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Country Update—Australia

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ABSTRACT

The three years 2020–2022 have seen strong growth in the Australian geothermal sector. Growth has been led by the direct use of geothermal heat both with and without heat pumps, but there has also been a resurgence of interest in power generation.

Direct use projects have proliferated in the states of Western Australia and Victoria. Geothermal heating projects for a hotel, aged care facilities, public swimming pools, aquaculture, space heating, a large greenhouse development, and others have been completed or are underway in those states, including a feasibility study to utilize mine water as a geothermal source. Over 36 MW_t of installed capacity is identified as of January 2023, an increase of 3 MW_t (9%) since the WGC 2020+1 country update.

The demand for ground source heat pumps continues to grow, including the progressive rollout of a 750-home GSHP system for a housing development in Sydney, NSW. At least 71 MW_t of GSHP capacity was installed around the country as of January 2023, an increase of 9 MW_t (14.5%) since the WGC 2020+1 country update.

Companies listed on the Australian Securities Exchange developing projects to produce lithium internationally include Vulcan Energy and Controlled Thermal Resources. Other companies have applied for exploration licenses across wide regions of the country, including in the Cooper Basin in Central Australia, where previous activities discovered lithium concentrations in geothermal brines.

The hot spring spa sector has arguably seen the most rapid growth in the development of geothermal energy resources. The world class Peninsula Hot Springs in Victoria continues to expand, with new geothermally heated pools, accommodation and horticulture facilities completed or under construction since 2020. At least three new hot spring resorts opened around the country in the period since 2020, and two more are scheduled to open in 2023. Several more in advanced planning and design stages.

State governments have promoted geothermal projects. The Victorian government released 'Geothermal Guidelines' intended to streamline the regulatory process for direct use projects, and also supported mapping, research and design projects to better understand and exploit the economic potential of hot sedimentary aquifers in the Gippsland Basin. The Queensland government updated its Geothermal Regulations (which control how geothermal exploration and production is undertaken in the state) in 2022, including world-first adoption of the UNFC Geothermal Specifications for reporting geothermal resources. There has been a proliferation of applications for geothermal exploration licenses in South Australia and the Northern Territory, and the Western Australian government is expected to announce the results of a competitive bidding round for 21 geothermal exploration areas in early 2023.

Interest also reignited for geothermal power generation. The town of Winton in Queensland, commissioned Australia's first new geothermal power plant in 25 years in 2020. Although the plant experienced some teething problems, it is expected to be brought back online. Other interest in geothermal power has been driven by a rush to produce 'green' hydrogen for domestic consumption and export, and a drive by large industries to decarbonize their energy sources. Strike Energy Ltd applied for Western Australia's first new geothermal exploration license in a decade in late 2021, before the state launched the competitive tender round. Other companies have applied for large exploration areas in South Australia, Northern Territory, Queensland and South Australia.

1. INTRODUCTION

The three years 2020–2022 have seen strong growth in the Australian geothermal sector. Growth has been led by the direct use of geothermal heat both with and without heat pumps, but there has also been a resurgence of interest in power generation. The hot spring spa sector has arguably demonstrated the most rapid growth in the development of geothermal energy resources. All of this has happened within the context of volatile international energy markets, an accelerating commercial transition to renewable power generation, and legislation for more ambitious emission reduction targets by state and federal governments. Australia lacks any operating geothermal power plant at the time of writing (January 2023), but applications for exploration licenses cover large areas of the country. Volatile and rising domestic natural gas prices are stimulating increased interest in direct-use of geothermal heat for industrial purposes.

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, a situation that is arguably impeding the growth of a GSHP industry 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 2022) 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 2022) 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 2021) allows 'over the counter' applications for geothermal licenses. The Geothermal Energy Act 2010 (as amended in 2022) 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 2023.) The Act allows 'over the counter' applications for geothermal licenses. The Mining Regulations 2016 (as amended in 2023) 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 (as amended in 2021) 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 2019) in **Tasmania**. The Act allows 'over the counter' applications for licenses.

In 2022, Australia updated its Nationally Determined Contribution to reducing global emissions under the 2015 Paris Agreement from 26–28 per cent to 43 per cent below 2005 levels by 2030. The Australian government (with bipartisan support) in 2001 mandated a Renewable Energy Target (RET) for the proportion of 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 the 'Large Generation Certificate' (LGC) earned by renewable energy generators at a rate of one per megawatt hour of generation and traded through a regulated market. Figure 2 illustrates how the value of LGCs has changed over time, including a significant increase from ~AUD35/MWh to ~AUD65/MWh (See 'Units and Abbreviations' below for conversion to USD as of January 2023) since mid-2021 (CER, 2022). In principle, geothermal power stations are eligible to earn and redeem LGCs as an additional source of revenue, but no geothermal project has yet reached that milestone. Ground source heat pumps are currently ineligible for a parallel Small Scale Renewable Energy Scheme (SRES) to incentivize solar water heater and air source heat pump systems, in spite of repeated efforts by the geothermal sector to have them included.

The Australian government's primary mechanism for reducing non-energy sector emissions is an 'Emissions Reduction Fund' of AUD4.55 billion. Projects earn an 'Australian carbon credit unit' (ACCU) for each metric ton of CO_2 (or equivalent) of emissions stored or avoided. ACCUs 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 was relatively steady around 30 AUD/t.CO_2-e in 2022 (Figure 2).

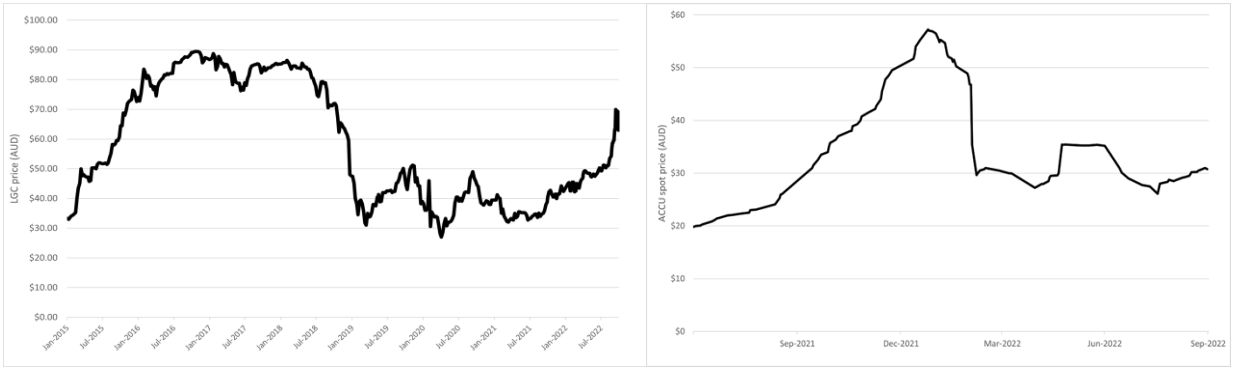

Figure 2. Average LGC (left) and ACCU (right) spot prices over time. CER (2022).

