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2015 -2020 New Zealand Country Update

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ABSTRACT

New Zealand has been in a period of consolidation in the geothermal electricity sector over the last 5 years following a period of rapid growth in the utilization of geothermal energy in the prior 10 years. Two smaller power plants are in the process of being constructed or recently commissioned. At Ngāwha a 25 MWe plant is in the early construction phase and at Kawerau the 25 MWe Te Ahi O Maui plant was commissioned in September 2018. There is in total over 1000 MWe of installed geothermal electricity generation capacity which is typically contributing about 18% of national electricity in an electricity system dominated by renewable generation. New Zealand currently produces about 80% of its electricity from renewable sources and the new Labour-led coalition government is strategically targeting 100% renewable generation by 2035, and is introducing a Carbon Zero Bill in 2019. New Zealand's geothermal resources will have a key part to play as the country moves to this new future. There is a developing emphasis on the direct use of geothermal energy. Both the New Zealand Geothermal Association and the Bay of Connections have strategies and implementation activities that are both increasing employment in direct use geothermal businesses and fostering increased utilisation of geothermal energy directly. The Taupō Volcanic Zone is the area that is the focus of this activity currently. There has been activity in the geothermal heat pump sector with a number of commercial facilities using aquifer energy systems now operational in Christchurch as part of the rebuilding activity that has occurred post the 2011 Christchurch earthquake. New Zealand is entering a growth period in direct geothermal heat use, including geothermal heat pumps. New Zealand is at the cutting edge of geothermal technology, implementation and management. The paper identifies geothermal expertise that New Zealand has that is contributing internationally to the uptake of geothermal utilisation. The paper discusses the developments in the New Zealand geothermal sector since the update presented as part of the 2015 World Geothermal Congress in Melbourne, Australia. 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.

1. INTRODUCTION

The purpose of this paper is to provide an update on geothermal activities in New Zealand between 2015 and 2020. It provides some background information about the geothermal setting in New Zealand and legislative developments towards decarbonisation. Trends in electricity capacity and generation, direct heat use and drilling activity are discussed. There is a summary of investments in geothermal over this period, and employment and educational trends in the geothermal sector.

2. BACKGROUND

2.1 Resource Management Setting

Geothermal resources in New Zealand are managed under the Resource Management Act 1991 (RMA), for which the Ministry for the Environment has overall responsibility. Other central Government departments involved with geothermal management include Ministry of Business Innovation and Employment (MBIE), the Department of Conservation (DoC), and the Ministry of Foreign Affairs and Trade (MFAT).

Under the RMA regional councils (local government) allocate geothermal water, energy and heat, and geothermal discharges to the environment. Allocation is through resource consents (or permits). Management is through regional policies, but direction is provided by central Government through National Policy Statements, which regional policies must give effect to. This includes the National Policy Statements for Renewable Electricity Generation and Electricity Transmission. A National Policy Statement for Indigenous Biodiversity, including geothermal biodiversity is also under development.

Other key stakeholders include Iwi (Maori) Authorities, district councils, crown research agencies (e.g. GNS Science), Geothermal New Zealand Inc, tertiary institutes (e.g. the Geothermal Institute through University of Auckland) and the New Zealand Geothermal Association.

2.1.1 Regional Geothermal Policies

The Waikato and Bay of Plenty Regional Councils manage 90% of the country's high temperature geothermal resource, all in the Taupō Volcanic Zone (TVZ). Ngāwha is 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 management of the resource. 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).

<u>Waikato Regional Council Geothermal Policy and Plans</u>

The Waikato Regional Council's geothermal policies have been operative for over ten years. A review of the regional plan is scheduled for 2020 and changes may include setting limits on the development potential for individual geothermal systems, clarifying policies and rules around reinjection, and specifying in greater detail the monitoring and reporting requirements of consent holders. There is also likely to be more collaboration in decision-making with Maori Tribal Authorities.

