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2020-2023 New Zealand Country Update

Katie McLean[1,2], Ted Montague[1,2], Samantha Alcaraz [1,3], Stephen Daysh[4], Penny Doorman[5], Katherine Luketina[6], Kennie Tsui[1], Brian White[1,7], Sadiq J. Zarrouk[1,8]*

[1] New Zealand Geothermal Association, New Zealand
[2]Contact Energy Ltd., Wairakei Power Station, Taupo, New Zealand
[3] GNS Science, Private Bag 2000, Taupō, 3350, New Zealand
[4] Mitchell Daysh, PO Box 149, Napier 4140, New Zealand
[5] Bay of Plenty Regional Council, PO Box 364, Whakatane 3158, New Zealand
[6] Waikato Regional Council, 401 Grey St, Hamilton 3240, New Zealand
[7] White Heat Limited, New Zealand
[8] Department of Engineering Science, The University of Auckland, Private Bag 92019, Auckland, New Zealand
*s.zarrouk@auckland.ac.nz

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ABSTRACT

The paper discusses the developments in the New Zealand geothermal sector since the update was presented as part of the 2020 World Geothermal Congress in Reykjavik, Iceland. The paper includes the tables requested by the International Geothermal Association, and the text discusses direct heat utilisation, electricity generation, environmental and regulatory aspects, personnel, education, training and investment.

Despite the COVID-19 pandemic, New Zealand witnessed active development in the geothermal electricity sector, with the 168 MWe Tauhara power plant under construction and active exploration at Taheke. In total, there is over 1050 MWe of installed geothermal electricity generation capacity typically contributing about 18.1 % to the national electricity generation.

In 2020, the NZ government declared a climate emergency. The previous year, in 2019, the NZ parliament approved a bill to make NZ net carbon zero by 2050. Both these actions demand an accelerated and expanded electrification of our society and economy and aim to achieve 100% renewable generation by 2035 (Wood, 2019). While geothermal power generation results in very limited carbon emissions, New Zealand's geothermal resources will have a key part to play as the country moves to this low-emissions future. There are significant developments in the direct use of geothermal energy, but few industries have successfully been awarded funding from the Government Investment in Decarbonising Industry (GIDI) Fund to help them switch from fossil fuel to geothermal energy.

New Zealand has always been at the forefront of geothermal technology, implementation, management and education. This paper identifies New Zealand geothermal expertise that is contributing internationally to the uptake of geothermal energy.

1- INTRODUCTION

As guardians of the gifted geothermal resources, engaging with Tangata whenua (indigenous people) is central to our geothermal community. Tangata whenua has a special relationship with the natural resources we rely on, as they have been utilising these resources for many decades.

New Zealand is a world leader in the exploration and development of geothermal energy both for electric power production and direct-use applications. The pioneering development of two-phase geothermal systems started in Wairakei in the early 1950s.

The New Zealand government understand that sustainable geothermal energy is a key contributor to its efforts in transitioning to a net zero carbon emission target and strongly supports all aspects of the industry.

1.1 Statutory Overview

The day-to-day management of geothermal resources in New Zealand is primarily the responsibility of the local (regional) government, which operates under legislation (i.e. the statutes) passed by the central government. The current primary statute is the Resource Management Act 1991 (RMA), under which regional councils sustainably manage geothermal resources, allocate geothermal water, energy and heat, and manage geothermal discharges. Allocation is through resource consents (or permits). The central government provides direction through National Policy Statements, which regional policies must give effect. Relevant National Policy Statements include those for Renewable Electricity Generation, Electricity Transmission, and Freshwater.

Central government departments most relevant to domestic geothermal management include the Ministry for the Environment (MfE); Ministry of Business Innovation and Employment (MBIE) which essentially includes a “Ministry of Energy”; the Energy Efficiency and Conservation Authority (EECA); the Department of Conservation (DoC). Other entities involved directly in geothermal include Iwi (Māori) Authorities and Māori land trusts, district councils, crown research institutes (e.g. GNS Science), tertiary institutes (e.g. the Geothermal Institute of the University of Auckland) and the New Zealand Geothermal Association.

Internationally, relevant stakeholders include the Ministry of Foreign Affairs and Trade (MFAT), New Zealand Trade and Enterprise (NZTE), which is the New Zealand government's international business development agency, and the geothermal exporters' association Geothermal New Zealand Inc.

The current statutory framework has undergone significant reform in recent years, and further reforms are signaled, particularly in relation to climate/energy and the environment. Those most relevant to geothermal are outlined below:

1.2 Climate Change Legislation

The New Zealand government has taken a number of key initiatives to give effect to the Paris Agreement, including the declaration of a climate emergency, reforms to the Emissions Trading Scheme, the end of offshore fossil fuel exploration, the establishment of an independent Climate Change Commission, and enactment of Climate Change Response (Zero Carbon) legislation. This legislation sets zero carbon targets to transition New Zealand to a low emissions future. As a result, New Zealand's carbon reduction target has since been updated (31 October 2021) and sets a new headline target of a 50 per cent reduction of net emissions below our gross 2005 level by 2030, and commits New Zealand to be net carbon zero by 2050.

To achieve these emissions reduction targets, emissions budgets are set by the government through an Emissions Reduction Plan. This plan sets strategies, policies and actions, including emissions budgets (5 yearly steps) to drive the transition to a low carbon economy. The Ministry released the first Emissions Reduction Plan for the Environment in 2022 (Budget, 2022). This requires New Zealand to reduce its emissions by an extra 11.5 megatonnes of carbon dioxide equivalent (Mt $CO_{2\text{-}e}$) between 2022 and 2025.

The transition to renewable and low-carbon energy is supported by the central government through various initiatives. The Government Investment In Decarbonising Industry (GIDI) Fund of $719 million has been established to ease the transition of the industry from fossil fuel to low-carbon energy, including geothermal. Only a small number of geothermal projects (EECA webpage) have benefitted from this fund, but this number is anticipated to increase. The government is also providing funding support through the Māori and Public Housing Renewable Energy Fund, which could benefit local geothermal heating schemes in the future. The Carbon Neutral Government Programme (CNGP) aims to transition the public sector to carbon neutrality by 2025.

These actions all demand accelerated and expanded electrification and transition to low-carbon industrial and domestic direct heat, all of which will include significant contributions from geothermal. The government has set a 100% renewable electricity target by 2035. Currently, 83 per cent of electricity generation is from renewable candidates (18.1 % from geothermal energy). Collaboration between energy providers is a key driver to achieving these targets. For example, Transpower (the Crown entity that manages the national electricity grid) is looking to develop Renewable Energy Zones. New Zealand's renewable energy associations (Bioenergy Association New Zealand, New Zealand Geothermal Association and New Zealand Wind Energy Association) are calling for prioritised domestic emissions reductions through enabling renewable energy initiatives (https://www.nzgeothermal.org.nz/news--events/aotearoas-renewable-energy-associations-joint-statement/). New Zealand's geothermal resources will have a key part to play as the country moves to this low emissions future.

Geothermal developments have also benefitted from other central government incentives not specifically targeted to carbon reduction, including the Regional Strategic Partnership Fund.

1.3 Environmental Legislation

The overarching legislation for geothermal management is the RMA, which aims to sustain resource management for future generations. After 30 years of implementation, the government is repealing this Act and introducing three new statutes (likely in 2023):

- Natural and Built Environments Act (NBA), replacing the RMA and including natural environmental limits.
- Spatial Planning Act (SPA), requiring regional spatial strategies;
- Climate Adaptation Act (CAA) focuses on managed retreat from coastal and other areas affected by climate change.