Brailsford et al. (2018) stated, "states and territories continue to lead the way on renewable energy in the ongoing absence of credible national climate policy," and the situation persists in early 2023. States and territories have introduced their own renewable energy and emission reduction targets which in some cases are more ambitious than Australia's targets reported above. State and territory targets announced as of January 2023 (excluding interim targets) are:

- Western Australia—Net zero emissions by 2050; no renewable energy target
- Northern Territory—Net zero emissions by 2050; 50% renewable energy by 2030
- South Australia—Net zero emissions by 2050; 100% renewable energy by 2030
- Queensland—Net zero emissions by 2050; 80% renewable energy by 2035
- New South Wales—Net zero emissions by 2050; no renewable energy target
- Victoria—Net zero emissions by 2050; 40% renewable energy by 2025
- Tasmania—Net zero emissions by 2030; 200% renewable energy by 2040 (i.e. generate twice the state's internal consumption, exporting the excess)
- Australian Capital Territory—Net zero emissions by 2045; achieved 100% renewable energy since 2020

1.2. Financial support from Governments

Despite professing to support renewable energy industries to replace fossil fuels in Australia's energy mix, in recent years neither the Australian government nor any state or territory governments has provided any financial support or financial incentives for investment into geothermal power generation. Existing government financial incentives and support seems to focus solely on intermittent wind and solar power and on the production of hydrogen as a storage/carrier medium. These policies ignore the fact that non-intermittent geothermal power could be used to produce hydrogen on a sustainable basis without the need for backup energy sources or storage.

More concerning for the geothermal power sector is the official position by the Australian Renewable Energy Agency (ARENA) about the financial viability of geothermal power in Australia. ARENA is an Australian Government advisory and funding agency whose legislated purpose is to support the global transition to net zero power systems by accelerating the pace of pre-commercial innovation. Unfortunately, ARENA wrongly claims that geothermal electricity generation is not commercially viable in Australia. ARENA appears to have reached its position based on the commercially unsuccessful Habanero 'engineered geothermal system' (EGS) project managed by Geodynamics Limited in a very remote part of South Australia c.2000–2015. The Habanero project encountered unique challenges not representative of the range of opportunities that exist in Australia for geothermal power, particularly in regard to 'hot sedimentary aquifer' (HSA) geothermal systems. Geothermal power generation should actually fall well within ARENA's responsibility to commit funds to enable ultra-low cost renewable generation. For example, the successful operation of a geothermal power plant for over 25 years (1992–2018) at Birdsville in Queensland tangibly demonstrated the inaccuracy of ARENA's position on the commercial viability of geothermal power. Furthermore, a report commissioned by ARENA itself (Lovegrove et al., 2018) concluded that geothermal energy—particularly HSA geothermal—offers the lowest cost option for 24-hour dispatchable (i.e., baseload) electricity in Australia (Figure 3).

At the state level, **Strike Energy Ltd** was awarded a two million AUD grant for its geothermal project in the northern Perth Basin from the Clean Energy Future Fund managed by the Government of Western Australia (Strike Energy Ltd, 8 April 2022).

Geothermal hot springs projects, however, have fared better in terms of government financial support. **Metung Hot Springs** in Victoria was awarded a total of three million AUD towards its AUD10 million stage-one hot springs development from a state government post-bushfire Local Economic Recovery Grant and a federal government Regional Growth Fund. **Phillip Island Hot Springs** (Figure 4), also in Victoria, received AUD4.7 million towards its AUD46 million stage-one development from the state government's Regional Tourism Investment Fund (RTIF). This development is under construction in January 2023 and anticipated to open in October 2023. **Peninsula Hot Springs** (Figure 4) received AUD3.3 million under the RTIF towards a AUD12 million expansion of its operation in Fingal on Victoria's Mornington Peninsula, which will open in 2023. **Cunnamulla Hot Springs** in the outback town of the same name in Queensland (Figure 4) received a AUD10 million Economic Development Grant from the Murray Darling Basin Authority for the construction of a hot spring resort which will open in June 2023.

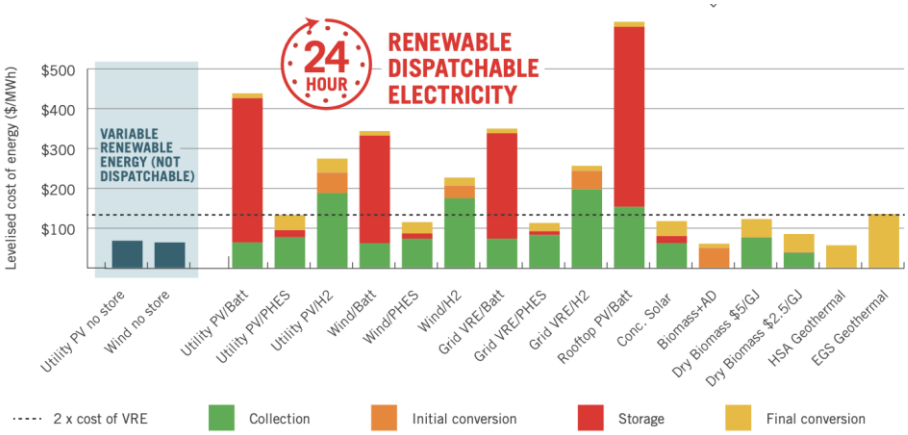

Figure 3. Levelized cost of energy (AUD/MWh) for 24-hour dispatchable power using different generation & storage options. From Lovegrove et al. (2018).

Figure 4. Phillip Island Hot Springs (top left, under construction); Peninsula Hot Springs (top right, under expansion); Cunnamulla, QLD (bottom, hot springs under construction)

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.