<u>Bay of Plenty Regional Council Policy and Plans</u>

The Bay of Plenty Regional Council is currently reviewing its regional plans geothermal provisions. The community is closely involved in the review, particularly Maori. Focus areas include the identification of geothermal features, better data on use of the resource, efficiency, use of Māori traditional knowledge and a review of current modelling and monitoring approaches. The Council has also developed (through the Bay of Connections) an Energy Strategy, and has worked with the New Zealand Geothermal Association in the implementation of the GeoHeat Strategy.

<u>Northland Regional Council Policy and Plans</u>

The Northland Regional Council has only one high-temperature geothermal system and does not have specific geothermal sections in its policy documents. However its Regional Plan has policies relating to geothermal water and energy, that enable renewable energy generation and that recognise the benefit of Ngāwha power station to the regional economy. Some protection is also provided for geothermal surface features.

2.2 The Geothermal Resource

There are 129 identified geothermal areas throughout New Zealand, with fourteen in the 70-140ºC temperature range, seven in the 140-220ºC range and fifteen in the >220ºC range (New Zealand Geothermal Association). Most high temperature systems are located in the TVZ, which extends from Whakaari/White Island in the Bay of Plenty southwest to Mt Ruapehu (Figure 1).

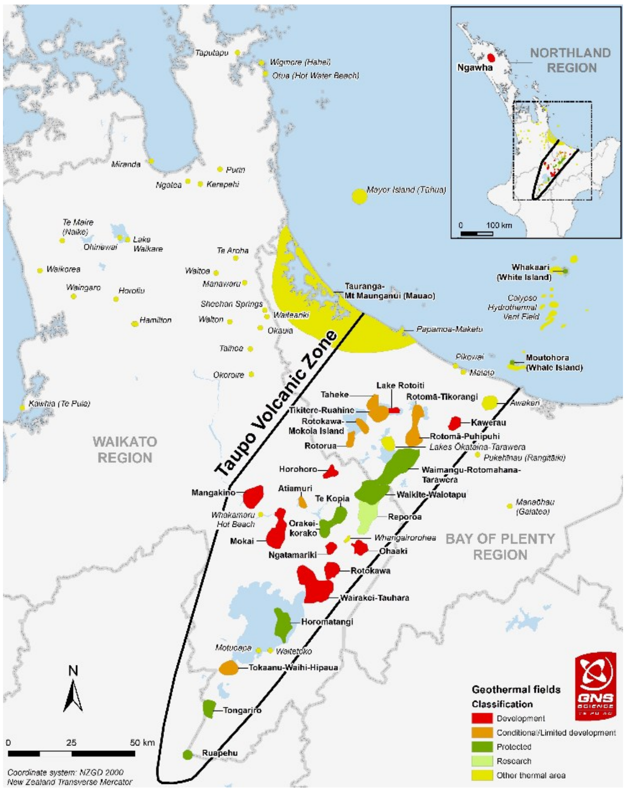

Figure 1: New Zealand Geothermal Systems including Taupō Volcanic Zone (Source, New Zealand Geothermal Association Website)

Development systems include Wairakei, Tauhara, Ohaaki, Mokai, Ngatamariki, Rotokawa, Ngawha, and Kawerau, which are all developed for electricity generation, and some also for direct heat use. Conditional or Limited Development systems, including Taheke, Tikitere, Rotokawa, Atiamrui, Tokaanu have potential for development, provided effects on surface features can be managed appropriately. Other systems, such as Rotorua are managed to protect surface features while allowing some small scale direct heat use. There are also a number of Low Temperature Systems, which have potential for development for direct heat use e.g.Tauranga.

No development is permitted within Protected Systems (e.g. Waimungu, Whakaari White Island, Waikite, Orakeikorako) which are managed to protect surface features for their intrinsic, cultural, ecological and landscape values.

