queensland) in early-2020, and a tender was released in mid-2019 for design and construction of another small geothermal plant in Thargomindah (Queensland).

Rising domestic natural gas prices over 2015–2019 triggered interest in direct-use of geothermal heat across the country. The local government in Portland (Victoria) remains enthusiastic about re-commissioning a suspended geothermal district heating system, but this can only be achieved with state government support that has so far proven elusive. In Western Australia, space and pool heating for aquatic centers represented the majority of new direct-use geothermal installed capacity. A census completed by AGA in 2018 identified 86 MWt of installed capacity (direct-use and GSHPs) for all operating geothermal projects, tipped to grow to 151 MWt during the period 2020-2025.

In 2020, the Australian geothermal hot springs industry was in a period of significant growth. Such projects are generally embraced by local communities as opportunities to provide permanent local employment and year-round tourism attractions. Two existing and six new commercial projects are well evolved in the state of Victoria, with others in various stages of planning or under construction in all other states of Australia. PhD research into the mental and physical effects of hot springs is underway at RMIT University, while a PhD student at Victoria University is researching the economic and social effects on communities as a result of hot spring developments.

The economics of GSHPs are at a tipping point in Australia, with several large housing developments electing to include community scale installations of GSHPs (including up to 900 houses in one New South Wales development.) In 2018, GSHPs comprised 61 MWt of the identified total installed geothermal capacity in Australia but only one quarter of the produced thermal energy. Their use was mostly for heating, ventilation and air-conditioning (HVAC) although there were some reported applications for residential pool heating. GSHPs were installed across Australia but most systems were in eastern states, primarily New South Wales. Up to 20 MWt of residential GSHPs capacity might have been installed prior to 2000, but this is difficult to quantify due to a lack of standardized reporting of GSHP installations in Australia.

Direct-use looks set to continue as a focus of geothermal development in Australia for the next five years, while interest in geothermal power could see a renaissance if federal and state policy settings shift towards supporting low emissions, reliable, cost effective power supply.

Individuals within the Australian research sector remain aware of and enthusiastic about the potential for geothermal energy in the country and have played a key role in raising awareness of the potential for GSHPs in particular. Researchers are investigating the challenges and opportunities for geothermal direct-use and power generation.

Representation of the Australian geothermal sector shifted in 2016 to the newly incorporated Australian Geothermal Association (AGA) with individual membership after deregistration of the previous Australian Geothermal Energy Group (AGEG) and Australian Geothermal Energy Association (AGEA) of institutional membership. AGA replaced AGEG as the Australian affiliate to the International Geothermal Association.

1. INTRODUCTION

The six years from 2015–2020, inclusive, saw the focus of geothermal development in Australia continue to move from electrical power generation to direct-use and ground source heat pumps (GSHPs). This happened within the context of a sustained lack of bipartisan energy and climate policies at federal and state level across the country. The resulting investment uncertainty for renewable power, coupled with continuing reductions in the cost of wind and photovoltaic power generation, provided powerful disincentives for commercial investment in geothermal electricity. Rising domestic natural gas prices over the same period, however, have stimulated interest in direct-use of geothermal heat across the country.

1.1. Geothermal legislation and policy environment

The Commonwealth of Australia (Figure 1) is a federation of states and territories. Under the Australian Constitution, regulation of geothermal resources falls under the control of the states. Different states have enacted individual pieces of legislation to control the exploration and development of geothermal energy. In most cases, legislative instruments specifically target deep drilling for power generation and mirror prior pieces of legislation controlling the exploration and production of petroleum or mineral resources. In most states, the production of geothermal energy for direct-use is explicitly excluded from specific geothermal legislation, regulated instead under existing frameworks for groundwater management. The installation and operation of ground source heat pumps remains effectively unregulated in Australia.

Figure 1. The Commonwealth of Australia, showing topography, state and territory boundaries and capital cities.

In **Western Australia**, the Petroleum and Geothermal Energy Resources Act 1967 (as amended in 2017) provides for the exploration and recovery of geothermal energy. It allows the Western Australian Government to progressively release blocks of land for open tender, or for explorers to apply for a Special Prospecting Authority. The Geothermal Energy Act 2009 (as amended in 2016) controls the exploration and development of geothermal energy in the **Northern Territory**. It defines geothermal energy resources as "(a) geothermal water or (b) rock or any other material containing heat energy." The Act allows 'over the counter' applications. In **South Australia**, the Petroleum and Geothermal Act 2000 (as amended in 2018) allows 'over the counter' applications for geothermal licenses. The Geothermal Energy Act 2010 (as amended in 2016) controls the exploration and development of 'large-scale' geothermal energy extraction in **Queensland**. The Act defines geothermal energy as "heat energy derived from the earth's natural (subsurface) heat." The Act allows 'over the counter' applications. Exploration and production of geothermal energy in **New South Wales** are 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." The Geothermal Energy Resources Act 2005 governs exploration for geothermal resources in the state of **Victoria**. The Act allows the state government to release blocks of land across the entire state for open tender. Geothermal resources are classified as 'Category 6' minerals under the Mineral Resources Development Act 1995 (as amended in 2017) in **Tasmania**. The Act allows 'over the counter' applications for licenses.

Policies on climate change and renewable energy have been highly politicized by Australian political parties since the early 2000s, with major changes introduced by each new government. At the international level, Australia's commitment under the 2015 Paris Agreement is to reduce emissions by 26–28 per cent below 2005 levels by 2030, building on Australia's Kyoto Protocol commitment to reduce emissions by 5–25% per cent below 2000 levels by 2020. The Australian government (with bipartisan support) in 2001 mandated a Renewable Energy Target (RET) for Australia's annual electricity generation to come from renewable sources. This was initially set at 9,500 GWh/yr of renewable electricity by 2010. After a change of government in 2007, the target was raised in 2009 to 41,000 GWh/yr by 2020, which was predicted to be 20% of total generation. Another change of government in 2013 saw a review of the RET scheme and a reduction of the target in 2015 to 33,000 GWh/yr by 2020, with the justification of keeping to the 20% goal in light of a reduction in total predicted generation. The target will remain flat at 33,000 GWh/yr until the scheme ends in 2030. The main mechanism for meeting the target is 'Large Generation Certificates' earned by renewable energy generators and traded through a regulated market. In principle, geothermal power stations are eligible for LGCs, but with the 33,000 MWh/yr target already fully met by existing and planned solar and wind projects, the RET provides little incentive for geothermal power. A parallel Small Scale Renewable Energy Scheme (SRES) to incentivize solar water heater and air source heat pump systems provides no incentive for ground source heat pumps, in spite of repeated efforts by the geothermal sector to have them included.

The government's primary mechanism for reducing non-energy sector emissions is an 'Emissions Reduction Fund' of AU$4.55 billion (US$3.45 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 the Clean Energy Regulator, the spot price for ACCUs in late 2020 was around AU$16.50 (US$12.50) per tonne of CO_2 (or equivalent) stored or avoided by a project. There is some suggestion that new renewable energy projects that do not register for the RET after 2020 might be eligible to generate ACCUs, but this is yet to be tested.

Brailsford et al. (2018) concluded, “states and territories continue to lead the way on renewable energy in the ongoing absence of credible national climate policy.” Several states have specifically introduced their own renewable energy and emission reduction targets. Namely, Tasmania (100% renewables by 2022, zero net emissions by 2050), Australian Capital Territory (100% renewables by 2020, zero net emissions by 2045), South Australia (zero net emissions by 2050), Victoria (40% renewables by 2025, zero net emissions by 2050), Queensland (50% renewables by 2030, zero net emissions by 2050), New South Wales (zero net emissions by 2050), Northern Territory (50% renewables by 2030).