Of the tertiary institutions in Australia, **University of Melbourne** (UoM) is arguably the most engaged in geothermal energy research through ongoing collaboration with industry, Victorian government departments, and with some support from ARENA. Specific projects commenced, progressed or concluded by UoM and partners since 2020 include:

- Metro Tunnel Project—A four-year project (2018–2022) supported by Rail Projects Victoria and led by the Faculty of Engineering and IT that demonstrated the efficiency of capturing geothermal energy from the foundations of a new subway station 40 m underground for heating and cooling surrounding buildings (UoM, 2022).
- Yanderra Shallow Geothermal-Solar Systems Demonstration—A collaboration supported by ARENA and commenced by the Faculty of Engineering and IT in 2021 to demonstrate the financial and environmental benefits of a hybrid ground-source heat pump system powered by solar PV with gas back-up to heat and cool a commercial poultry breeding facility in Yanderra, NSW.
- Gippsland Geothermal Mapping and Cost Analysis Tool–Information Gathering and Geothermal Economic Algorithms—A two-year collaboration (2020–2022) between the Faculty of Science and the Geological Survey of Victoria, supported by Latrobe Valley Authority, to map geothermal aquifers in Gippsland, Victoria, and develop algorithms to estimate potential thermal power production, drilling costs and cost of energy.
- Opportunities for Electricity Generation from Geothermal Resources in Gippsland—A six-month desktop project supported by Latrobe Valley Authority in 2022 to investigate the technical and economic viability of generating geothermal power in Gippsland, Victoria. The project looked at four specific scenarios and concluded that a hybrid geothermal–solar PV–thermal storage system is technically feasible and could supply economically competitive dispatchable power in some locations.
- Smart Geothermal Industrial Loop—A nine-month project (completion in the second half of 2023) supported by Regional Development Victoria to design and cost Australia's first geothermal district heating system to sell heat to independent end users. The project entails geological and engineering studies, and an assessment of legislation and regulation that may impact the commercial sale of heat in Victoria (Cariaga, 2023).

Curtin University and **University of Technology (Sydney)** completed a three-year collaborative investigation into the impact of a large commercial deployment of ground source heat pumps (GSHPs) in 'Fairwater', a housing estate in Western Sydney. The study provided evidence to support the industry-wide adoption of GSHPs into local energy infrastructure; demonstrated a positive impact on peak demand and total consumption for grid energy; quantified the energy performance of the GSHP system and positive impact on cost of living for residents (compared to business as usual); calculated economic costs and benefits to the developer, residents and energy utilities; established the commercial merits of industrywide adoption of GSHP technologies and systems approaches in residential greenfield developments; and demonstrated positive impacts with respect to the urban heat island effect (ARENA, 2023).

The **University of New South Wales** offered both undergraduate and postgraduate units in Geothermal Engineering in 2022. The **University of Melbourne** delivered a post-graduate course on Sedimentary Basin Resources in 2022, which included a significant section of HSA geothermal resources and a field trip to Peninsula Hot Springs.

A PhD candidate at **Victoria University** is undertaking research to find a set of key indicators to determine the social, environmental and economic impacts of hot springs on the local communities in which they are located. The PhD research was into its third year and entering its trial phase in early 2023, with anticipated completion by the end of 2023. The project will lead to a longitudinal study over the coming 20+ years with a global set of towns being involved to help steer the future course of the global hot spring sector.

Glen Ivy Hot Springs (California) and Peninsula Hot Springs (Victoria) are funding a three year project by the School of Health and Biomedical Sciences at **RMIT University** conducting robust research into balneotherapy. In early 2023, the project had already produced a PhD candidate-led systematic review of balneotherapy and mental health outcomes, a global bathing survey with 4000+ respondents, and clinical trials into hot springs bathing, sleep and mental health.

1.4. Investment by geothermal companies

Triggered in part by legislation by governments in Australia to move away from fossil fuels, since early 2021 there has been a notable leap in the number of applications by companies for geothermal exploration licenses for the purpose of power generation, particularly in Western Australia, South Australia, Queensland and the Northern Territory (Figure 5). In general, state governments have been very slow to process the applications and very few if any new tenements have yet been granted as of January 2023. Some of the inaction may be due to the regulatory authorities not having enough administrators with a sufficient understanding of the nature of geothermal energy. Accordingly, there has been very little real investment in geothermal power projects in recent years.

A notable example is in a region known as the Mid-West north of Perth, Western Australia. There, mid-tier petroleum company **Strike Energy Limited** ('Strike') acquired the right to a geothermal tenement application over what many interpret as the most prospective part of the northern Perth Basin for HSA geothermal power (e.g. Ballesteros et al., 2020) Strike has discovered large quantities of natural gas near the same location, from which it plans to produce ammonia. Strike is awaiting the grant of the tenement to enable it to appraise the viability of geothermal power for its planned developments. Other mineral and petroleum companies are currently competing for ownership of natural gas resources in the area. At least one of those companies has substantial investments in geothermal projects in Europe where it hopes to recover lithium from geothermal brines.

Companies listed on the Australian Securities Exchange developing projects to produce lithium internationally include **Vulcan Energy** and **Controlled Thermal Resources**. Other companies have applied for exploration licenses across wide regions of the country, including in the Cooper Basin in Central Australia, where previous activities discovered lithium concentrations in geothermal brines. **Fortescue Future Industries**, owned by one of Australia's richest men, assembled a team to bullishly identify and develop geothermal energy projects globally.