The proposed purpose of the NBA: *Te Oranga o te Taio* (the health of the environment) indicates that sustainable management will still be at the heart of the legislation, including limits, and that current geothermal system classifications may be retained. The reform will result in improved recognition of Te Tiriti o Waitangi (a nation's founding document) and reflect Treaty principles, including partnership in resource management and decision-making.

Other environmental policy developments relevant to geothermal are the National Policy Statement for Freshwater 2020 and a draft National Policy Statement for Indigenous Biodiversity. The latter will contain specific directions for the protection of geothermal biodiversity, which is one of New Zealand's most threatened ecosystem types and will have implications for geothermal developments.

It is also noted that the Resource Management Amendment Act 2020 (RMAA) has aligned the RMA and the Climate Change Response Act (Zero Carbon) by now requiring RMA decision-makers to consider climate change mitigation and greenhouse gas emissions in their plan-making and consenting decisions. This will have important implications for geothermal development.

1.4 Regional Council Geothermal Policies

The Waikato and Bay of Plenty Regional Councils manage 90% of the country's high-temperature geothermal resources, all in the Taupō Volcanic Zone (TVZ). The exception is Ngāwha, a high-temperature system in Northland Region. These regional councils manage geothermal under their regional policy statements and by regional plans that provide detailed policies and rules for sustainable resource management. Both the Waikato and Bay of Plenty Regional Policy Statements classify geothermal systems according to their values, current uses and potential for future use (e.g. Protection, Conditional Development and Development). A number of policy reviews are either underway or scheduled for review in the near future. This includes a review by the Bay of Plenty Regional Council of all of its geothermal provisions in 2022.

The central government has also signaled that it will be reviewing the structure of local government, including the form and functions of regional and district councils. This is likely to affect how day-to-day management of geothermal resources is delivered and is likely to require greater partnerships between government agencies and Māori.

2. ELECTRICITY GENERATION (TABLE 1 AND 2 IN APPENDICES)

In 2021, geothermal electricity generation remained almost constant at 7,820 GWh, -0.2% from 7,834 GWh in 2020.[1] Production was broadly consistent among all fields (Figure 1), with Kawerau down slightly due to a forced outage and Ngāwhā doubling its output due to a full year of contribution from the new plant OEC4.

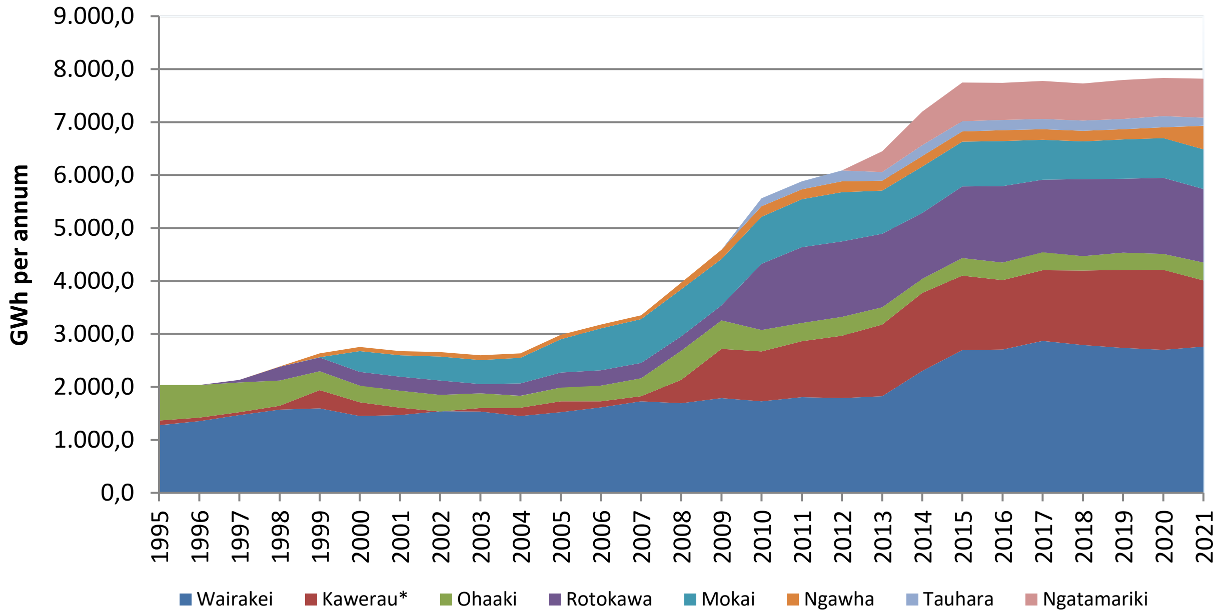

Figure 1: Geothermal Power Generation by Field (Sources: NZ Electricity Authority, MBIE, company operating reports).

2.1 Contribution to New Zealand Power supply

Geothermal comprised 18.1% of the nation's total power generation in 2021, on par with 2020 and steady since 2015 (Figure 2). Renewable generation rose slightly for the year from 81.1% to 82.0% due to wind and solar generation increases.

It can be seen in Figure 2 that beginning around 2005, a trend of increasing renewable generation (mostly geothermal and wind) has led to a decreasing trend in fossil fuel generation (particularly natural gas and coal). Generation from coal has been increasing again in recent years (since 2017), though this is projected to decrease again (Figure 3).

[1] MBIE has revised the geothermal generation statistics upward by 2% to 3% over the last 10 years

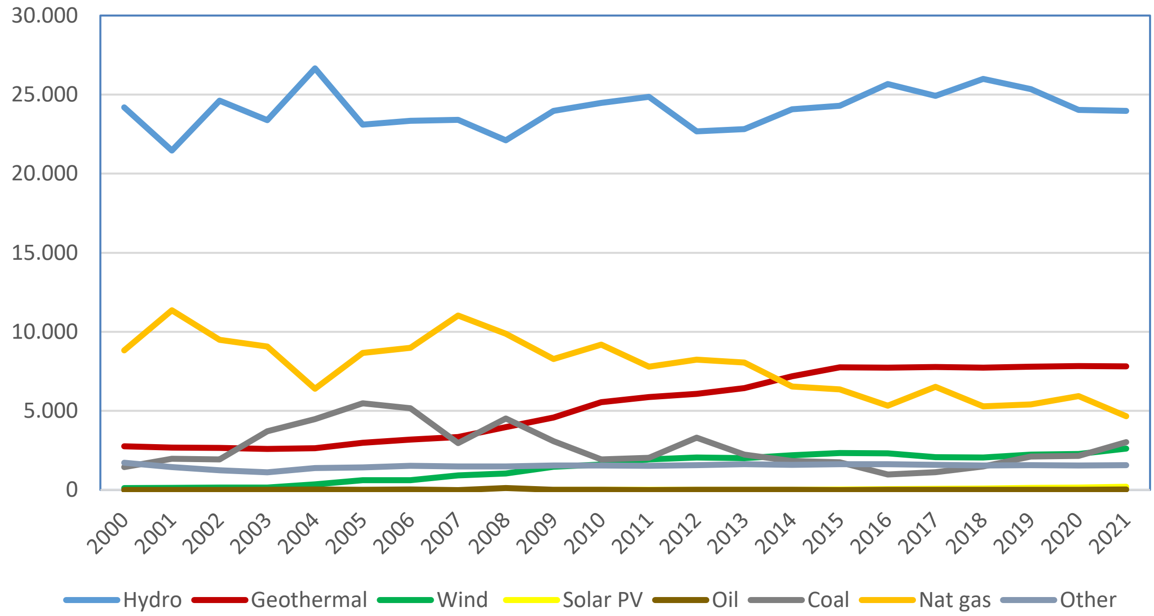

Figure 2: Annual NZ Power Generation in GWh by Fuel (Sources: MBIE)

2.2 Generation Capacity Changes

Operators did not commission any new plants during 2021 and 2022. However, Mercury Energy incrementally increased the capacity of the Rotokawa binary by 2 MW, and another 3 MW at nearby Nga Awa Purua by reconfiguring the steam field at the cost of $30 million.