1.2. Financial support from Governments

The Australian Renewable Energy Agency (ARENA) was established in 2012 for ten years to consolidate Australian government funding of renewable energy projects. It was allocated AU$2 billion (US$1.5 billion) to make available as grant funding to renewable energy projects until 2022. Beardsmore et al. (2015) summarized the geothermal projects that had received ARENA funding up to 2014. ARENA established an International Geothermal Expert Group (IGEG) in 2013, which generated a report in 2014 (Grafton et al., 2014). Based on the recommendations in the report, ARENA adopted an investment strategy for geothermal power that “promote[s] innovation and assist[s] the geothermal sector towards a more cost-competitive path and with a strong emphasis on research and development in both finding (other than drilling) and flowing the resource” (Grafton et al., 2014). The IGEG furthermore concluded that utility-scale power generation from geothermal projects might only be competitive in Australia by 2030 under optimistic assumptions.

Between 2014 and early 2020, ARENA awarded grants for two geothermal projects:

- Structural Permeability Map Project—AU$450k (US$340k) towards a AU$1.61M (US$1.22M) project by the University of Adelaide to deliver a national database and map of natural fractures and subsurface permeability in several Australian basins to better target geothermal resources. Commenced in October 2015 and completed in March 2018 (Hansberry, 2018);
- Residential Heat Pump Study—AU$500k (US$380k) to Climate-KIC Australia to coordinate a AU$1.64M (US$1.25M) three-year study of the performance of ‘deep well direct exchange’ (DWDX) ground source heat pumps installed in a residential community in Western Sydney. Commenced in 2019 for completion in 2022.

More recently, ARENA has indicated a reluctance to invest further in geothermal energy; “while ARENA has historically invested significantly in geothermal energy, this isn't an area we are continuing to support” (pers.comm. P. Cohn, ARENA, 19 March 2019.)

In late 2019, the Federal Government committed AU$1 billion (US$0.75 billion) to a ‘Grid Reliability Fund’ to be administered by the Clean Energy Finance Corporation (Prime Minister of Australia, 2019). The fund will invest in clean energy projects that increase the stability and reliability of national electricity. While details of the fund have not yet been released, it is possible that geothermal power projects will be eligible for investment,

Other funding bodies have also provided support to the geothermal sector. For example, in 2016 the Deep Blue hotel and spa in Warrnambool, Victoria, was awarded AU$650k (US$490k) from the federal government’s Tourism Demand Driver Infrastructure Program to help add more than 20 indoor and outdoor geothermal ‘experiences’ (including salt, mud and jetted pools) to the spa’s existing five geothermal mineral bathing pools. The City of Mandurah in Western Australia completed the Mandurah Aquatic and Recreation Centre redevelopment using a geothermal energy heat source in 2015, assisted by a AU$2M (US$1.5M) grant from the federal government Community Energy Efficiency Program (CEEP). The City of Canning received AU$0.947M (US$0.72M) from the same program, plus AU$0.70M (US$0.53M) from the Western Australian Department of Sport and Recreation, to provide geothermal heat to the Riverton Leisureplex.

Individual government agencies have also directly financially supported geothermal energy technology by including GSHPs and geothermal direct-use in designs to meet energy efficiency mandates. Examples commissioned during the reporting period include a light rail substation in Sydney, and several municipal aquatic centres in Western Australia and Victoria.

1.3. Geothermal research

The relevant major national research institutions, **CSIRO** and **Geoscience Australia**, disbanded their formal geothermal energy research groups before 2015, but several of their staff are individual members of the Australian Geothermal Association (see Section 1.5 below) and their ongoing research into subsurface resources and energy as well as geological carbon storage produces outcomes relevant to geothermal energy.

The **University of Adelaide** continues to host the ‘South Australian Centre for Geothermal Energy Research’ (SACGER), which focuses on (a) understanding the distribution of subsurface permeability using 3D seismic and MT data; (b) the geochemistry of geothermal fluids and resultant precipitation and scaling; (c) modeling fractured reservoirs for engineered geothermal systems; and (d) understanding and modeling stress and fluid-pressure in unconventional geothermal systems.

The ‘Queensland Geothermal Energy Center of Excellence’ at the **University of Queensland** now forms part of the ‘Renewable Energy Conversion Centre of Excellence.’ Its research focuses on identifying geothermal energy sources and fluid flow routes; evaluating regional opportunities for geothermal power in Queensland; demonstrating ground source heat pump technology under a range of climatic conditions; and the rheological behavior of high-temperature drilling fluids.

The **University of New South Wales** offered both undergraduate and postgraduate units in Geothermal Engineering in 2020. On the Residential Heat Pump Study mentioned in Section 1.2 above, Climate-KIC lists the **University of Technology Sydney** (UTS) and **Curtin University** as partners. The **University of Melbourne** received a grant from the Australian Research Council for the project ‘Optimisation of Shallow Geothermal Systems for Australian Schools’ running from 2017 to 2021, and a grant from the Victorian state government through the Latrobe Valley Authority for the project ‘Gippsland geothermal mapping and cost analysis tool — information gathering and geothermal economic algorithms’ for 2020–2021. The university also published the Victorian Geothermal Assessment Report in 2016 (Beardsmore et al., 2016). Other universities including **Newcastle University** also supported geothermal research programs.

1.4. Investment by geothermal companies

Company **investment in geothermal power generation** largely stalled during the reporting period. As of late 2018, a handful of companies controlled a total of about 40 geothermal licenses covering an area of about 35,000 km^2 across the country (Figure 2). This represent about a 90% reduction in license area since the previous Country Update in 2015. Furthermore, only a bare minimum of work was carried out on those licenses during the reporting period, pending a material change in the geothermal energy investment climate. No wells were drilled directly for geothermal power during the reporting period.

One exception to the trend described above is ongoing activity by Peak Services PL, a service group 100% owned by the Local Government Association of Queensland (LGAQ). Peak Services is helping LGAQ members, regional local councils in Queensland, invest in small-scale geothermal power plants in regional towns using hot water from the Great Artesian Basin. The orange spots scattered across Queensland in Figure 2 indicate the geographic distribution of the prospective sites. The first 300 kW_e plant was be commissioned at Winton (small green spot above “QU” in “QUEENSLAND” on Figure 2) in 2020, with investment variously reported as AU$3.1M (US$2.4M; Queensland Government, 2019) to AU$3.5M (US$2.7M; ABC, 2015). Tender documents were issued for the design and construction of a second plant, in Thargomindah, in mid-2019. A new bore costing AU$620,000 (US$470,000) was drilled in Ilfracombe in 2018, which specifically made “allowances for future…possibility of a geothermal power generator being incorporated with the bore at a later date.” (Queensland Government, 2018)

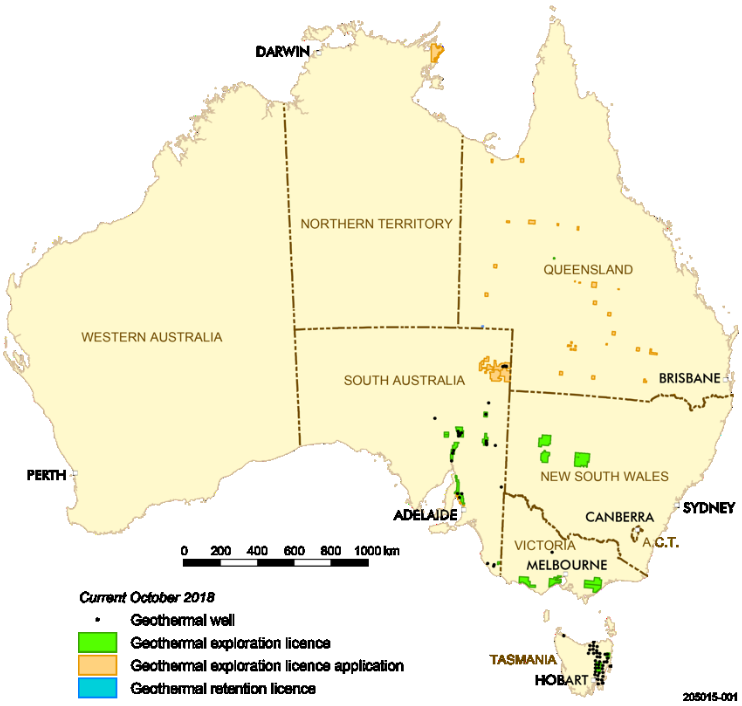

Figure 2. Distribution of geothermal exploration licenses (for power generation) and wells in Australia in late 2018.