3 CENTRAL GOVERNMENT REGULATORY DEVELOPMENTS

Central Government initiatives that influence the geothermal industry have included more emphasis on the energy "trilemma" of security, environmental sustainability and affordability, as well as safety.

3.1 Security

With respect to security, the electricity free market has pricing signals which have so far ensured security of supply. In periods when hydro lake levels are low or are significantly less than average for the time of year then spot prices can be high, providing incentive to build new plant. Monopoly elements of the network are regulated and an Electricity Authority helps to ensure efficient operation and development of the market environment.

3.1 Sustainability and affordability/Decarbonisation

The Government's Productivity Commission was asked to identify options to reduce domestic greenhouse gas emissions through a transition to a low-emissions economy, while continuing to grow income and wellbeing for New Zealanders. The inquiry investigated opportunities to reduce New Zealand's emissions, in the context of an ambition to achieve net-zero emissions by 2050. Recommendations included the reform of the existing emissions trading scheme, the establishment of an independent Climate Change Commission, development of credible laws and policies, and encouragement of investment and innovation (Productivity Commission 2018).

Under the Paris Agreement, the Government has agreed to reduce greenhouse gas emissions by 30% below 2005 levels by 2030. New Zealand's electricity industry contributes about 5% of the national greenhouse gas emissions. Currently, 83 percent of electricity generation is from renewable energy (18% from geothermal energy), and the Government has set an electricity target of 100% renewable electricity by 2035 (in a normal hydrological year). However, there is an element of negotiability in this if wider considerations justify a change.

An Interim Climate Change Commission was established to consider implications of this policy. In its report (ICCC, 2019), it advocated for "accelerated electrification" in which transport and process heat would be subject to policies to encourage uptake. This would be matched by a shift to renewable electricity sources in the 96-99% range. The final remaining percentage would be by a step increase in electricity price that might be considered unacceptable. New Zealand has premium geothermal, wind and hydro resources that can readily compete with fossil fuels on generation price. The modelled ongoing shift to renewable energy sources included significant investment in geothermal and wind energy. A final step price increase (Figure 2) would result from the need to overbuild renewable electricity to account for dry hydro years i.e. effectively reducing load factor (and could involve spilling wind and hydro, and venting or throttling geothermal wells in normal or wet hydro years).

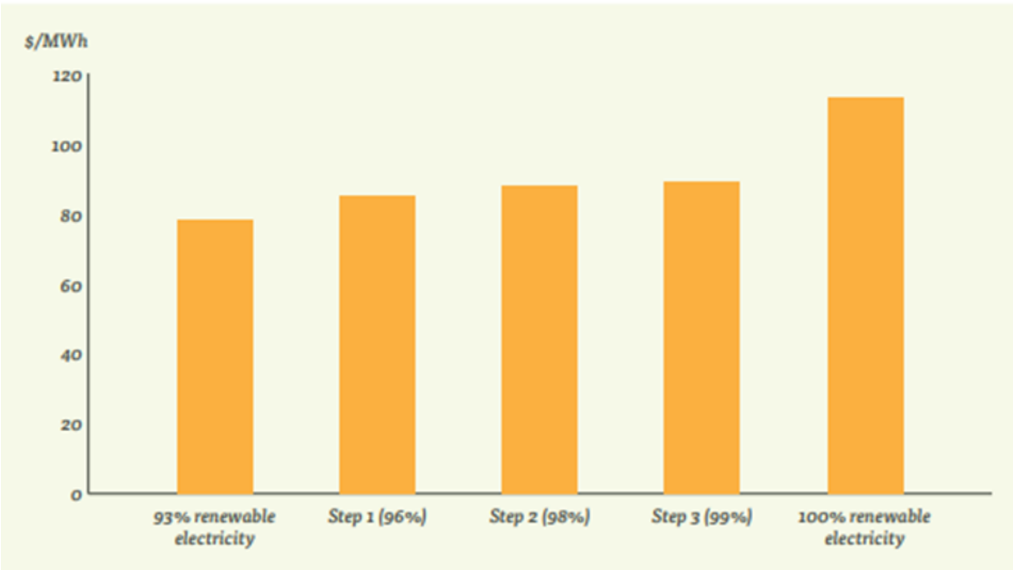

Figure 2: Modelled wholesale price (NZD) of electricity by 2035 – steps to 100% renewable electricity (Source: ICCC 2019)