The electricity industry is making significant progress toward the government's goal of 90% renewable generation by the year end 2025. A projection of confirmed and likely wind, geothermal and solar projects (Figure 3) shows renewables rising from 82% of generation in 2021 to 88% in 2026. In the upside case, solar PV growth lifts renewables to the 89% mark.

Over the projection period, geothermal generation rises 23% from 7,820 GWh to 9,603 GWh in 2026. This arises exclusively from brownfield projects, which are known resources, mostly with existing power stations.

This projection has some simplifying assumptions from our analysis based on publicly available information. Consumption rises at 0.5% per year; hydro conditions are assumed to be normal, and the NZ Aluminium Smelter continues to operate after the scheduled closing in 2024. Huntly units 1 & 2 (coal-fired) were scheduled to close at the end of 2022, but the projection has these continuing through 2023. However, coal-fired generation will cease in 2025 in line with owner Genesis' planning. The big unknown is gas-fueled plant capacity and supplies with Methanex, TCC, and E3P, all due for major maintenance decisions before 2025. Contact has announced its commitment to closing the Taranaki Gas Combined Cycle station, enabled by the new Tauhara geothermal power station.

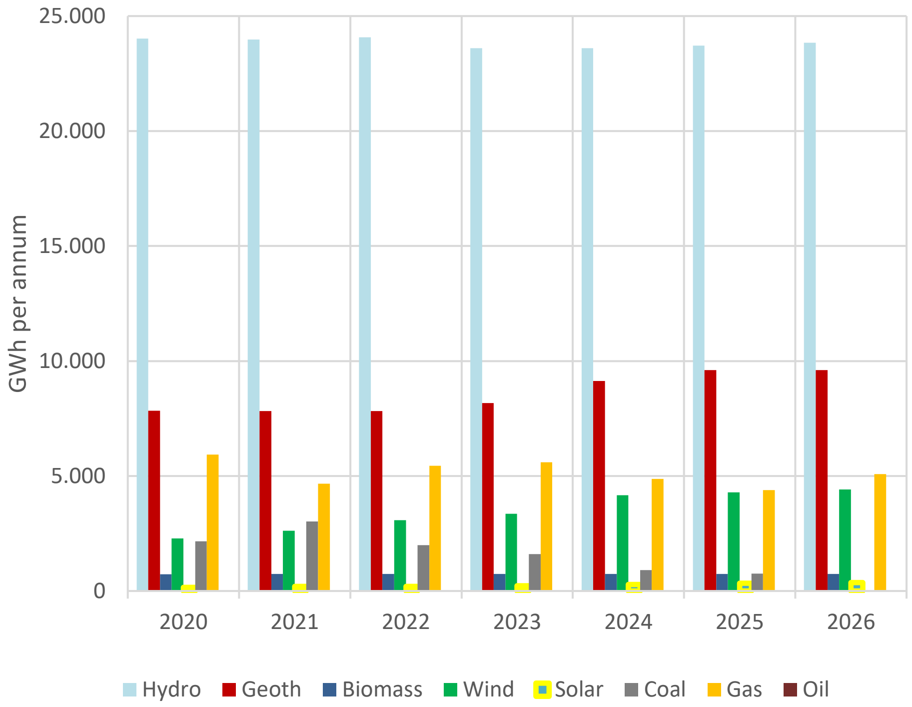

Figure 3. Projected Renewable Generation Growth Through 2026; GWh for 2020 and 2021 are actuals.
(Sources: MBIE, press reports, company investor presentations)

2.3 New Power Developments

The Tauhara geothermal power station construction is progressing at Contact Energy. While there have been some COVID-19-related delays, the 168MWe (net) station is due to reach commercial operation during the second half of 2023. Contact Energy estimates the construction cost at roughly US $3,300/kW.

The development comprises a single, triple flash, condensing steam turbine with a vertical condenser, a combination of Non-condensable gas (NGC) extraction, and a forced-draft cooling system. Sumitomo is the EPC contractor, with Fuji Electric supplying the turbine generator and Naylor Love providing the balance of the plant within the power island.

Steam for the turbine will be supplied by six production wells and augmented by four injection wells. These wells have been drilled and completed utilising MB Century's Rig 32 and wireline services; Western Energy provided specialist well-output testing services.

Construction of the above-ground gathering and injection system is underway; the principal contractors are Hicks Brothers (earthworks), United Civil (civil works), Culhams Engineering (separation plants), Steiner and Moses (vent and pump stations), Warners Construction (cross country piping), and Cassidy Construction (buildings).

The new station will inject into the national electricity grid, supply electricity to the electricity market, and be on long-term contracts with large industrial users.

Taheke: Eastland Ltd and Taheke T8C JV successfully drilled an appraisal production well in 2021, and the well was tested in June 2022.

3. NEW DIRECT USE DEVELOPMENTS (TABLE 3, 4 AND 5 IN APPENDICES)

While COVID-19 continued to chill efforts promoting direct geothermal uses, four notable successes emerged between 2020-2023.

Geo40 commissioned New Zealand's first commercial-scale silica recovery plant (Ohaaki Northern Plant) at Ohaaki Field in late 2020. This plant processes 6,800 tonnes per day of separated geothermal water to yield an anticipated 5,000 tonnes of colloidal and precipitated silica products per year. Trials of lithium extraction commenced at the Ngawha Plant in 2022 (Geo40's original pilot plant at Ohaaki).

Tissue maker Essity announced final investment approval for its geothermal steam-drying project at Kawerau in 2022. EECA contributed a $1.65 million grant to this NZ $16 million investment that will reduce carbon emissions by 23%.

In December 2021, the Tūaropaki / Obayashi joint venture (Halcyon Power) started hydrogen production at its 1.5MW geothermally powered (green) hydrogen pilot plant. The Halcyon plant (supplied by Hydrogenics Ltd.) is New Zealand's first green hydrogen plant with a design capacity of up to 250Nm^3 per hour of hydrogen; the first-year production target is 180 tonnes per year.

A new industrial estate is being developed in Taupō, called He Ahi, the Tauhara Clean Energy Park. Users will have the opportunity to tap into geothermal energy to power their activities. The 45-hectare site is located in the existing industrial area on the northern edge of Taupō town. The land is co-owned by several local iwi groups and is subdivided into numerous sections. Each site will be specifically designed and built to meet the requirements of the tenant. Contact Energy Ltd. will supply geothermal energy to the tenants from the existing infrastructure associated with the nearby Te Huka geothermal power station.