Another exception is a commercial project assessing the potential for power generation from a hot sedimentary aquifer reservoir in the North Perth Basin, Western Australia. Ballasteros et al. (2020) reported details of the project that could potentially support more than 100 MWe of generation. An application for an exploration license was pending at the time of writing in late 2020 and expected to be approved early in 2021.

Investment in direct-use of geothermal energy increased in the reporting period, with a large portion of the investment coming from local councils. Geothermal aquatic center projects were all driven by local councils (City of Canning, City of Mandurah, City of Cockburn, City of Stirling and City of Armadale in WA, and Latrobe City Council in Victoria). The total investment for these projects was about AU$20M (US$15M) based on available information in the public domain. In most cases, the projects were funded directly from the councils’ building reserves or loans, with state or federal government financial support limited to just AU$3.7M (US$2.8M). These investments were driven by projected savings in operating costs compared to natural gas boiler systems, with payback periods less than ten years based on projected future gas prices.

Investment into geothermal spas in the coming 1-2 years is estimated at over AU$100 million (US$75M), largely from private enterprise, with a further AU$220 million (US$165M) investment expected over the 3-5 year period. The largest share of these investments will be in Victoria, with AU$60 million (US$45M) in the next 1-2 years and AU$190 (US$145M) over 3-5 years. Other states with current or planned geothermal spa developments in coming five years include Western Australia, Northern

Territory, South Australia and Queensland. True investments in geothermal health and wellbeing tourism could be even larger as interest is rapidly growing.

1.5. Geothermal organizations

There have been changes to the organizational representation of the Australian geothermal sector during the reporting period. The *Australian Geothermal Energy Group* (AGEG) and the *Australian Geothermal Energy Association* (AGEA) were both deregistered in 2016, and the *Australian Geothermal Association* (AGA) inherited AGEG and AGEA assets and legacy material. Incorporated in 2016, AGA is a professional society whose members are individuals working in industry, academia and government representing the full range of geothermal applications from ground source heat pumps to direct industrial heat supply, recreational bathing and wellness, and electrical power generation. Affiliated with the International Geothermal Association, AGA was born to promote and encourage the science, technology and development of geothermal energy in Australia. It is not-for-profit, non-party political and non-sectarian. AGA aims to be the central point for information on all things geothermal in Australia. The AGA has established sub-committees to provide special interest members forums. These include a Hot Springs committee, the Victorian members of which established an *Australian Hot Springs Industry Charter* in May 2018 to support the collaborative evolution and development of the industry. Other committees are focused on power generation and direct-use. A companion WGC2020 paper (Beardsmore et al., 2020) describes AGA's goals and activities in greater detail.

During 2020, the ground source heat pump sector in Australia organized into a new organization, the Australia and New Zealand Earth Energy Association (ANZEEA), with the inaugural officeholders taking office in late 2020. AGA and ANZEEA hope to work closely together on messaging and communication about GSHPs to the Australian public.

Australia remains a member of the *International Partnership for Geothermal Technology* (IPGT). The purpose of the IPGT is to accelerate the development of geothermal technologies such as engineered geothermal systems and supercritical systems through international cooperation. Other members are the United States, Iceland, New Zealand and Switzerland.

Australia also remains a member of the International Energy Agency's *Geothermal Technical Collaboration Programme* (IEA Geothermal), along with 12 other countries, Ormat Technologies Inc, the European Commission, and the Spanish Geothermal Technology Platform (Geoplat). IEA Geothermal focusses on sharing information; developing technologies, techniques and best practices for exploration, development and utilization; and producing and disseminating authoritative information and databases. The contracting party within Australia is the Department of State Development, State Government of South Australia.

2. GEOLOGY BACKGROUND

Knowledge of the geology of Australia has not significantly changed from the description provided by Beardsmore et al. (2015). We summarize that previous description here. Continental Australia lies wholly within the Indo-Australian tectonic plate with no active plate boundaries on land. While numerous, active surface thermal features are clearly artesian in nature. Australia is barren of high enthalpy hydrothermal geothermal energy sources. Parts of the country are, however, prospective for hot sedimentary aquifers and 'petrothermal' type geothermal sources.

Australia can be broadly divided into three provinces based on the age of the underlying basement (Figure 3). The Western Shield Province is characterized by Achaean aged crust. The Central Shield Province is composed predominantly of Proterozoic crust. The Eastern Province is of Phanerozoic age. Large sections of the Central Shield Province have been shown to host unusually high concentrations of heat producing radioactive elements such as uranium and thorium (McLaren *et al*., 2003). This unusual chemical enrichment keeps the crust warmer than it otherwise would be. Heat flow values are much higher through central Australia than might normally be expected for rocks of that age (Cull, 1982).

Figure 3. Broad divisions of the Australian continental crust based on basement age.

3. GEOTHERMAL RESOURCES AND POTENTIAL

No new geothermal resources or potential have been formally quantified since the 337,395 PJ of recoverable heat reported by Beardsmore et al. (2015). Qualitatively, however, the search for geothermal potential has shifted from hot crystalline basement and deep fractured sediments to naturally permeable hot sedimentary aquifers, and Ballasteros et al. (2020) estimated 90% probability that a hot sedimentary aquifer in the Kingia Sandstone of the North Perth Basin (Western Australia) could support 122 MWe generation for 30 years.

Much of the country is overlain by Phanerozoic sedimentary basins of various size and depth. While some of these are filled with highly silicic material, others contain shallow, thick successions of thermally insulating rocks that retard the flow of heat to the surface and elevate average thermal gradients. The Gippsland Basin in the southeast of the country, for example, contains some of the world's largest deposits of brown coal, while basins throughout New South Wales and Queensland are well endowed with black coal. The shallow units of the Perth and Otway Basins contain thick insulating clay-rich and calcareous rocks, respectively. The shallow units of the Great Artesian Basin have high proportions of thermally insulating shale. All of these basins host productive aquifers from primary porosity, and there are also known productive fractured rock aquifers. Many of these regions are prospective for 'hot sedimentary aquifers'. The deep blue and deep green areas on Figure 4 show the geographic coverage of these regions.