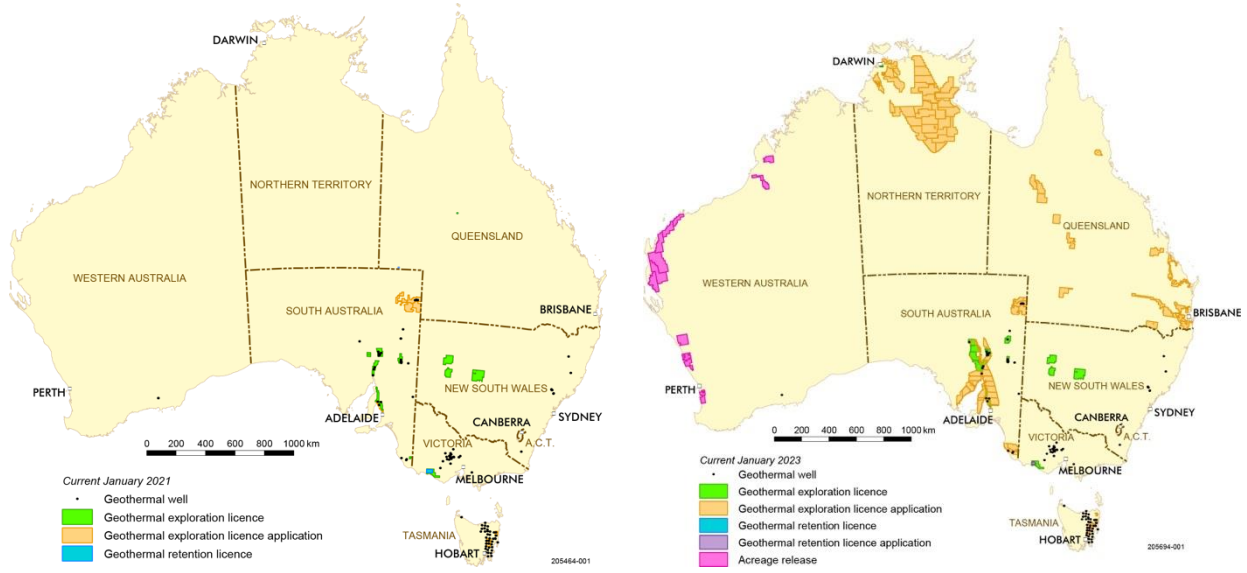

Figure 5. Geothermal licenses and applications as of January 2021 (left) and January 2023 (right). Note the significant increase in activity in Western Australia, South Australia, Queensland and the Northern Territory.

Most Australian states regulate 'low' temperature direct-use geothermal resources under different legislation to 'high' temperature resources which require more expensive drilling and extraction technologies. This makes direct-use projects generally easier to develop, which has led to strong investment in direct use of geothermal energy in recent years. This was revealed in a census of geothermal energy installations completed and published by the Australian Geothermal Association in 2019 and accessible on AGA's website (www.australiangeothermal.org.au). In particular, there has been substantial growth in investment and development of hot spring leisure and tourism facilities in Victoria, Queensland and Western Australia. Steady growth has also been observed in the ground source heat pump (GSHP) sector for residential and commercial heating and cooling. Examples include the Fairwater estate in Western Sydney (ARENA, 2023) and the proposed St Hilaire project in Wallan, Victoria (St Hilaire, 2023).

Investment into geothermal hot spring spas in the coming 1–2 years is estimated at over AUD100 million, largely from private enterprise, with a further AUD220 million investment expected over the 3–5 year period. The largest share of these investments will be in Victoria, with AUD60 million in the next 1–2 years and AUD190 million over 3–5 years. Peninsula Hot Springs alone invested AUD13.5 million in 2017/18, a further six million AUD in 2019/20, AUD12 million in 2023, and will invest a further AUD150 million over the coming 2–4 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. Alba Thermal Springs on the Mornington Peninsula in Victoria opened its AUD100 million geothermal spa facility in October 2022.

1.5. Geothermal organizations

The Australian Geothermal Association (AGA) continues to expand its role as the peak representative body for the geothermal sector in Australia, and aims to be the central point of information for all things geothermal. The AGA expanded its membership categories in 2022 to include Community, Professional and Corporate members. Professional members are individuals working in industry, academia and government roles directly related to geothermal energy. As a not-for-profit, non-party political and non-sectarian organization, the AGA continues to advocate for a full range of geothermal applications from GSHPs to direct industrial heat supply, recreational bathing and wellness, to electrical power generation.

The AGA is an Affiliate Member of the International Geothermal Association (IGA; https://www.lovegeothermal.org/) and an active participant in the Asia-Western Pacific Regional Branch of the IGA. The AGA became a member of the Global Geothermal Alliance (GGA; https://www.globalgeothermalalliance.org/) in 2021 and has actively participated in several GGA initiatives. In addition, Australia remains a member of the International Partnership for Geothermal Technology (IPGT; https://ipgtgeothermal.org/), and a member of the International Energy Agency's Geothermal 'Technical Collaboration Programme' (IEA Geothermal; https://iea-gia.org/). Australia's contracting party to IEA Geothermal is the South Australian Department of State Development.

In 2021, the GSHP sector in Australia incorporated a new organization, the Australasian Renewable Earth Energy Association (AREEA), whose purpose is to promote the development and application of GSHP systems by providing a platform for knowledge sharing, education and training, industry collaboration and encouraging the implementation of standards which lead to quality design and installation of these systems. AGA and AREEA hope to work closely together on messaging and communication about GSHPs to the Australian public.

Also in 2021, eleven existing and aspiring geothermal hot spring spa operators formed the Australian Hot and Mineral Springs Bathing Alliance (https://www.bathing.org) to collectively enhance and grow the sector across the country.

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. Australia can be broadly divided into three provinces based on the age of the underlying basement (Figure 6). 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). Australia is barren of high enthalpy hydrothermal geothermal energy sources but large parts of the country are prospective for hot sedimentary aquifers.

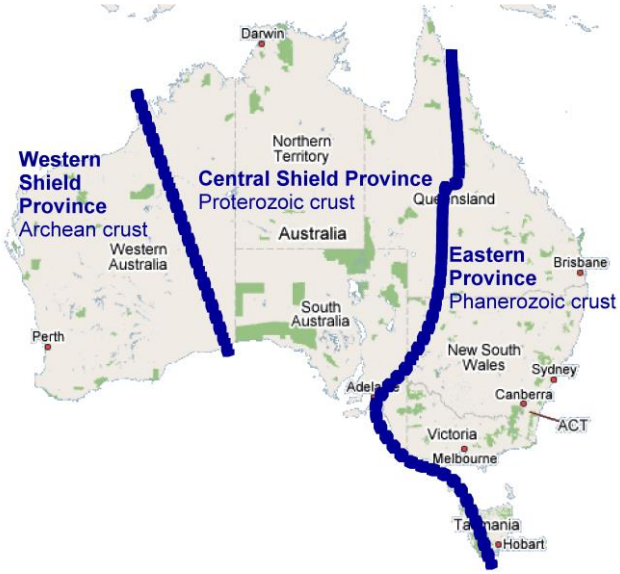

Figure 6. Broad divisions of the Australian continental crust based on basement age.