During 2022 the Rohe Hothouse scheme successfully won consent for 18 Ha of glass-house capacity at Ohaaki geothermal field. This greenhouse will use heat and CO_2 from the Ohaaki Power Plant to enhance growing conditions.

4. CARBON EMISSIONS

4.1 Annual Discharges and Trends

The calendar year 2021 CO_2-e emissions data appears below (Table 4); the figures represent CO_2-equivalent emissions data, including methane x 25 Global Warming Potentials per New Zealand's regulations. The data has been provided to the New Zealand Geothermal Association by operators of the geothermal power stations. Generation data has been verified against data from the Electricity Authority (EMI website).

Table 2.1 Geothermal CO_2-e emissions data for the calendar year 2021 (Montague et al., 2022).

Station	Total Steam	Emissions Factor	Net Generation	Total CO_2e	Emissions Rate	Operational Emissions Intensity	Lifecycle Emissions Intensity
	Tonnes	t CO_2e/t steam	GWh	Tonnes	t CO_2-e/day	gCO_2-e/kWh(net)	gCO_2-e/kWh(net)
Wairakei	9,692,282	0.00200	1046	19,385	53	19	29
Te Mihi	11,177,491	0.00480	1373	53,652	147	39	49
Poihipi	2,643,705	0.00490	341	12,954	35	38	48
Ohaaki	2,685,423	0.03330	339	89,425	245	264	274
Te Huka	1,016,659	0.00780	152	7,930	22	52	62
Rotokawa	1,308,855	0.01260	205	16,492	45	80	90
Nga Awa Purua	7,148,869	0.00838	1182	59,908	164	51	61
Mokai	5,134,637	0.00462	754	23,722	65	31	41
Ngatamariki	3,993,610	0.00926	740	36,981	101	50	60
Kawerau	6,040,604	0.01290	804	77,924	213	97	107
TOPP1	574,659	0.01020	100.3	5,862	16	58	68
TAOM	1,129,772	0.01000	198.7	11,298	31	57	67
GDL	238,621	0.01310	70.1	3,126	9	45	55
Ngawha OEC1-3[2]	716,235	0.08469	193	60,658	166	315	325
					MEDIAN	52	62
					25th PERCENTILE	40	50
					75th PERCENTILE	75	85
					MW WEIGHTED AV	64	74

[2] Ngawha Generation reports that the results from OEC4 have not yet stabilised

The MWe-weighted average emissions intensity of the 14 geothermal power stations in the above table is 64 gCO_{2-e}/kWh(net). This has declined from 69 gCO_{2-e}/kWh(net) in CY2020, and is part of an ongoing declining trend over the past seven years (Figure 4). The exponential decline rate is 6% per year.

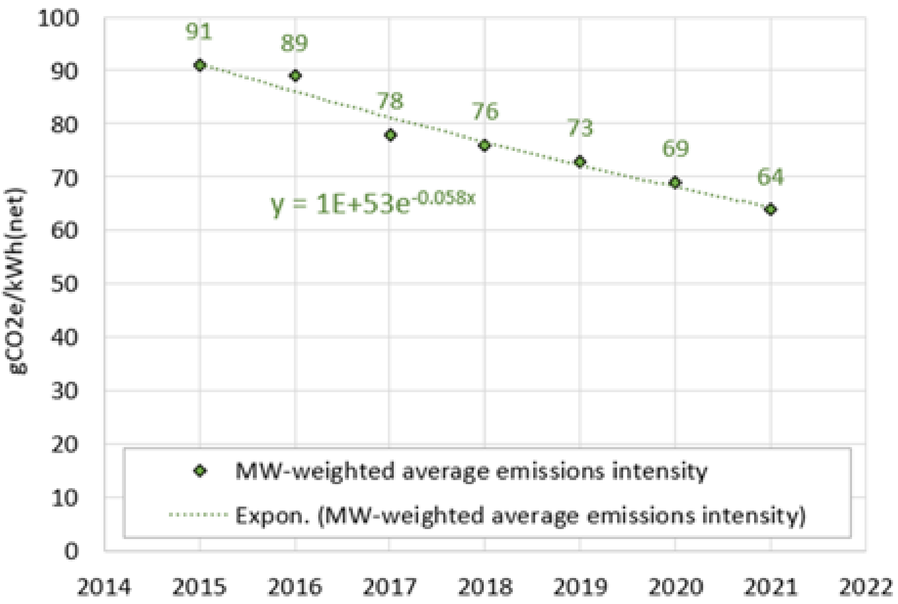

Figure 4: Steady decline of MWe-weighted average emissions intensity for seven years from 2015 to 2021 (Montague et al., 2022).

The emissions data in Figure 4 are operational emissions only. The full lifecycle emissions for geothermal can be estimated by adding 10 gCO_2e/kWh(net) to account for emissions associated with materials and construction, maintenance and decommissioning (Fridriksson et al., 2017). By this method the full lifecycle CO_{2-e} emissions from NZ geothermal power stations for CY2021 are also estimated in Table 2.1, and the overall MWe-weighted average lifecycle emissions are 74 gCO_{2-e}/kWh(net).

Other sources of energy are compared on the basis of median lifecycle emissions intensity, which is 62 gCO_{2-e}/kWh(net) for NZ geothermal in 2021 (Table 2.1). This compares to lifecycle emissions from other renewables of 44 for solar photovoltaics, 19 for hydro and 11 for wind. Fossil fuels have median lifecycle emissions intensities an order of magnitude higher, of 450 gCO_2e/kWh(net) for gas combined cycle plants and 980 for coal (McLean and Richardson, 2021).

4.2 Reducing carbon emissions

Emissions from geothermal power stations can be reduced or eliminated with the application of CO_2 reinjection technology. This technology diverts the CO_2 gas stream (along with CH_4 and H_2S) from venting to the atmosphere and instead dissolves the gases in water (separated geothermal water and/or condensate) where is carried back underground to where it came from, via the usual reinjection system (https://www.youtube.com/watch?v=B-5s2LxnejQ). All the major geothermal companies in New Zealand have active trials, or plans for, CO_2 reinjection. This includes Mercury Energy, Contact Energy, Ngawha Generation and Eastland Generation, which together represent 96% of New Zealand's geothermal electricity generation.

Mercury Energy Ltd commenced a trial of CO_2 reinjection at Ngātamariki Power Station near Taupo in October 2021. This involved full injection of gas emissions from one of the four OEC units (therefore a ¼ reduction in emissions), added into the brine-condensate reinjection fluid, and reinjected in one injection well. One quarter of the emissions from Ngātamariki represents around 9,000 tonnes of CO_2e annually. The results to date are very encouraging, with the ongoing carbon reinjection process showing no disruption to power generation or detrimental effect on the underground reservoir environment and geothermal well performance (Ghafar et al., 2022). The trial will continue to fully determine the viability of reinjecting carbon dioxide into the geothermal reservoir without affecting the power station's operation. If successful, Mercury will evaluate if similar technology can be extended to Ngātamariki's three other units and to Mercury's other geothermal power stations.

Contact Energy's trial of CO_2 reinjection at the Te Huka power station became fully operational in November 2022. The plant is currently reinjecting 100% of emissions with no detrimental effect on the plant or reservoir. When CO_2 reinjection is not being utilised the emissions from Te Huka are around 8,000 tonnes of CO_{2-e} annually. If this success continues, then Te Huka will become the first official zero-carbon geothermal power station in New Zealand.