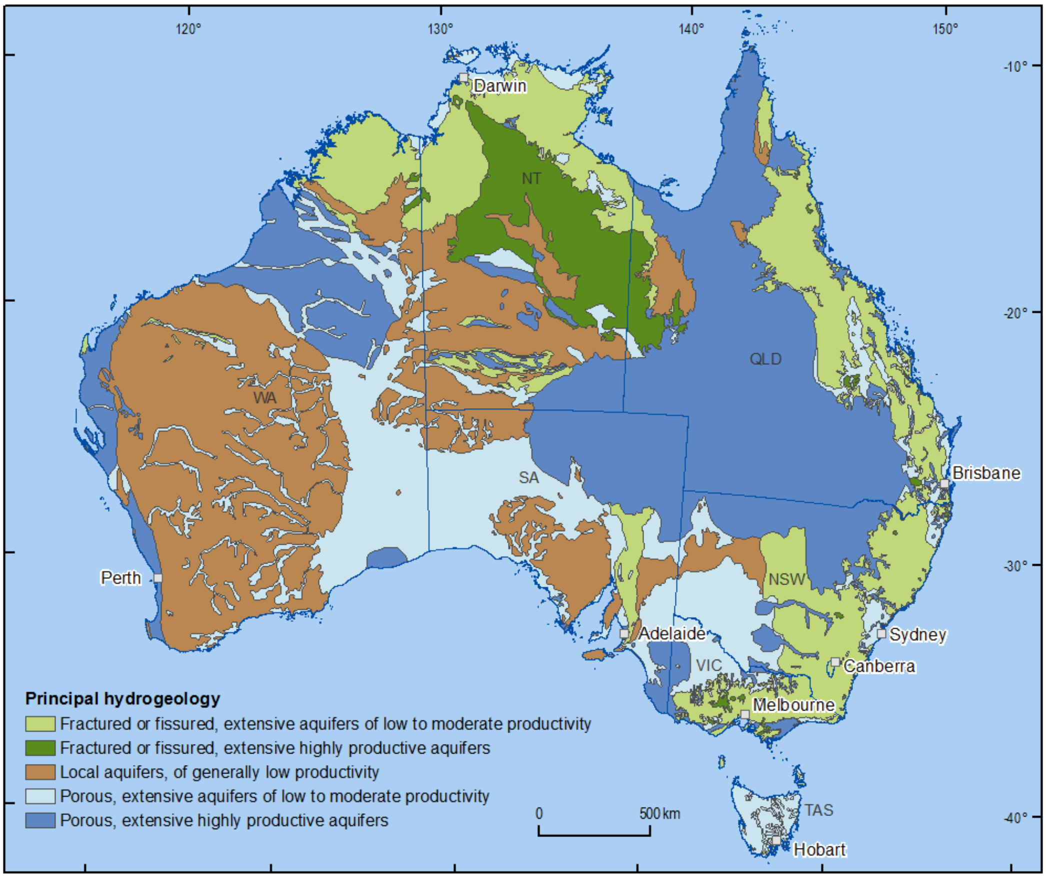

Figure 4. Hydrogeology of Australia. Source: Geoscience Australia.

4. GEOTHERMAL UTILIZATION

4.1. Present and planned production of electricity

The latest annual electricity usage statistics for Australia are from 2019 (Australian Government Department of the Environment and Energy, 2020), during which 265,117 GWh of electricity were consumed; 79% generated from fossil fuels, 5% from hydro, and the remaining 16% from a mix of biofuels, wind and solar PV. The Australian Energy Market Regulator publishes data on installed generator capacity for the 'National Electricity Market' (NEM), one of the world's longest interconnected power systems covering eastern and southern Australian states and territories. The NEM, however, does not extend to Western Australia. We sourced information about power plants in Western Australia from Wikipedia (2019). The combined generating capacity of the NEM and Western Australia totaled approximately 54,000 MW_e in 2019, of which 37,000 MW_e (68%) was powered by fossil fuels (black coal, brown coal, natural gas), 7,555 MW_e (14%) from hydro, and 9,700 MW_e (18%) from other renewables. The figures are summarized in Appendix Table 1.

As mentioned in Section 1.1 above, the Australian Government required 20% of the total electricity generation in 2020 to come from renewable sources. The figures above show that 21% of generation already came from renewable sources in 2019. New capacity commissioned since 2019 will continue to increase the renewable proportion beyond 20%. The Australian Energy Market Operator (AEMO) foresees renewables offering the least-cost solution to replace aging fossil fuel (particularly coal) fired generators as they are retired in the coming decades. AEMO (2018) specifically stated:

"Over the 20-year plan period, AEMO anticipates the retirement of a substantial portion of the NEM's conventional generation fleet. A significant number of coal-fired generators in the NEM have either advised that they are closing or will reach the expected end of technical life in this plan period. Collectively, the generators expected to retire by 2040 produce around 70 terawatt hours (TWh), or 70,000 gigawatt hours (GWh), of energy each year. This is close to one-third of total NEM consumption…When these resources retire, the modelling shows that retiring coal plants can be most economically replaced with a portfolio of utility-scale renewable generation, storage, distributed energy resources, flexible thermal capacity, and transmission."

Most of the expected transition will occur beyond 2025, with only one coal-fired generator scheduled for retirement before 2025; the 2,000 MW_e Liddell Power Station in New South Wales in 2022. AEMO (2018) modelled as a 'neutral' or base case that 15,000 MW_e of additional solar, wind and distributed storage capacity will be brought online by 2025 (Figure 5), which will more than compensate for the retired coal fired plant.

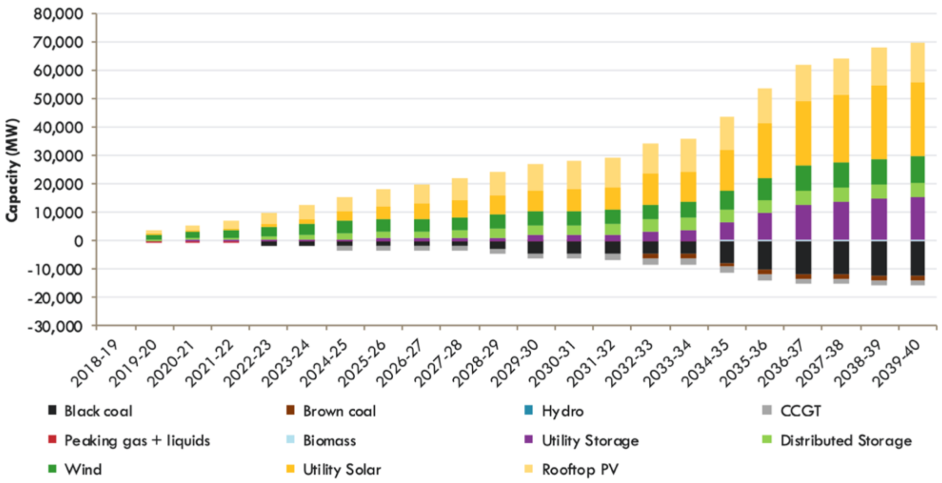

Figure 5. Relative change in installed capacity in the Neutral case, demonstrating the shift from coal to renewable energy. From AEMO (2018).

4.2. Utilization of geothermal energy for electric power generation as of 31 December 2020

As mentioned in Section 1.4 above, small-scale geothermal power plants are being developed in regional towns across western Queensland using hot water from the Great Artesian Basin. While a long-running 120 kWe (gross) geothermal plant at Birdsville (Queensland) was decommissioned in 2018 in favor of solar PV with battery storage, two new 155 kW_e (gross) geothermal generators were commissioned at Winton (Queensland) during 2020. The generators directly provide electricity to major Council assets through a private underground network. In addition, Bulloo Shire Council issued tender documents on 4 June 2019 "for the design and construction of a small scale geothermal plant in Thargomindah" (Consolidated Tenders, 2019), 1,000 km due west of Brisbane, Queensland, with a closing date of 8 July 2019. A bore drilled in Ilfracombe (Queensland) in 2018 was specifically designed with "allowances for future…possibility of a geothermal power generator being incorporated with the bore at a later date." (Queensland Government, 2018). These systems all utilize organic Rankine cycle (ORC) generators converting thermal energy from geothermal water in the temperature range 80–90°C. Power conversion from these resource temperatures (some of the lowest in the world) is only economic because the bores already exist to provide town water, and the generators are offsetting expensive diesel generators and water cooling facilities due to the remoteness of the towns (off-grid or edge-of-grid).