3.3 Safety

Central Government is also active in health and safety reforms. Many of these reforms were triggered by a New Zealand coal mining disaster at Pike River in 2010 in which 29 people lost their lives (White 2013). Due to the relatively low risk and proven safety culture of the New Zealand geothermal industry the geothermal regulatory review has been delayed. However the geothermal industry has still been impacted by reforms indirectly. Drilling rigs which can be used for oil and gas drilling have needed full Safety Cases developed. All existing (and planned) binary cycle plant comes under "major hazard" regulations because of the quantities of combustible hydrocarbons used as working fluids.

4. GEOTHERMAL UTILIZATION - PRESENT AND PLANNED PRODUCTION OF ELECTRICITY (TABLE 1 AND 2 IN APPENDICES)

The last five years have been relatively quiet in terms of geothermal (or any energy) development in New Zealand. However, small additions are leading the way to what is expected to be a major drive to decarbonise the economy and to lift productivity.

Figure 3 shows recent historical growth in New Zealand renewable generation (MBIE 2019). Hydro generation dominates total generation, and for a long time coal and gas have played an important role in terms of taking up the variability in hydro generation (dry years versus wet years) or taking up load when hydro levels were low (e.g. before the spring thaw) or demand levels were high (mid-year winter). Geothermal energy has played an important and growing baseload role, while wind adds to the total generation reducing the stress on hydro generation. The gas generation was previously through gas-fired combined cycle plants, but the much-reduced need for baseload generation from gas now means that it is better to have simple cycle gas turbines for peaking duty, thus leading to progressive retirement of the combined cycle plants.

Table 1 in the appendices shows present generation and that expected by the end of 2020. Note that any additional renewable generation is likely to displace fossil fuel generation, and the overall expectation is for minimal electricity supply/demand growth.

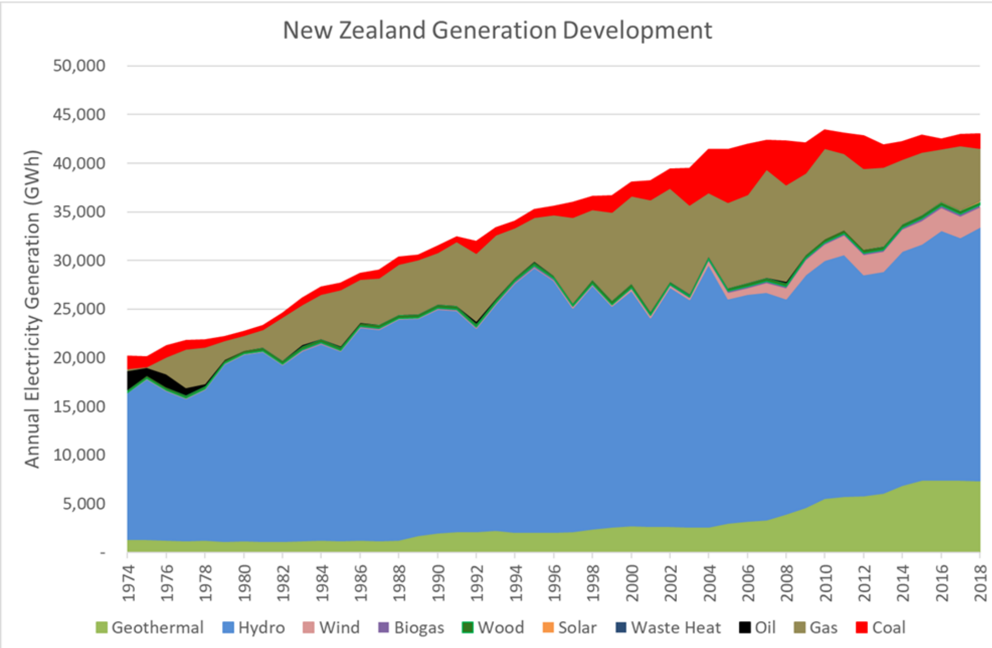

Figure 3: Historical growth in New Zealand electricity generation (Source: MBIE, 2019)