Ngawha Generation has a trial of 100% CO_2 reinjection at one station, OEC1, which has been operational since early 2022. Ngawha Generation is aiming for 100% reinjection across its fleet of geothermal power stations at Ngawha. Eastland Generation plans to transition to CO_2 reinjection at its Te Ahi O Maui power station by 2024.

4.3 Carbon Market

NZ carbon prices almost doubled over 2021, altering the economic dispatch order for plants (Figure 5). The marginal fuel costs for gas (OCGT) and coal (Rankine) now exceed $100 per MWh (Figure 6), making the dispatch of thermal power greater than the full Levelized cost of wind and geothermal. In addition, for the first time, the marginal cost of gas-fired OECGs is now lower than for the coal-fired Rankine units.

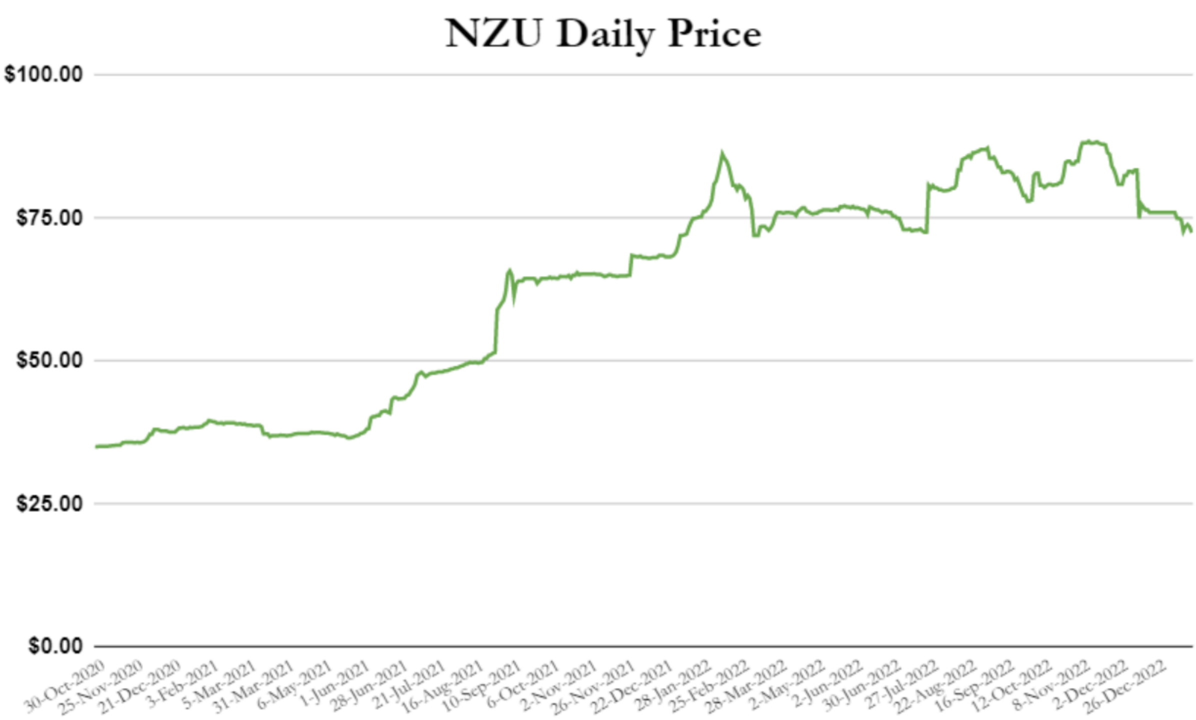

Figure 5: Carbon Prices surge between 2020-2022 (Carbon Forest Services, [Carbon Trading — Carbon Forest Services](#))

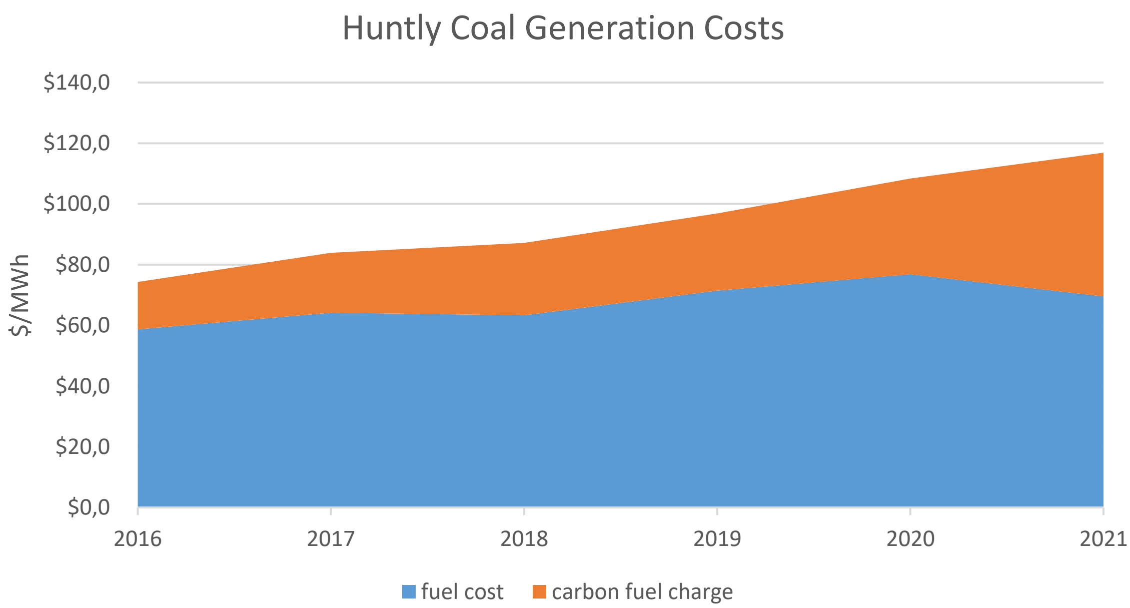

Figure 6: The increasing dispatch cost of coal generation on a fuel-only basis. (Sources: Genesis Energy, MBIE)

4.4 Geothermal in the Electricity Market

While power generation/consumption continued to be flat in 2021, the spot electricity market continued allocating tight supplies. A confluence of factors, including periodically dry hydro conditions, constrained gas supply, and below-average wind conditions, pushed the average spot price (at the Haywards Grid Exit Point (GXP)) up over 50% from $111/MWh in 2020 to $178/MWh in 2021. However, commercial contract prices generally remained steady (Figure 7).