3. GEOTHERMAL RESOURCES AND POTENTIAL

Two geothermal resource statements have been publicly announced since the 337,395 PJ of recoverable heat reported by Beardsmore et al. (2015). Strike Energy Ltd reported a resource of 203 PJ_e of electricity, the equivalent of 226 MWe of power generation for 30 years, for its northern Perth Basin project area described in Section 1.4 above (Strike Energy, 5 May 2022). Greenvale Mining reaffirmed an earlier state government resource estimate of more than 3 GW_e of electrical power potential in the Millungera Basin in Queensland (Greenvale Mining Ltd, 6 September 2022).

Much of the rest of Australia is also 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 Otway Basin contain thick insulating calcareous rocks. 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 7 show the geographic coverage of these regions.

4. GEOTHERMAL UTILIZATION

4.1. Present and planned production of electricity

The latest annual electricity statistics for Australia are from 2021 (DISER, 2022), during which 267,452 GWh_e of electricity was generated; 71% generated from fossil fuels and 29% from a mix of hydro, biofuels, wind and solar PV. The Australian Energy Regulator publishes data on installed generator capacity for the 'National Electricity Market' (NEM) covering eastern and southern Australian states and territories, but the NEM does not extend to Western Australia. We sourced information about power plants in Western Australia from Wikipedia (2023). The combined generating capacity of the NEM and Western Australia totaled 66,594 MW_e at the end of 2021, of which 41,573 MW_e (62.4%) was powered by fossil fuels (black coal, brown coal, natural gas) and 25,021 MW_e (24%) by renewables. The figures are summarized in Appendix Table 1.

The federal government's focus on reducing emission increased significantly in 2022 following a change of government. One of the results is an acceleration in the retirement of coal fired generators in both the NEM and Western Australia. This change has been accompanied by a dawning recognition that substantial additional dispatchable capacity will be needed to firm the intermittent power supply from solar PV and wind generation (Figure 8). Although the focus to date has been on battery storage, it is hoped that the potentially unique contribution of geothermal power generation will be recognized and embraced.

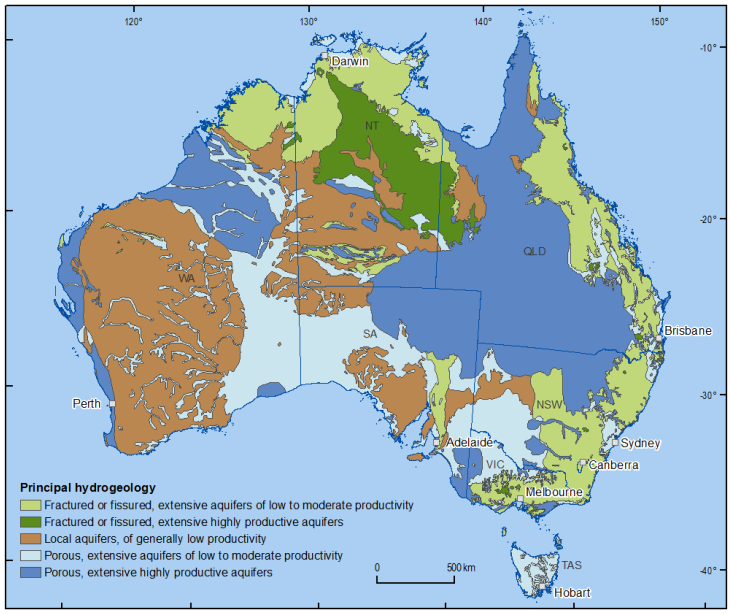

Figure 7. Hydrogeology of Australia. Source: Geoscience Australia.

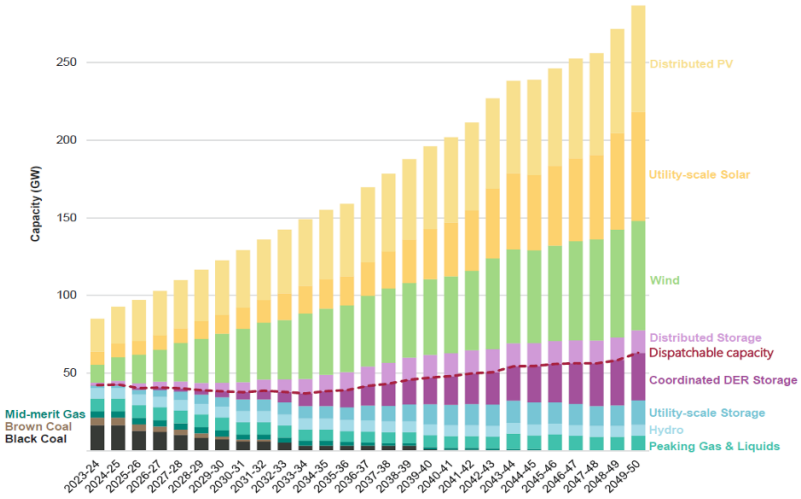

Figure 8. Forecast capacity in the NEM under the 'Step Change' scenario showing the shift from coal to renewable energy and storage. From AEMO (2022).

Since the decommissioning of the long-running 120 kW_e (gross) geothermal plant at Birdsville (Queensland) 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 provided electricity to major local council assets through a private underground network. Unfortunately, the power plant is currently inactive pending the outcome of an legal dispute between the council and the project manager. Meanwhile, progress on the development of new small-scale geothermal power plants in regional towns across western Queensland using hot water from the Great Artesian Basin has also languished.

Although there has been little change in the utilization of geothermal energy for electric power generation in the reporting period, there has been a significant increase in the amount of activity and anticipation in the sector, as shown in Figure 5. Companies Greenvale Mining and Within Energy are actively pursuing opportunities in Queensland. In Western Australia, Strike Energy announced its geothermal resource of 203 PJ (Strike Energy, 5 May 2022) and is currently finalizing the pending award of the exploration license 300 km north of Perth. The geothermal source is within the Permian Kingia Sandstone at depths of ~4000 m and temperatures of ~170°C (Ballesteros et al., 2020).