4.3. Utilization of geothermal energy for direct heat as of 31 December 2020 (excluding heat pumps)

Australia's only geothermal district heating system, at Portland in Victoria, remains decommissioned since 2006 for a variety of reasons including environmental (heat depleted water was being discharged into a surface stream). The Glenelg Shire Council announced its intention in 2018 to refurbish the district heating pipeline network at a cost of more than AU$1 million (US$0.7 million; Meldrum, 2018). This may allow connection of a new geothermal bore (yet to be constructed) in the future, but the council has indicated a more immediate intention to provide hot water from woodchip biomass (Glenelg Shire Council, 2018). In spite of this, geothermal energy is increasingly being recognized as a cheap source of thermal power, relative to natural gas combustion, particularly in the Perth Basin of Western Australia, and Otway and Gippsland Basins of Victoria (Appendix Table 3). This is reflected in the clusters in the SW and SE of the country on Figure 6, which shows installed geothermal capacity (direct heating and cooling, including heat pumps) identified in a national census conducted by the Australian Geothermal Association in late 2018.

Peninsula Hot Springs (PHS) on the Mornington Peninsula and Deep Blue Hotel and Hot Springs in Warrnambool, both in Victoria, utilize geothermal heat extracted via heat exchangers to provide space heating in their buildings since 2005 and 2007, respectfully.

The direct-use of geothermal energy in Perth is growing, with most geothermal heat plants constructed in only the last five to ten years. As of mid-2019, thirteen large leisure centres in Western Australia primarily used geothermal energy to heat pools and space (e.g. Figure 7; Appendix Table 3), and one large bore field provided direct cooling to a major supercomputer in Perth (Sheldon et al., 2015). This burgeoning industry has been supported by research at the former 'Western Australian Geothermal Centre of Excellence' (Trefry, 2012), and has been further encouraged by research focused on the thermal characterization of the Yarragadee aquifer (Niederau et al., 2017) and mechanical engineering for pool heating (Lovell et al., 2019). The geothermal source for all pool heating is the mid-Jurassic (Bathonian) clastic sedimentary rocks of the Yarragadee Formation at depths to about 1150 m, with production temperatures ranging from about 40°C to 50°C and flow rates of 10 to 40 liters per second (Pujol et al., 2015). The aquifer could support higher flow rates, but these have not been required with the scale of current projects. Collectively these geothermal plants provide an estimated 247 TJ of thermal energy per year. Regulations require 100% reinjection of the cooled fluid. As seen with many clastic geothermal sources globally, the main operational issue has been to manage bore injectivity. Gradual design improvements and adoption of best practices from the deep groundwater replenishment and oil and gas industries have resulted in successful, economic reinjection (Pujol et al., 2018).

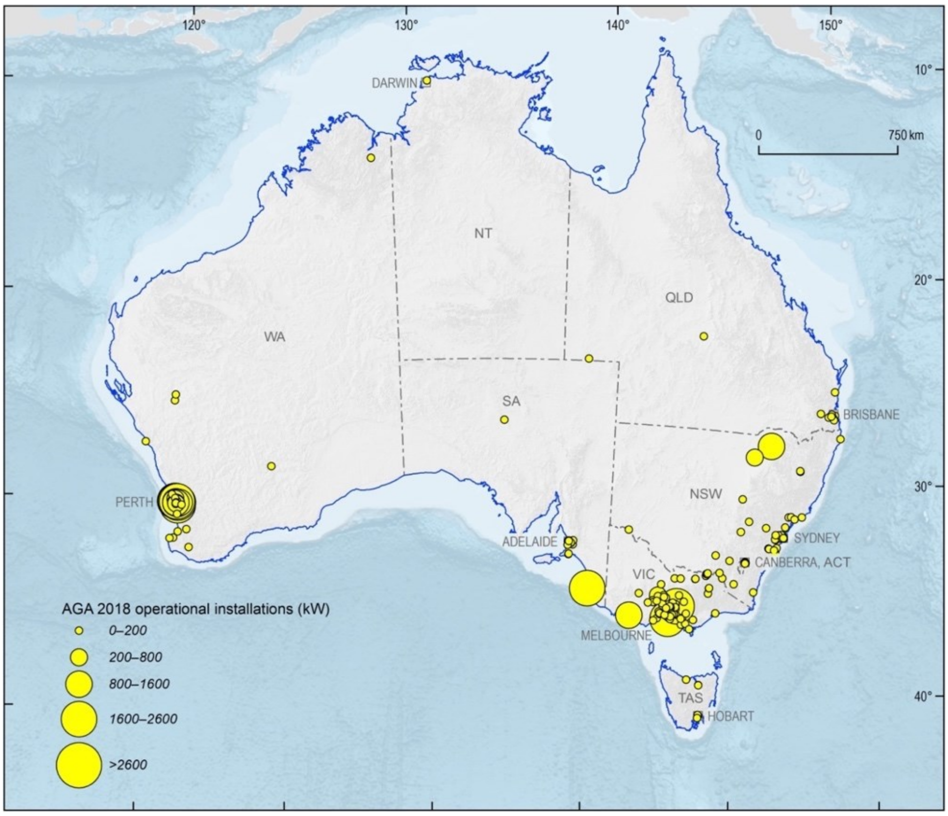

Figure 6. 2018 operational geothermal installations in Australia

Figure 7. Scarborough Beach Pool in Western Australia uses a geothermal heating system (Source: Douglas Mark Black Photography, 2017)

At Robe in South Australia, the company Robarra grows barramundi (edible tropical freshwater fish) in tanks that hold fresh geothermal water pumped directly from a 335 m deep bore in the Dilwyn Aquifer. The water comes from the bore at 29°C, in the optimal temperature range for growing barramundi, and provides over 43 TJ of thermal energy per year. In Victoria, Mainstream Aquiculture operates a barramundi farm at Werribee, using 28°C fresh geothermal water directly to grow the fingerlings. Midfield Group in Warrnambool significantly reduces its natural gas consumption by feeding 'preheated' geothermal water into its wash-down and sterilization system at its industrial meat processing facility. The Latrobe City Council (LCC) is developing the Gippsland Regional Aquatic Centre (GRAC). Geothermal energy will be used for pool water heating and space heating. Production well drilling and bore construction was successfully completed to 642 m depth between August and October 2019 (Figure 8). A review of geophysical logs suggested a bottom hole temperature of 68°C and neutron porosity values in excess of 33% across the aquifer interval. At the time of writing at the end of December 2020, the project was in the final stages of commissioning with pumping and injection tests having been successfully completed at about 30 L/s, consistent with the objectives of the project (Rockwater, pers. communication). Other potential direct-use applications are being identified in the region to utilize this promising geothermal resource.

Figure 8. Gippsland Regional Aquatic Centre in Victoria will use a geothermal heating system (Source: Drilltec, 2019)

The use of geothermal water in the recreational / wellness / tourism hot spring sector deserves special mention because of the strong growth in that sector in recent years. At a global level the hot springs industry was estimated to have a value of US$56 billion and growing at an average annual rate of 4.9% between 2015 and 2017 (Yeung and Johnston, 2018). Every state in Australia has hot springs, with over 50 unique locations so far identified (Figure 9). At least 15 of these support commercial bathing, day spa and accommodation. A total of seven wells were drilled for commercial bathing between 2015 and the end 2019, with several new projects proposed for drilling in the ensuing five years, primarily in Victoria. While Australia accounts for only a small fraction of the value of the global thermal/mineral springs industry (Global Wellness Institute, 2018), the Australian industry is growing rapidly.