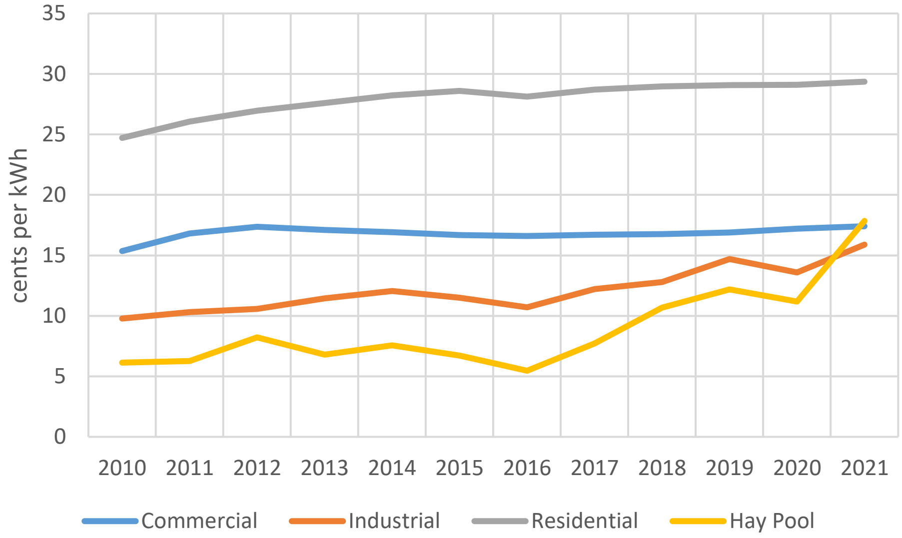

Figure 7. Annual Residential, Commercial, Industrial & Spot Prices (Sources; MBIE; Electricity Authority)

5.0 DRILLING AND COMPLETIONS ACTIVITY (TABLE 6 IN APPENDICES)

Despite COVID-19 delays, the drilling and well services sector maintained activity as operators drilled 7 deep and 9 shallow wells in 2021. Most of the deep activity centred at Tauhara Field as MB Century drilled 6 production and injection wells for Contact Energy's Tauhara project. Tiger Drilling drilled a deep appraisal well at Taheke for Eastland Energy.

5.1 Drilling Trends

Drilling activity has generally steadied post-2015 (Figure 8) to support new developments at Ngāwhā and Tauhara. Over this period, Kawerau was the most active field (11 wells), with Tauhara second (10 wells) and Ngāwhā third (6 wells).

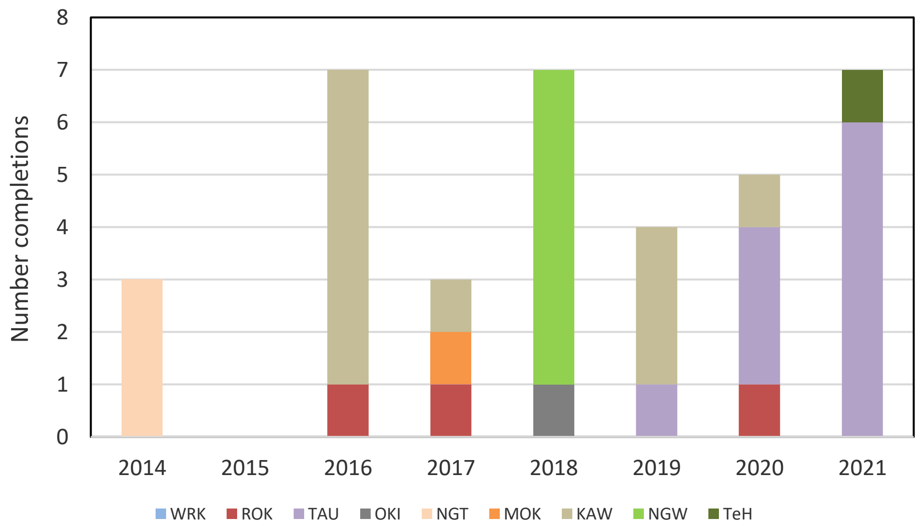

Figure 8 New Zealand Deep Wells Drilled by Field (Sources: press reports, Environment Waikato, BOP Regional Council)

6.0 GEOTHERMAL EDUCATION, RESEARCH AND PROFESSIONAL PERSONNEL (TABLE 7 IN APPENDICES)

The COVID-19 pandemic has significantly reduced the number of international students entering New Zealand since March 2020. This has impacted education and research programs at the University of Auckland and other institutions. However, the COVID-19 protection measures enforced by the New Zealand Government meant that in 2020, the geothermal training programme at the Geothermal Institute (University of Auckland) was the only international geothermal education programme running that year. The programmes in Iceland (GRÓ-GTP, Reykjavik) and (Kyushu University, Japan) did not run in 2020 due to the pandemic.

Remote learning suddenly became mainstream for all education providers, presenting significant challenges for field-based education programmes like the Post Graduate Certificate in Geothermal Energy Technology (PGCert) course at the Geothermal Institute. In 2021 the PGCert ran the first fully audio-visual recorded field trip, which made it possible for international students to attend the field trip remotely, observe the field measurement techniques and apply the field data to their studies; this continued in 2022. The plan is to run in-person classes and field trips for all international students from 2023.

Figure 9 provides the PGCert enrolment numbers, showing the impact of the pandemic on student numbers. The number of enrolments increased in 2022; with the return of some of the MFAT scholarships and some internationally funded scholarship students. There is a significant increase in the number of enquiries and applications, and it is hoped to return to pre-COVID-19 levels in 2023.

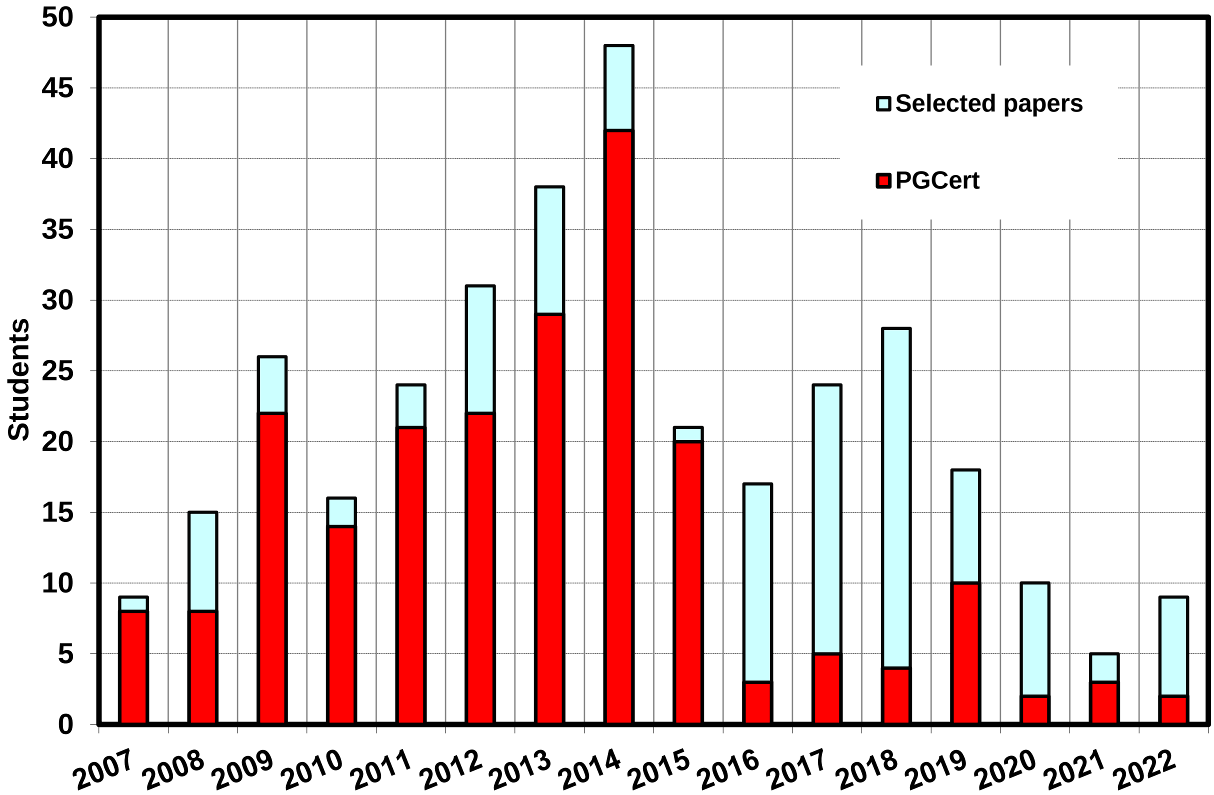

Figure 9: PGCert enrolment numbers since the start of the course in 2007

7.0 SERVICES SECTOR ACTIVITIES AND INVESTMENT (TABLE 8 IN APPENDICES)

7.1 MFAT Global Geothermal Initiatives

The New Zealand Ministry of Foreign Affairs and Trade (MFAT) global energy programme continued to render geothermal technical support throughout 2021. While COVID-19 continued to slow service conveyance, the adaptations to online delivery systems developed over 2020 progressed the provision of technical assistance.