4.2. Utilization of geothermal energy for direct heat

At Robe in South Australia, the company Robarra grows barramundi fish (edible Asian sea bass) 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. In Victoria, Mainstream Aquiculture operates a barramundi farm at Werribee, using 28°C fresh geothermal water directly to grow the fingerlings. Midfield Meats in Warrnambool uses geothermal water for washing down

and sterilizing its industrial meat processing facility. The Latrobe City Council has been heating the Gippsland Regional Aquatic Centre (GRAC) with geothermal energy for over a year (Figure 9). Given the success of the project, other direct-use potential applications are being identified in the region to utilize this promising geothermal resource. In particular, Regional Development Victoria awarded a 380,000 AUD grant to the University of Melbourne to design a geothermal heating loop for an industrial zone in Morwell, Victoria. Various industrial partners are working with the University of Melbourne to realize the geothermal potential of the region which hosts a world class geothermal resource at shallow depths (68°C and >500 darcy.meters at only 550 to 650 m depth at the GRAC).

Figure 9. Plant room of the Gippsland Regional Aquatic Centre, geothermally heated since 2021.

Australia's only geothermal district heating system, connected to thirteen buildings at Portland in Victoria until 2006, remains decommissioned for a variety of reasons including environmental (heat depleted water was being discharged into a surface stream). The district heating loop was reduced in size after the geothermal bore was decommissioned, but continued to service seven council buildings using heat from two 1 MW_t gas-boilers. The Glenelg Shire Council replaced the gas boilers in 2019 and announced its intention to refurbish the 35-year-old distribution pipeline, with construction to start in 2023. The new pipeline may allow heat supply from a new (yet to be constructed) geothermal bore at some point in the future, particularly in light of high natural gas prices in eastern Australia. In fact, wholesale gas prices in eastern Australia have sky-rocketed since 2019 (Figure 10), which has significantly improved the business case for geothermal heat for district heating and other process heat applications across Australia.

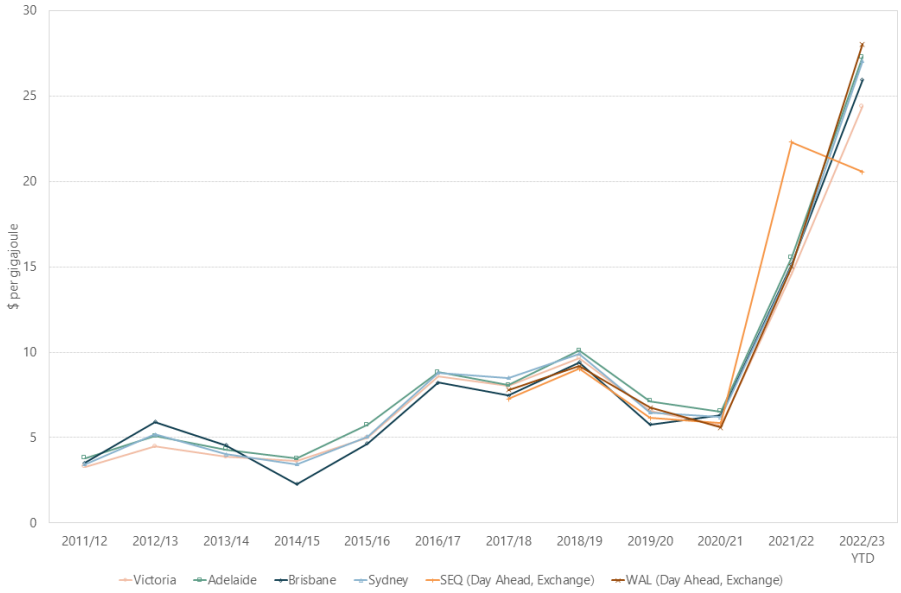

Figure 10. Average annual wholesale gas price (AUD/GJ_t) in six Australian gas markets since 2011/12. Source, Australian Energy Regulator.

The capital cost of the boiler, along with operation and maintenance costs, ensure that the levelized cost of energy (LCoE) for natural gas process heat applications is significantly higher than the wholesale price for natural gas (Figure 11). For example, for a municipal swimming pool consuming about 35,000 GJ_t of heat annually, the LCoE is about 27.5 AUD/GJ_t for a new gas system, or 25 AUD/GJ_t for an existing system, when the wholesale gas price is 20 AUD/GJ_t, as was common in 2021. At a wholesale price of 25 or 30 AUD/GJ_t, as seen during 2022, the LCoE of natural gas process heat is even higher.

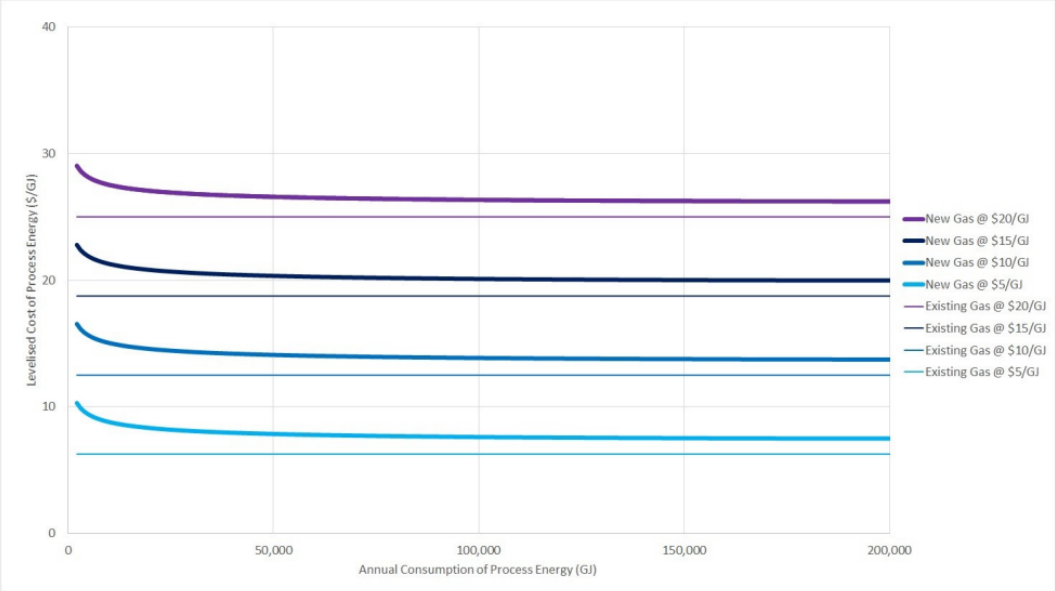

Figure 11. Levelised cost of energy for natural gas process heat (AUD/GJ_t) delivered through a new build or through an already fully depreciated system, for different natural gas wholesale prices (ITP, 2015)

Geothermal energy from hot sedimentary aquifers 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 the Otway and Gippsland Basins of Victoria. ITP (2015) estimated the LCoE for geothermal heat from hot sedimentary aquifers at 11.6 AUD/GJ_t. Fu et al. (2023) arrived at a similar conclusion for the Gippsland Regional Aquatic Centre, calculating from actual heat production and cost data over a 12-month period (22 July 2021 – 21 July 2022) that the net present value of the GRAC's geothermal heating system was positive so long as the purchase price of natural gas was equal to or greater than 10.80 AUD/GJ_t. The retail price of natural gas for Latrobe City Council at the time was over 31 AUD/GJ_t, confirming the strong business case for geothermal heating. Even in Western Australia, where the wholesale price of natural gas is generally lower than the east coast because of a gas-reservation policy, geothermal energy is competitive with new gas installations over project lifetimes.