Australia's preeminent geothermal spa is at Fingal, on the Mornington Peninsula 75 minutes' drive from Melbourne, where Peninsula Hot Springs produces 47°C water from the Werribee Formation at 640 m (Pujol et al., 2020). The tourism attraction received over 540,000 visitors in the year to 30 June, 2019 and employed 330 full and part time staff, which makes it one of the largest tourism operations in Victoria. Peninsula Hot Springs invested AU$13.5 million (US$10.3M) in 2017/18, a further AU$6 million (US$4.5M) in 2019/20, and will invest a further $30-50 million (US$23–38M) over the coming 2-4 years.

In spite of severe disruptions caused by the COVID 19 pandemic, which plunged much of the hot springs industry into lockdown on several occasions, the sector had a construction and development boom in 2020. Three new hot springs projects in Queensland, at Bourke Town, Talaroo Station and Cunnamulla, all received state funding between $1.5 to $5 million (US$1.1–3.8M). Victoria has two projects under construction—Alba Hot Springs on the Mornington Peninsula (US$30–38M) and Saltwater Hot Springs on Phillip Island (US$11–15M)—and another in East Gippsland called Metung Hot Springs (US$7.5M) is close to commencing construction. Nunduk Resort in Victoria and Tawarri Hot Springs in Western Australia each received planning approval and will commence construction in 2021. The Australian hot springs industry will see many new hot springs project launches in 2022. The 'Great Victorian Bathing Trail' research conducted in 2018/19 has become a catalyst for the industry in the state of Victoria and is helping to create a framework for a cohesive and collaborative thermal bathing industry sector.

Elsewhere around the country, recreational swimming and bathing centers use natural warm/hot spring water ranging in temperature from 28°C (Hastings, Tasmania) to 72°C (Innot Hot Springs, Queensland). The artesian geothermal water at Hastings supplies a single outdoor public swimming pool after passing through a filtration and chlorination system. The water used in the bathing facility at Innot Hot Springs is produced from a 56 m deep bore and used water is discharged into a cooling pond at the rear of the property. Innot Hot Springs also has an artesian flow of hot spring water into the river by the side of the caravan park and built bathing facility. Other locations around the country where artesian water is utilized for bathing purposes include Moree (New South Wales; 41°C), Pillaga (New South Wales; 37°C), Lightning Ridge (New South Wales; 41.5°C), Mataranka Springs (Northern

Territory, many springs ranging from 30-50 °C), Dalhousie Mound Springs (South Australia; 38–43°C), Zebedee Springs (Western Australia: 28-32°C), Talaroo Station (North West Queensland; 44°C), Lorella (Northern Territory) and many others.

Dalhousie Mound Springs is a group of over 60 natural artesian springs located in Witjira National Park on the western fringe of the Simpson Desert in northern South Australia. In 1915, the total flow rate of the Dalhousie Springs complex was over 2,000 ML/day (23,000 L/s), but drilling and production from the Great Artesian Basin had reduced this to 1,500 ML/day (17,000 L/s) by 2000 (Ponder, 2002). For tens of thousands of years, the Lower Southern Arrente and the Wangkangurru people (indigenous language groups) managed the water resources in a harmonious and sustainable way to provide water, food, life and connection on an important traditional travel path. Today, indigenous elder Dean Ah Chee from Dalhousie Springs works closely with the South Australian state authorities to manage and conserve the resource through a combination of traditional skills and knowledge and western scientific methods (Ah Chee, pers.comm.) Utilization rates are difficult to determine for most of the springs measured above. Many discharge rates to the surface and 'outlet' temperatures are unrecorded. For others, the flow rate is poorly constrained.

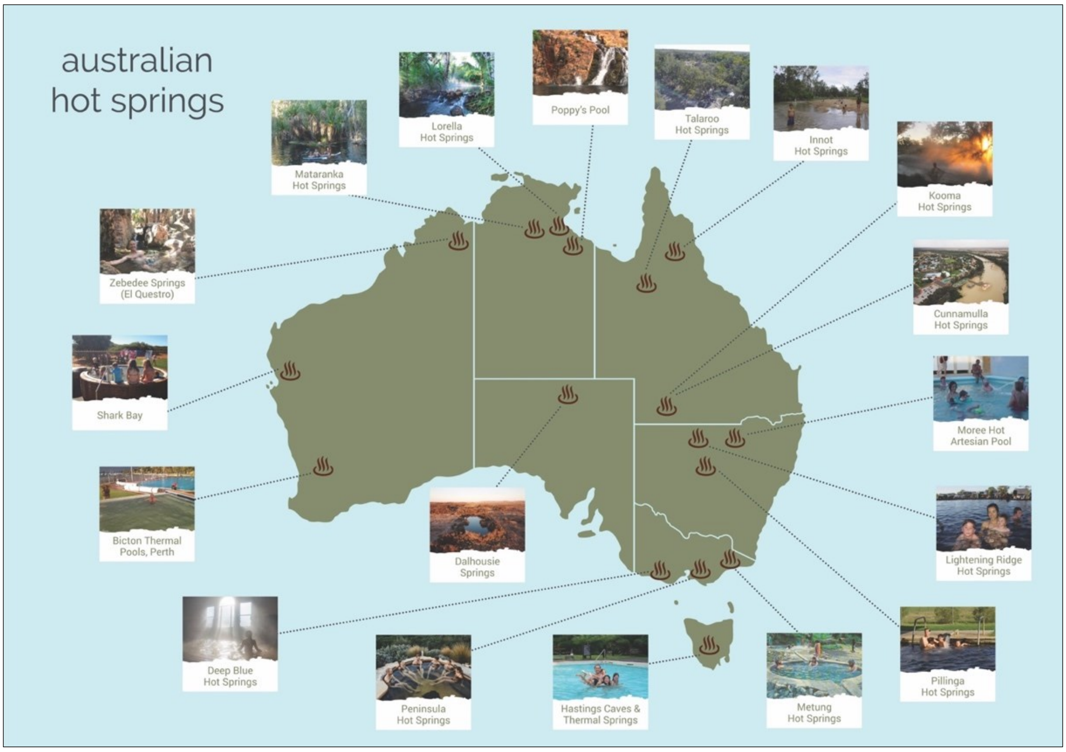

Figure 9. Selected Australian hot springs

The worldwide hot springs industry has gifted funding over three years to Melbourne based RMIT University's School of Health and Biomedical Sciences for robust balneotherapy research. The partnership has so far produced a PhD candidate-led systematic review of balneotherapy and mental health outcomes, a Global Bathing Survey of 4000+ respondents, along with clinical trials begun in late 2019 into hot springs bathing, sleep and mental health.

4.4. Geothermal (ground source) heat pumps as of 31 December 2020

The AGA conducted a census during 2018 of existing and planned ground source heat pump (GSHP) installations. The census provided updated figures to those reported by Beardsmore et al. (2015) and suggests that the rising price of natural gas relative to electricity in Australia is driving demand for GSHPs along with other direct-uses of geothermal energy. Beardsmore et al. (2020) provides more details of the census outcomes.

The process of collecting census data also clarified some anomalies in previously reported GSHP data. Burns et al. (2000) and Beardsmore and Hill (2010) each reported a compilation of existing GSHP installations, while Chopra (2005) and Beardsmore et al. (2015) did not. Burns et al. (2000) stated that "ground and water source heat pumps have been widely adopted for air conditioning throughout Australia, with at least 2000 [residential] installations in place." Beardsmore and Hill (2010) effectively duplicated the same list of installations. While those previous authors did not quantify the capacity, we assumed an average installed capacity of 10 kW_t per residential installation (conservative estimate) for a total 20 MW_t. Our total reported capacity also includes 2.5 MW_t of commercial GSHP installations reported by a single installer (e.g. Heat/Cool: Wagga Wagga City Council 1.33/1.63 MW_t, Hobart Grand Chancellor Concert Hall 780/710 kW_t, Cowra Shire Council 230/280 kW_t, Macquarie University 170/370 kW_t (GeoExchange, 2019.) Appendix Table 4 provides aggregated data for each state and territory.