Growth in geothermal generation can be seen at the bottom of Figure 3. It is apparent that development in New Zealand has been stepwise, with some lulls, including in the last 5 years. (White and Chambefort 2016). There have been increments in generation since the 1980s. Changes in this generation are summarised in Appendix Table 2, with points to note:

- Eastland Generations's Te Ahi o Maui 25 MWe binary cycle development at Kawerau and developed in partnership with Kawerau A8D Ahu Whenua Trust was commissioned in 2018.
- Active drilling has been undertaken at Ngawha for Top Energy and construction is currently under way for the Ngawha 3, 31.5 MWe binary cycle station with commissioning expected to be completed around October 2020. Resource consents exist for a further equal output development in future.
- Not seen in Table 2 is Contact Energy's current preparations for further investigations into the potential development for Tauhara II (or variation of that) near Taupo and adjacent to Wairakei. Drilling will be underway when this paper is finalised.
- The Wairakei, Poihipi and Te Mihi stations owned by Contact Energy Ltd. on the Wairakei geothermal field have interconnected steam supplies. Consents are insufficient to fully load all stations, but Contact is able to move steam to different stations as they see fit. Te Mihi has the highest enthalpy wells, and the station is the most efficient station so now that it has operated for a few years, Contact is choosing to preferentially load that largely at the expense of the older Wairakei station. Consequently, the Wairakei station is shown as derated by 44 MWe, though this can still generate at full load if required. Redistribution of production now means that the Wairakei binary cycle plant is sensitive to heat exchanger scaling, but can operate at full load when exchangers are clean.
- The Kawerau field continues with active development led by Ngati Tuwharetoa Geothermal Assets (NTGA) mainly focused on direct use (discussed later). NTGA has also acquired the TOPP1 23 MWe binary cycle plant from Norske Skog Tasman paper mill.
- Contact Energy's Ohaaki station continues at restricted production. The last HP set has been retired and only one IP condensing turbine remains in operation with the other available for spares. The retirement of all HP sets means the field has been derated in well operating pressure.

- Generation in other fields continues as normal and valuable work is being done in mineral extraction and hydrogen generation research.

Figure 3 also shows growth in electricity supply/demand post World War II, but static supply and demand since 2008. This leads to uncertainty about future generation requirements. However, the drive to reduce carbon emissions is leading to interest in electric vehicles (or potentially hydrogen powered vehicles for which the hydrogen would be generated from predominantly renewable electricity) and possibly electric boilers for some industries. The overall expectation is for some increase in electricity demand.

Projections of demand and generation out to 2035 indicate growth of between 450 and 700 MWe of new geothermal generation. This will eventually be limited by availability of consentable fields and possibly the risk appetite for greenfield development, as all development to date has been based on fields proven by a government drilling programme in the 1980s.

Currently wind and geothermal generation seem equally attractive to developers, and commercially preferable to fossil-fuel options except for peaking duties. However the capital cost of wind generation continues to decline, and wind may eventually be developed in preference to geothermal generation.

In terms of the major developers, both Contact Energy Ltd. and Mercury[1] Ltd. have largely retained their geothermal expertise for ongoing maintenance of existing operations, and this capability will enable them to undertake new developments. As thermal generation is squeezed out of the New Zealand electricity generation market, geothermal generation could be the major source of carbon emissions for electricity generation. Figure 4 shows that this is still far from the case currently.