Through these efforts, MFAT successfully pivoted all geothermal programmes for remote and online delivery, which has enabled technical assistance to continue through the COVID-19 pandemic. While the 100% remote model, in many cases, has not been ideal and required creativity, patience, and perseverance, it has helped keep the New Zealand geothermal sector relevant, visible and active with global partners.

In 2021 MFAT and partners (Geothermal Institute, Jacobs, Contact Energy, Seequent) provided an array of technical capacity-building activities to East Africa.

- In Djibouti, MFAT partners supplied the Office Djiboutien de Development d’Energie Geothermique with drilling advice for the planned 3-well exploration drilling programme at Gale-Le-Koma and the proposed slim holes for PK-Ambado.

- In Ethiopia, MFAT partners provided Ethiopia Electric Power with drilling and testing advice as well as virtual Q&A sessions for the Aluto-Langano development drilling (× 12 wells).
- In Tanzania, MFAT partners supported the Tanzania Geothermal Development Company with exploration and slim-hole drilling advice/peer-review, as well as conceptual modelling training.

In the Caribbean, under a regional, partner-led, demand-driven facility, MFAT did the following:

- Collaborated with the inter-governmental agency, the Organisation of Eastern Caribbean States (OECS) and engaged widely with regional geothermal partners to explore opportunities for geothermal direct uses across the region.It is hoped to progress a direct-use project through to the feasibility stage next.
- Provided technical support to the Government of Grenada. Assistance avenues include the procurement process for exploration drilling services, which will lead to further support; delivering a package of work partnering with the University of West Indies (UWI); supporting surveying and mapping of a new geothermal resource in the northern region of Dominica. This resource is planned to be developed into a Green Industrial Eco Park by the Green Climate Fund (GCF).
- Providing support to the Government of St Lucia in their efforts to further explore their geothermal potential via a World Bank-funded slim hole drilling exploration program. Support includes technical capacity support during the initiation phase, capability development and training.

In Indonesia MFAT:

- Provided technical assistance (under GEOINZ) to Badan Geologi (BG) in their role in the Government Drilling Programme. This involved reviewing conceptual models for drilling, running workshops on drilling strategies and joining BG on field visits, as well as providing drilling advice and support for the first two areas being explored with slimhole wells;
- Continued supporting SNI (Indonesian National Standard) through input into documents and meetings; COVID-19 caused a shift in the Government of Indonesia priorities, stalling regulatory change within this sector and pausing the usual regulatory support to EBTKE;
- Provided technical assistance to PT SMI to develop a GREM framework and evaluation and provided advice on the Candradimuka proposal from GeoDipa;
- Conducted, in collaboration with Ormat, a highly successful industry workshop at the end of 2020 that included a series of weekly webinars on developing lower-temperature geothermal resources;
- Maintained regular contact with Partners in order to keep connected and adjust to new developments and restrictions during the rapidly changing environment of COVID-19.
- Continued to provide, under NZSTIGS, vocational training for geothermal trades, technicians and plant operators to increase the skills and capability of the geothermal workforce; COVID-19 restrictions migrated training from in-person to online; this required developing new material to align with online learning and teaching.

7.2 Other Service and Promotional Activities

Despite COVID-19, the period between 2020 and 2023 proved a busy year for the geothermal service sector. Some of the highlights include:

- **Jacobs** was appointed owner engineer by Supreme Energy for Muara Laboh phase 2 (65 MWe) development. In addition, MFAT selected Jacobs to lead the East Africa Drilling Support project.
- Callaghan Innovation awarded **MB Century (MBC)** the prestigious Hi-Tech Maori Kamupene o te Tau/Maori Company of the Year for its work in developing the Multi Finger, High-Temperature Casing Caliper (HTCC-MF). This tool has been deployed to subsidiaries in the Philippines. In addition, during the year, MBC conducted a casing condition survey programme using their (HTCC-EM)- tool in Mexico in association with a local wireline operator.
- **MTL** has been working with our colleague Fichtner as owner Engineer for the Olkaria 1 Unit 6 Geothermal Project in Kenya. The 82MW project was completed earlier this year. MTL has also been engaged as a steamfield designer for a significant brownfield geothermal project in New Zealand, as well as multiple geothermal plant upgrade projects.
- Technology company **Seequent** was acquired by US-headquartered Bentley Systems in July 2021. The transaction was one of the largest in New Zealand's history in the tech sector at US$1.1 billion. Seequent continues to operate as a standalone division of the Bentley Systems Group and is still headquartered in Christchurch. Seequent's Leapfrog software now supports > 65% of installed geothermal power generation capacity globally, and expansion of their geothermal business has led to additional staff being hired in North America, Asia Pacific and Europe.

- **AECOM** was appointed lenders engineer by the Asia Development Bank for the Dieng and Patuha Expansion projects (by GeoDipa). AECOM was also appointed by EDC as the owner's engineer to facilitate the Palinpinon control system upgrade. Star Energy appointed AECOM as consulting engineer for various performance improvement projects in Indonesia.

The Geoheat Action Group released their third action plan in February 2022, focusing on promoting tangible, industrial-scale projects in developed fields. This consortium of service providers, economic development agencies, iwi, and research organisations will execute the strategy over the next two years. The funding was only secured through June 2020, so the business development position was suspended. Despite COVID-19 disruptions, the Geoheat Action Group has continued supporting dialogue between the geothermal community and the Climate Change Commission to ensure advice to the government recognises the substantial benefits of geothermal energy for direct-use heat applications.