The increasing recognition of geothermal energy as a source of process heat is reflected in clusters in the SW and SE of the country on Figure 12, which shows installed geothermal capacity (direct heating and cooling, including heat pumps) identified in a national census of geothermal installations conducted by the Australian Geothermal Association in 2018 (AGA, 2019). As of 2022, fifteen large leisure centres in Western Australia primarily use geothermal energy to heat pools and space, with a total installed capacity of nearly 20 MW_t between them. Collectively these geothermal plants provide an estimated 200-250 TJ of thermal energy per year. Regulations require 100% reinjection of the cooled fluid. The geothermal source for all 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). 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). The aquifer could support higher flow rates, but these have not been required with the scale of current projects. Future projects are contemplating flow rates up to 110 liters per second as well as higher temperatures up to 60–70°C for greenhouse heating.

A number of new projects have been announced since the 2018 AGA census was completed and published, including:

- Large leisure centers heated by geothermal energy in Western Australia have continued to displace natural gas usage. A total of five projects have undertaken successful workovers to maintain injectivity over the last three years. Workovers are now routinely being completed using only a crane and a working table instead of a drilling rig (Figure 13).
- In 2021, the Latrobe City Council (LCC) commissioned the 2.3 MW_{th} geothermal heating system for the Gippsland Regional Aquatic Centre (GRAC);
- A $100 million hot springs development opened on the Mornington Peninsula, Victoria, in mid-2022 close to the existing Peninsula Hot Springs. The development, Alba Thermal Springs and Spa, included the completion of two injection bores using directional drilling methods, measurement-while-drilling ('MWD') and log-while-drilling ('LWD') equipment, a first for a geothermal project in Australia;
- In 2022, the City of Joondalup elected to refurbish its geothermal system that was first commissioned in 2005 to increase the supply of energy to Craigie Leisure Centre;

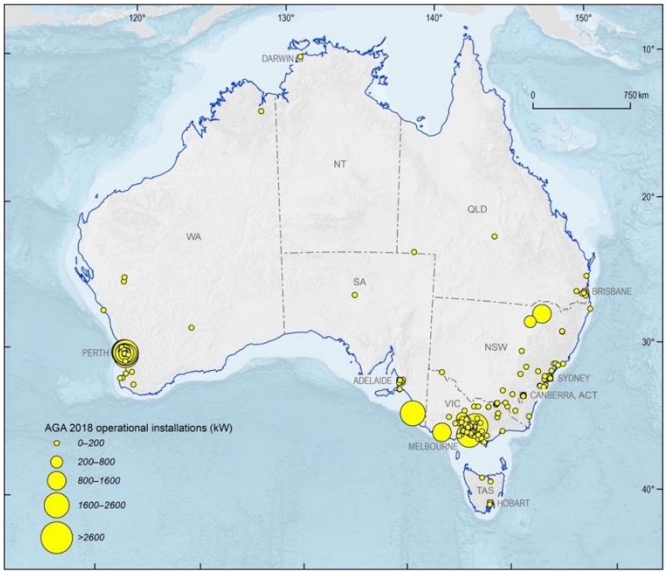

Figure 12. Operational geothermal installations in Australia in 2018. AGA (2019).

- In late-2022, the Victoria Government awarded a 380,000 AUD grant to the University of Melbourne to design a geothermal heating loop for an industrial zone at Morwell; Victoria;
- By mid-2023, the bores providing direct cooling to the Pawsey supercomputer in Perth as described in the WGC 2020+1 Australia Country Update (Beardsmore et al, 2021) will have operated for 10-years. Operating data indicate the system has provided nearly 110 PJ_t of cooling to date. Subject to a 10-year anniversary modelling review outcome, the system may be operated for another 10 years to coincide with a major upgrade of the supercomputer and IT systems;
- Numerous process heat projects are reportedly at the planning or design stage, including up to five pool heating projects in WA, at least two large-scale aquaculture and greenhouse projects in WA and Victoria, cooling for a very large data center in WA, and multiple projects at the planning stage in Victoria). Those various projects have the potential to double the amount of energy provided by direct-use of geothermal heat in Australia in the coming years.

Figure 13. Example of rig-less workover to maintain injectivity of a 1 km deep geothermal system that has been operating for 12 years in Perth.

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 will receive 600,000 visitors in the year to 30 June 2023 and employed 370 full and part time staff, which makes it one of the largest tourism operations in Victoria. 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 the period 2020–2023. Three new hot springs projects in Queensland, at Bourke Town, Talaroo Station and Cunnamulla, all received grant funding from the state, with the Cunnamulla project scheduled to open in June 2023. Two new projects opened in Victoria in October 2022: Alba Thermal Springs on the Mornington Peninsula, and Metung Hot Springs. Phillip Island Hot Springs is under construction on Phillip Island and anticipated to open in October 2023. Nunduk Resort in Victoria and Tawarri Hot Springs in Western Australia are still awaiting final planning and resource approval and hope to commence construction in 2023. The Australian hot springs industry will see many new hot springs project launches and significant upgrades in 2023. 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. In 2021 the Hot and Mineral Springs Bathing Alliance (https://www.bathing.org) was formed to provide a collective voice for the emerging sector.