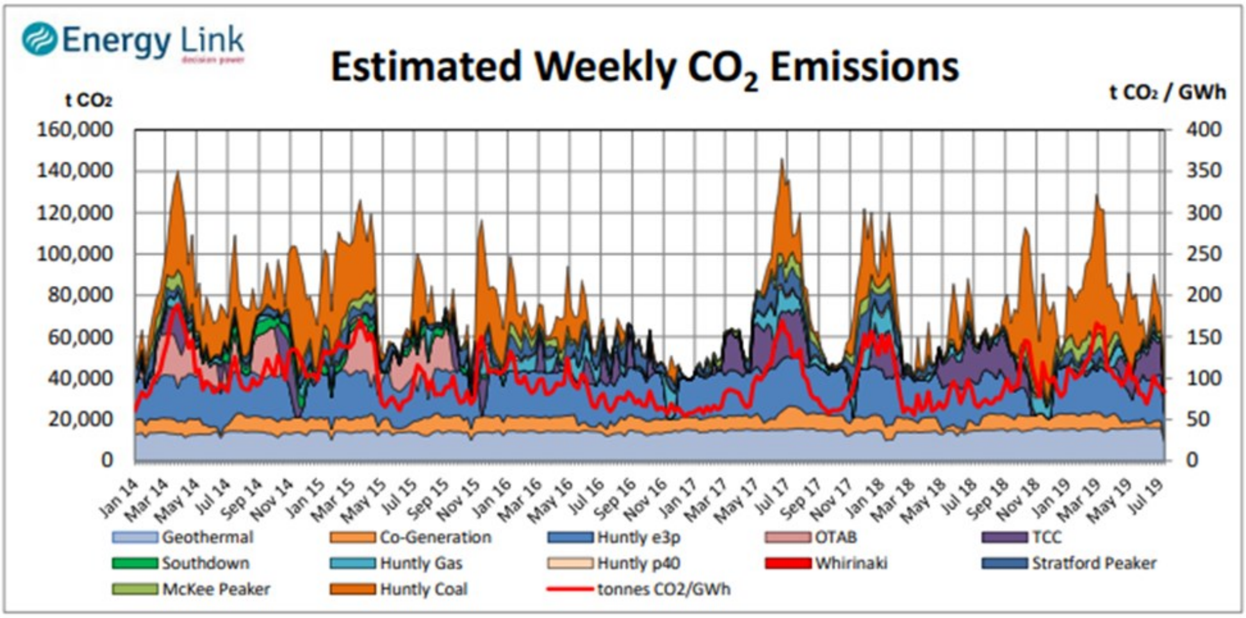

Figure 4: Estimated weekly emissions from the New Zealand electricity market (source: Energy Link).

New Zealand companies still disperse all gas discharged from fields above the station cooling towers. There is clear evidence that emissions do decrease with time, although development of new sectors of a field could lead to increases. Drives to 'zero carbon' may eventually force gas reinjection options, or cleanup for commercial uses. For now, there is careful monitoring and attempts to counter distorted information implying some New Zealand geothermal generation can have carbon emissions higher than natural gas-fired generation. There is ongoing research on natural fugitive emissions from geothermal fields and how these are affected by development. For now, geothermal station emissions are counted as fugitive emissions, whereas natural field emissions are not monitored.

4.1 New Zealand Activities Internationally

The major New Zealand developers are no longer actively looking to develop geothermal fields internationally. However New Zealand expertise is recognised and sought after globally due to the quality and success of New Zealand plants. Geothermal consultants can be found through commercial channels, or with the assistance of Geothermal New Zealand or the New Zealand Geothermal Association (www.geothermalnewzealand.com and www.nzgeothermal.org.nz).