The Geoscience Australia building in Canberra (ACT) remains the country's largest single ground source heat pump (GSHP) installation. The system supplies 2,500 kW of thermal power to 210 'Water Furnace Premier' ground source heat pump units of various capacity within a building with a floor space 40,000 m^2. The ground loops are arranged in 44 sets of eight vertical boreholes (total of 352 boreholes) drilled to 104 m depth in ground with an undisturbed temperature of 18.2°C. These loop-sets are connected to four flow and return headers in the plant room, each with its own primary circulating pump. The four pumps reject or extract heat evenly across the entire loop field.

A number of commercial GSHP service providers emerged into the market during the reporting period, including one of the largest Australian utility companies. The utility worked with a property developer to install direct exchange ('DX') GSHP systems to each of 900 new homes being built at a residential development in Blacktown, NSW. The systems will have a combined capacity of 10 MWt, making it the largest user of geothermal energy in Australia (Alinta Energy Geothermal, 2019). The utility left the GSHP market in 2020 amid a market recall of some DX systems.

In 2018, GSHPs comprised 61 MWt of the identified total installed geothermal capacity in Australia but only one quarter of the produced thermal energy. Their use was mostly for heating, ventilation and air-conditioning (HVAC) although there were some reported applications for residential pool heating. GSHPs were installed across Australia but most systems were in eastern states, primarily New South Wales.

The University of Melbourne has active research projects to demonstrate the practicality and value of GSHPs under Australian conditions. One output of the research was an estimate of capacity factor for three GSHP systems installed in Melbourne of just 0.23 for heating and 0.04 for cooling, based on observed patterns of usage (Lu et al., 2017).

4.5. Summary of geothermal direct heat use as of 31 December 2020

Appendix Table 5 summarizes the direct-use of geothermal energy quantified for Australia as of mid-2019. The direct-use of geothermal energy appears to be increasing in spite of a general absence of government subsidies. This suggests that geothermal energy is already economically competitive with alternative sources of heat, primarily natural gas, although the levelized cost of geothermal heat has not yet been quantified in the public domain for any given project. The future for the direct-use of geothermal energy looks strong, in light of projected continued increases in the wholesale price of natural gas, which averaged ~AU$10/GJ (~$US7.5/GJ) in the east coast gas markets in mid-2019.

4.6. Wells drilled for electrical and direct-use of geothermal resources from 1 January 2015 to 31 December 2019 (excluding heat pump wells)

The 'Country Update' presented for Australia at the 2015 World Geothermal Congress in Melbourne, Australia, reported on completed and planned geothermal drilling in Australia from 1 January 2010 to 31 December 2014. Total drilling in that period amounted to a total of 18.2 km for three electrical power and nine direct-use bores. Appendix Table 6 summarizes the data.

Drilling during the current reporting period (excluding ground source heat pumps) was dominated by aquatic center and geothermal hot springs projects. The small power plant developments in Queensland require no drilling because they utilize existing town water bores with no injection. Total drilling amounted to ~17.2 km. This included 13 wells (12.1 km) for aquatic centers in Western Australia (1 exploration, 6 production, 6 injection), providing capacity of ~13 MWt. In addition, nine wells (5.1 km) were drilled (2 exploration, 1 production, 4 injection) or refurbished (1 production, 1 injection) for five geothermal hot springs developments in Victoria (1 operating, 1 under construction, 3 at proof-of-concept stage).

4.7. Allocation of professional personnel (with university degree) to geothermal activities

Detailed employment statistics are not recorded for the geothermal sector in Australia. However, with reductions in the number of projects, both commercial and research, and a consolidation of the geothermal sector towards direct use applications, the authors estimate that direct professional employment within the sector has shrunk from fewer than 50 person-years in 2014 to fewer than 20 in 2019 (Appendix Table 7). The exception to this trend, however, is the hot springs sector, where professional employment has probably significantly increased as a result of the spa and leisure projects. Estimates of employment numbers for this sector were unavailable at the time of writing.

4.8. Total investments in geothermal for 2015–2019

Appendix Table 8 summarizes the investments into geothermal energy R&D and projects described in the above sections. It is difficult to quantify private investments, and to attribute the proportion of those investments directly related to the supply of geothermal energy, but the numbers in the table reflect the information presented in sections above.

5. DISCUSSION

There is a sense amongst the proponents of geothermal energy in Australia that further growth and development of the sector is being held back by a general lack of awareness and understanding of the opportunity within the general public. A major objective of the Australian Geothermal Association (AGA), therefore, is to increase awareness through education and outreach. AGA's census project in 2019 (Beardsmore et al., 2020) was conducted partly to provide a solid set of information upon which to base communications.

Some sectors of the geothermal industry, however, are clearly growing without AGA's involvement. At the time of writing in 2020, the Australian geothermal hot springs industry is in a period of significant growth. Such projects are generally embraced by local communities as opportunities to provide permanent local employment and year-round tourism attractions. Two existing and seven new commercial projects are currently expanding, under construction or soon to commence construction in the state of Victoria alone, with others in advanced planning in at least five other states.

The economics of GSHPs are also at a tipping point in Australia, with several large housing developments electing to include community scale installations of GSHPs (including up to 880 houses in one New South Wales development.)

Individuals within the Australian research sector remain aware of and enthusiastic about the potential for geothermal energy in the country, and have played a key role in raising awareness of the potential for GSHPs in particular. The reality of research funding, however, has resulted in few dedicated research programs or projects investigating geothermal direct-use or power generation.

Direct-use looks set to continue as a focus of geothermal development in Australia for the next five years, while interest in geothermal power could see a renaissance if government policies shift towards supporting low emissions, reliable, cost effective power supply.

6. FUTURE DEVELOPMENT AND INSTALLATIONS

We can make several predictions for the development and installation of geothermal energy systems over the next five years based on the current momentum with respect to geothermal energy utilization in Australia. We expect the following:

- Several small ORC electricity plants to come online in western Queensland, perhaps amounting to a total capacity of around 1 MWe;
- Construction and beginning of business for eight additional hot spring spa resorts, four in Victoria and an additional four in other states;
- Increasing numbers of industrial scale GSHP systems included on new builds, driven by projected cost savings with respect to natural gas heating systems;
- Continued conversion or design of major aquatic centers in Western Australia drawing on geothermal heat;
- New industrial applications of geothermal energy, again driven by projected cost savings with respect to natural gas heating systems particularly in Victoria were gas prices have risen rapidly in recent years and there are good geothermal resources that are largely undeveloped;
- Maintenance of the status quo with respect to formal research and development for geothermal energy in Australia;
- No major change in federal government policy with respect to stimulating the development of renewable energy.