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APPENDICES

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify)		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 2022	1,050	7,820	1,562	7,968	5,401	23,992	0	0	biogas 37 wood 40 wind 824 solar 87	265 wood 483 wind 2616	9,045	43,267
Under construction in December 2022	168	1,334	0	0	0	0	0	0			168	1,334
Funds committed, but not yet under construction in December 2022	-	-	-	-	-	-	0	0	-	-	-	-
Estimated total projected use by 2023	1,218	9,154	1,562	7,968	5,401	23,992	0	0		3,154	9,213	44,601

TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2022

1) N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.
C = in construction; PC = planned construction

2) 1F = Single Flash; CST= condensing steam turbine
2F = Double Flash; BPT= back pressure turbine
3F = Triple Flash; B = Binary (Rankine Cycle)
D = Dry Steam; H = Hybrid (explain)
O = Other (please specify)

3) Electrical installed capacity in 2022

4) Electrical capacity actually up and running in 2022

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
Field	Power Plant Name	Year Com-missioned	No. of Units	Status[1)]	Type of Unit[2)]	Total Installed Capacity MWe[3)] net	Total Running Capacity MWe[4)] net	Annual Energy Produced 2021 GWh/yr	Total under Constr. or Planned MWe net
Wairakei			4	R	4 HP - BPT	34			
	Wairakei	1958-63	9		2 IP- BPT				
					4 LP - CST	157	115	957	
					3 MP - CST				
		1996	1	R	1 LP- BPT	4			
	Wairakei Binary	2005	2		B	15	10	89	
	Poihipi	1996	1		CST - 1F	50	43	341	
	Te Mihi	2013	2		CST -2F	168	160	1373	
Kawerau	Tasman TA3	1966	1	R	BPT	10			
	Tasman TA3	2004	1		BPT	9	5	21	
	Tarawera 1	1989	2	R	B	2.4			
	Tarawera 2	1993	1	R	B	3.5			
	GDL	2008	1		B	8.3	8.3	57	
	Kawerau	2008	1		CST-2F	100	100	804	
	TOPP1	2013	1		B	23	23	172	
	Te Ahi O Maui	2018	1		B	28	25	194	
Broadlands	Ohaaki		1	R	BPT-1F- H	11			
		1989	1	R	CST-1F	47			
			1	R	BPT-1F- H	11			
			1		CST-1F	47	37	339	
Rotokawa	Rotokawa	1997	4		H (BPT, B)	29	29	205	
	Rotokawa Extension	2003	1		B	5	5		
	Nga Awa Purua	2010	1		CST-3F	140	136	1,182	
Northland	Ngawha	1998	2		B	10	25	441	
	Ngawha 2	2008	1		B	15			
	Ngawha 3	2020	1		B	31.5	30		
	Ngawha 4	2026	1	PC	B				31.5
Mokai	Mokai 1	1999	6		H (BPT- B)	55	55		
	Mokai 2	2005	5		H (BPT - B	39	39	754	
	Mokai 1A	2007	1		B	17	17		
Tauhara	Te Huka	2010	2		B	26	26	152	
	Tauhara II	2023	2	C	CST-3F				168
	Te Huka 2	2025	2	PC	B				52
Ngatamariki	Ngat A	2013	3		B	82	82	739	
	Ngat B	?	1	PC	B				28
Tikitere	Tikitere A	?		PC	B				40
Total			47			1,055	970	7,820	320

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2022 (other than heat pumps)

[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. (^{o}C) - outlet temp. (^{o}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. (^{o}C) - outlet temp. (^{o}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.

Note: please report all numbers to three significant figures.

Locality	Type[1]	Maximum Utilization					Capacity[3]	Annual Utilization		
		Flow Rate	Temperature (^{o}C)		Enthalpy[2] (kJ/kg)			Ave. Flow	Energy[4]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5]
Northland	B		42	20			0.2	22	6	0.95
Auckland	B,H		50-65	30			2.6	17	57	0.69
Waikato	B, O, H, D, G, F						152		3360	0.67
Bay of Plenty (misc)	B, O, H, D, G, I, F						65		1239	0.60
Bay of Plenty (Kaweralu)	B, I		210				207.9	420	5450	0.88
Gisborne	B		40-50	30-35			0.004	0.1	0.14	1.00
Hawke's Bay	B		50-62	40			0.1	2	3	1.00
Taranaki	B, O		27				0.004	0.07	0.11	0.50
Canterbury	B		52	24			0.5	4	11	0.50
West Coast	B		55-60	36			0.4	5	6	0.50
TOTAL							428.708		10132.25	0.74

Table 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF 31 DECEMBER 2022

This table should report thermal energy used (i.e. energy removed from the ground or water) and report separately heat rejected to the ground or water in the
[1] pumps

[2] Report type of installation as follows: V = vertical ground coupled
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

[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

Note: please report all numbers to three significant figures

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)
Canterbury		11.5	53	H		2628	5.8	
		10	4	V		2628	0.4	
	12	32.3	8	W		2628	2.4	
Marlborough		28.7	3	H		2628	0.8	
Otago		13.7	24	H		2628	3.1	
		60.5	2	V		2628	1.1	
Southland		15.7	1	W		2628	0.1	
		6	6	H		2628	0.3	
Wellington		7.7	3	H		2628	0.2	
West Coast		4.3	2	H		2628	0.1	
Commercial installations								
Southland		10.7	1	H		2628	0.1	
Otago		19.6	1	H		2628	0.2	
Manapouri		14.2	1	H		2628	0.1	
Wanaka		23.6	1	W		2628	0.2	
Canterbury		23.1	1	W		2628	0.2	
Canterbury Hunting lodge		19.6	1	H		2628	0.2	
Dunedin Airport	12	240	2	W	> 5		0.8	
Jellie Park Complex	12			W	3		25.9	
Pioneer pool complex	12			W	3		25.4	
Christchurch South Library	12			W	3		2.7	
Christchurch Airport	12	3600	2	W	> 5		65.4	119.4
Canterbury University				W			95.4	88.2
Gen-i				W			0	23.4
Tait Communications				W			5.76	5.76
ECAN			2	W			7.02	7.02
The Terrace				W			17.4	17.4
Arts Centre			7	W			22.8	22.8
Bus Exchange			1	W			2.88	2.88
hurch Botanic Gardens Visitor				W			3.78	3.78
King Edward Barracks				W			25.2	25.2
Justice Precinct				W			30	30
Christchurch Central Library				W			21.6	21.6
IAG				W	>5			
Christchurch Town Hall		1200		W			23.8	23.8
TOTAL			126 plus				391	391

* Typical Heat Pump rating or Capacity is the average of the capacity of the installed units

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2022

1) Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] 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. (°C) - outlet temp. (°C)] x 0.131! (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
since projects do not operate at 100% capacity all year

4) Other than heat pumps

5) Includes drying or dehydration of grains, fruits and vegetables

6) Excludes agricultural drying and dehydration

7) Includes balneology

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)	83	886	0.32
Air Conditioning (Cooling)	-	-	-
Greenhouse Heating	24	366	0.48
Fish Farming	17	196	0.36
Animal Farming	0.1	2	0.5
Agricultural Drying 5)	-	-	-
Industrial Process Heat 6)	445	9105	0.66
Snow Melting	-	-	-
Bathing and Swimming 7)	63	1457	0.75
Other Uses (irrigation, frost protection, geoth. tourist park)	61	1785	0.95
Subtotal	693.1	12012	0.57
Geothermal Heat Pumps	>20	390	
TOTAL	713.1	12402	

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2020 TO DECEMBER 31, 2022 (excluding heat pump wells)

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

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Expl/Apprais	(all)	1	0	0		0
Production	>150° C	10	0	10		36,600
	150-100° C		9	9		
	<100° C	0		0		
Injection	(all)	5	3	8		
Observation	(all)	1		1		
Total		16	12	27		36,600

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Prograr
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2019	67.0	130.0	46.0	0.0	0.0	390.0
2022	73.0	142.0	46.0	0.0	0.0	732.0

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2022) US$

Period	Research & Development Incl. Million US$	Field Development Including Production Million US$	Utilization		Funding Type	
			Direct Million US$	Electrical Million US$	Private %	Public %
1995-1999	5	36		143	70	30
2000-2004	15	48		95	20	80
2005-2009	105	577		690	42	58
2010-2014	71	588	18	691	61	39
2015-2019	23	60	0	55	100	0
2020-2022	33	600	7	760	100	0