4.3. Geothermal (ground source) heat pumps

The Australia Country Update at WGC 2020+1 (Beardsmore et al., 2021) estimated a total installed capacity of ground source heat pumps of 61 MW_t. As with direct-use projects, the increased cost of natural gas in Australia has led to a period of significant growth in the number of GSHP installations for heating and cooling. Several new projects have been announced since the last comprehensive GSHP census was published in 2019 (AGA, 2019). They include:

- Between 2019 and 2022, the Fairwater precinct-wide geothermal project was completed. It provides heating and cooling to 750 homes in NSW using deep hole direct exchange ('DHDX') GSHP technology. Other large greenfield estates were also considered;
- The AUD1.64 million, three-year project known as the Fairwater Living Lab was funded by the Australian Renewable Energy Agency (ARENA), Frasers Property Australia and the NSW Office of Energy and Climate Change to examine the economic and environmental impacts of ground source heat pumps delivering heating and cooling to 750 homes at the Fairwater community. The study found that the homes use 21 per cent less electricity than comparable nearby suburbs because of geothermal technology. While this a significant saving compared to conventional technology, it is slightly less than reported in a similar 2-year study of two nearly identical adjacent houses in Perth, Western Australia, where savings achieved by a conventional brine loop GSHP were 26 to 51% in heating mode and 10 to 58% in cooling mode (Aprianti et al., 2021).
- Other major projects including the Arthur Boyd National Gallery and the Plumbing Industry Climate Action Centre (PICAC), which comprised 2800 m of conventional geo-bores and 192 energy piles. These projects all used more conventional brine loops as opposed to DHDX technology;
- Various projects of smaller scale were also progressed at Parliament of Victoria, at Rivergum Estate, Sydney light rail, Melbourne connect etc. Some of these projects incorporated innovative radial drilling methods;
- Another large-scale GSHP project was announced in 2022 and began construction in early 2023 for the heating and cooling of the Australian War Memorial in Canberra (Figure 14). It will incorporate 216 vertical boreholes to 148 m.

Figure 14. Close-loop geothermal drilling at the Australian War Memorial in 2023.

While exact numbers are not yet available, it is clear that at least 9 MW_t of additional capacity has been added since the WGC 2020+1 Country Update, an increase of 14.5%. Because GSHPs are used primarily for heating and cooling they generally have a lower capacity factor when compared to direct-use geothermal systems. As a result it is estimated that GSHPs represent 66.2% of the installed capacity in Australia but only 28.7% of the produced energy (in heating mode) and 29% in cooling mode.

In response to the growth of the GSHP industry, some of the companies operating in the field are investing in new drilling capability with one operator adding up to four drilling rigs in 2022.

4.4. Summary of geothermal direct heat use as of January 2023

Over 36 MW_t of installed capacity for direct use of geothermal heat from hot aquifers, and at least 71 MW_t of GSHP capacity, have been identified as of January 2023, an increase of 3 MW_t (9%) and 9 MWt (14.5%), respectively, since the WGC 2020+1 country update. New projects for direct use of geothermal heat from hot aquifers, and for geothermal heating and cooling with GSHPs, are both accelerating, driven largely by volatile and escalating prices for natural gas in the absence of government incentives. The quantified economic and technical performance of geothermal installations has clearly demonstrated that geothermal energy is already economically competitive with natural gas. The future for the direct-use of geothermal energy in Australia looks strong, especially since state governments (especially Victoria) are now taking serious interest in its potential.

5. DISCUSSION

There is renewed optimism across the broad geothermal community in Australia! After a decade of hope, almost every segment of the geothermal community is poised for a significant period of growth. The GSHP sector has incorporated a new association and its members are expanding their fleets of rigs and tackling larger and larger projects. The geothermal hot spring sector is investing hundreds of millions of dollars to develop Australia into a global hot spring destination. The direct use of geothermal energy from hot aquifers has proven itself economically competitive and much cleaner than natural gas across broad regions, and potential users are clamoring to develop new projects. And at the power generation end of the geothermal spectrum, new exploration licenses over hundreds of thousands of square kilometers of the country are expected to spawn a new rush of HSA and EGS projects.

The excitement and momentum is being driven almost entirely by the commercial sector. State and federal government geoscience and research agencies and most tertiary institutions are yet to respond to the commercial momentum by initiating or reinstating specific geothermal programs. We are unaware of any incentive program at any level of government that specifically seeks to incentivize geothermal development. Indeed, state government regulators have largely lost all personnel with experience of geothermal exploration and development—a situation that is potentially delaying the granting of exploration licenses.

AGA continues to grow as the peak body for Australia's broad geothermal community.

6. FUTURE DEVELOPMENT AND INSTALLATIONS

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

- Re-commissioning of the Winton Geothermal Power Plant, though possibly modified from its original plan;
- Recommencement of serious geothermal exploration after a 10-year hiatus, as large areas of exploration licenses are granted across several states;
- Accelerated growth of the GSHP sector, especially for large-scale residential property developments;
- Continued growth of the geothermal hot spring sector with construction and beginning of business for several new resorts and expansion of existing operations;
- Construction of a pilot geothermal district heating system in Gippsland (SE Victoria) and possible recommissioning of the existing geothermal district heating system in Portland (SW Victoria);
- 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 Gippsland, Victoria, where gas prices have risen rapidly in recent years and there are world-class geothermal resources that are largely undeveloped;
- No major change in federal government policy with respect to stimulating the development of geothermal energy.

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UNITS AND ABBREVIATIONS

ACCU = Australian Carbon Credit Unit

AEMO = Australian Energy Market Operator

AGA = Australian Geothermal Association

ARENA = Australian Renewable Energy Agency

AUD = Australian dollars (1.00 AUD = 0.71 USD in January 2023)

AWPRB = Asia Western Pacific Regional Branch

CER = Clean Energy Regulator

DISER = Department of Industry, Science, Energy and Resources

DHDX = deep hole direct exchange ground loops

EGS = engineered geothermal system

GGA = Global Geothermal Alliance

GJ_t = gigajoules of thermal energy

GSHP = ground source heat pump

GWh/yr = gigawatt hours per year

HSA = hot sedimentary aquifer

IEA = International Energy Agency

IGA = International Geothermal Association

LGC = Large Generation Certificate

MWh = megawatt hours

MW_t = megawatts of thermal power

NSW = New South Wales

PJ_t = petajoules of thermal energy

QLD = Queensland

RET = Renewable Energy Target

RTIF = Regional Tourism Investment Fund

SRES = Small Scale Renewable Energy

$t.CO_2$-e = metric tons of CO_2 equivalent emissions

UNFC = United Nations Framework Classification

UoM = University of Melbourne

WGC = World Geothermal Congress

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