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APPENDIX: DATA TABLES

Table 1. Present and planned production of electricity

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (biomass, wind, solar		Total	
	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr
In operation in December 2019	0.31	0.87*	30,076 + 6,858 (NEM + WA) = 36,934	212,100	7,523 + 32 (NEM + WA) = 7,555	17,500	0	0	9,249 +493 (NEM + WA) = 9,742	31,900	46,848 + 7,383 (NEM + WA) = 54,231	261,400
Under construction in December 2019	0	0										
Funds committed, but not yet under construction in December 2019	0.31**	0.87										
Estimated total projected use by 2020	0.62	1.7										

** Assumed 110 kWe (net) at 90% capacity after 44 kW fans subtracted from 155 kWe gross from single generator, limited by available water entitlement*
*** Assumed same as current operating plant*

Table 2. Utilization of geothermal energy for electric power generation as of 31 December 2019

Locality	Power Plant Name	Year Com-missioned	No. of Units	Status[1)]	Type of Unit[2)]	Total Installed Capacity MWe[3)]	Total Running Capacity MWe[4)]	Annual Energy Produced 2019 GWh/yr	Total under Constr. or Planned MWe
Winton, Queensland	Winton Geothermal Plant	2019	2		B (ORC)	0.31	0.16		
Birdsville, Queensland	Birdsville Geotherma Plant	1992	1	R	B (ORC)	0.12	0.12		
Innamincka, South Australia	Habanero Power Plant	2013	1	R	B (H2O)	1.00	0.70		
Total									

1) N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.
2) 1F = Single Flash B = Binary (Rankine Cycle)
2F = Double Flash H = Hybrid (explain)
3F = Triple Flash O = Other (please specify)
D = Dry Steam
3) Electrical installed capacity in 2019
4) Electrical capacity actually up and running in 2019

Table 3. Utilization of geothermal energy for direct heat as of 31 December 2019 (excluding heat pumps)

Locality		Type[1)]	Maximum Utilization					Capacity[3)]	Annual Utilization		
			Flow Rate (kg/s)	Temperature (°C) Inlet	Temperature (°C) Outlet	Enthalpy[2)] (kJ/kg) Inlet	Enthalpy[2)] (kJ/kg) Outlet	(MWt)	Ave. Flow (kg/s)	Energy[4)] (TJ/yr)	Capacity Factor[5)]
Western Australia	n=14	B	379	38.3–50.6	28.0–38.2			19.6	153	247	40%
Western Australia	n=1	C	60	21.0	31.0			2.51	19	25	32%
Victoria	n=5	B	123	39.0–71.5	27.0–37.0			5.5	74	104	60%
Victoria	n=1	I	12	45.0	20.0			1.26	6	20	50%
Victoria	n=1	F	25	28.0	23.0			0.52	6	4	24%
South Australia	n=1	F	96	29.0	23.0			2.41	54	43	56%
Queensland	n=1	B	8	44.5	37.0			0.25	5	5	60%
New South Wales	n=1	B	31	40.0	30.0			1.30	19	25	60%
TOTAL	n=24		734	21.0–71.5	20.0–38.2			33.3	336	472	47%

1) I = Industrial process heat H = Individual space heating (other than heat pumps)
C = Air conditioning (cooling) D = District heating (other than heat pumps)
A = Agricultural drying (grain, fruit, vegetables) B = Bathing and swimming (including balneology)
F = Fish farming G = Greenhouse and soil heating
K = Animal farming O = Other (please specify by footnote)
S = Snow melting
2) Enthalpy information is given only if there is steam or two-phase flow
3) Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (°C) - outlet temp. (°C)] x 0.004184 *($MW = 10^6$ W)*
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001
4) Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 *($TJ = 10^{12}$ J)*
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154
5) Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
Note: the capacity factor must be less than or equal to 1.00 and is usually less,
since projects do not operate at 100% of capacity all year.

Table 4. Geothermal (ground source) heat pumps as of 31 December 2019

Locality	Ground or Water Temp. (°C)[1]	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type[2]	COP[3]	Heating Equivalent Full Load Hr/Year[4]	Thermal Energy Used (TJ/yr)	Cooling Energy (TJ/yr)	Installed Capacity (kW)
ACT	16-18	12.87	250	V	3.6	1752	14.65	14.65	3217
NSW	17-20	15.15	2373	V, H	3.6	1752	163.72	163.72	35942
NT	28-31	60.00	1	V	3.6	1752	0.27	0.27	60
QLD	20-25	17.12	190	V	3.6	1752	14.82	14.82	3253
SA	16-19	11.08	40	V, H	3.6	1752	2.02	2.02	443
TAS	13-15	33.68	47	V, H, W	3.6	1752	7.21	7.21	1583
VIC	16-19	20.61	356	V, H, W	3.6	1752	33.42	33.42	7337.5
WA	16-30	100.73	91	V, H, W	3.6	1752	41.75	41.75	9166.4
TOTAL							277.88	277.88	61001.9

1) Report the average ground temperature for ground-coupled units or average well water or lake water
2) Report type of installation as follows: V = vertical ground coupled *(TJ = 10^{12} J)*
H = horizontal ground coupled
W = water source (well or lake water)
O = others (please describe)
3) Report the COP = (output thermal energy/input energy of compressor) for your climate
4) Report the equivalent full load operating hours per year, or = capacity factor x 8760 *8760*
5) Thermal energy (TJ/yr) = flow rate in loop (kg/s) x [(inlet temp. (°C) - outlet temp. (°C)] x 0.1319
or = rated output energy (kJ/hr) x [(COP - 1)/COP] x equivalent full load hours/yr
Cooling energy = rated output energy (kJ/hr) x [(EER - 1)/EER] x equivalent full load hours/yr
Capacity Factor 0.2 Lu et al. (2017)

Table 5. Summary table of geothermal direct heat uses as of 31 December 2019

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]			
District Heating [4]			
Air Conditioning (Cooling)	2.5	25	32%
Greenhouse Heating		0	
Fish Farming	2.9	47	53%
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]	1.3	21	50%
Snow Melting			
Bathing and Swimming[7]	26.7	381	47%
Other Uses (specify)			
Subtotal	33.4	474	
Geothermal Heat Pumps	61.0	378.99	20%
TOTAL	94.4	853.0	

1) Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (oC) - outlet temp. (oC)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001
2) Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (oC) - outlet temp. (oC)] x 0.1319 *(TJ = 10^{12} J)*
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154
3) Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 *(MW = 10^6 W)*
Note: the capacity factor must be less than or equal to 1.00 and is
4) Other than heat pumps
5) Includes drying or dehydration of grains, fruits and vegetables
6) Excludes agricultural drying and dehydration
7) Includes balneology

Table 6. Wells drilled for electrical and direct use of geothermal resources from January 1, 2015 to December 31, 2019 (excluding heat pump wells)

Purpose	Wellhead Temp	Number of Wells Drilled: Electric Power	Direct Use	Combined	Other (specify)	Total Depth (km)
Exploration[1]	(all)	0	3	3		2.7
Production	>150° C					
	150-100° C					
	<100° C	0	8	8		6.4
Injection	(all)	0	11	11		8.1
Total						17.2

1) Include thermal gradient wells, but not ones less than 100 m deep

Table 7. Allocation of professional personnel to geothermal activities (personnel with university degrees)

Year	Professional Person-Years of Effort						Total
	(1)	(2)	(3)	(4)	(5)	(6)	
2014[(7)]	*5*	*1*	*15*	*1*	*0*	*25*	*47*
2015	1	1	3	0	0	10	15
2016	1	1	3	0	0	10	15
2017	1	1	3	0	0	10	15
2018	1	1	3	0	0	10	15
2019	1	1	3	0	0	10	15
Total	5	5	15	0	0	50	75

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Progran
(6) Private Industry
(7) From Beardsmore et al. (2015)

Table 8. Total investments in geothermal (2019 US$)

Period	Research & Development Incl.	Field Development	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	(2019 Million US$[1])	(2019 Million US$)	Million US$	Million US$	%	%
1995-1999	--	--	--	--	--	--
2000-2004	1.7	25	--	--	70	30
2005-2009	74	262	1.4	--	92	8
2010-2014	285	63	63	285	90	10
2015-2019[2]	2.3		23	2.5	87	13

1) Exchange rate at June 2019: AU$1.00 = US$0.695
2) All figures are approximate