The New Zealand Ministry of Foreign Affairs and Trade administers an Overseas Development Assistance programme, and has used New Zealand geothermal expertise as a means of providing niche support to partner governments. Over the last five years, MFAT has provided support to Indonesia (PGE development, government development, trades development, exploration drilling), East Africa (a partnership with the African Union Commission through a fund known as the NZ-Africa Geothermal Fund), the Caribbean (with activities currently focused on St Vincents and Dominica), and Vanuatu. Through much of this period MFAT has supported a Renewable Energy Envoy (Dr. Mike Allen) who has been able to represent New Zealand in a number of fora.

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[1] Formerly known as Mighty River Power Ltd.

5. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT USE (TABLE 3 AND 5 IN APPENDICES)

Direct geothermal use in the broadest sense is being fostered in New Zealand with significant initiatives since 2015. It was recognised in 2012 (Carey and Climo, 2012) that geothermal use, including direct geothermal use in New Zealand could be grown with improved coordination, prioritisation, awareness and marketing. The New Zealand Geothermal Association's Geoheat Strategy for Aotearoa NZ, 2017-2030 (Climo et al 2017) and the 2018-2019 Action Plan (Climo et al 2018), and the work of the Geothermal Business Development Lead contracted in late 2017 by the Bay of Connections (BoC) have been facilitating growth in direct geothermal use in the TVZ (Climo et al 2020a).

There are also overlapping central, regional and local government initiatives, industrial companies' goals; particularly those of Contact Energy Ltd and Ngati Tuwharetoa Geothermal Assets (NTGA) in growing direct geothermal use, and from Maori aspirations and values. Integration and leveraging is providing the platform for this success.

A number of direct use initiatives are being established in different locations, with project investment in total over NZ$80M and expected employment of over 100 people directly in businesses using geothermal (Climo et al 2020a). The projects cover a range of activities including dairy processing, food and beverage, mineral processing, wood processing and bathing. Some of the projects are identified in Table 1 below:

Table 1: Examples of businesses since late 2017, establishing or converting, that will utilise geothermal resources as part of their operations.

Business	Type	Geothermal Field	Activity	Capital Investment NZD Million	Projected FTEs[1]
Rogue Bore Brewery[3]	New	Wairakei	Brewing	5	~24
Waiū Dairy[3]	New	Kawerau	Milk processing	33	~40
Nature's Flame[3]	Conversion to geothermal energy	Tauhara	Wood pellet production	2010 investment of 34 Million. 2019 conversion cost is not known	~50
GEO40[3]	New	Ohaaki	Silica sol production	15	~30
Wai Ariki[2]	New	Rotorua	Balneology / Spa	30	

[1]*FTEs - Full Time Equivalents. These numbers include people working onsite at the operation and exclude energy suppliers and contractors FTE's.*

[2] *From Stuff (2017)*

[3] *From Climo et al 2020a*

5.1 Industrial Symbiosis

Scion, GNS Science, the University of Waikato and the forestry industry have been working on Industrial Symbiosis research for the Ministry of Business and Innovation,. Part of this focuses on providing renewable energy from forest residues or geothermal energy to reduce the carbon emissions profile of the New Zealand Process Sector whilst also releasing additional value. The forest residues to energy work was considered on the basis of substitution for carbon rich fossil fuels, whilst the geothermal work looked more at how additional value might be gained from forest resources that are being processed. Rather than burning the biomass as an energy source to support the timber processing operation, the energy for the wood processing is supplied by geothermal and the biomass / wastes are processed into valuable products. The Nature's Flame conversion example in Table 1 above is just this, where a biomass residual wastes boiler is being replaced with a geothermal energy supply, which then releases the wood wastes that had been burnt for energy so they can be turned into pellets for sale as a carbon neutral biomass fuel. Work associated with the research is reported to WGC 2020 in Alcaraz et al (2020).

5.2 Geothermal Minerals

New Zealand is seeking to gain commercial value by producing commercial minerals whilst increasing geothermal energy production potential. Work being undertaken is moving geothermal mineral extraction from the laboratory and pilot scale to the commercial scale (Climo et al (2020b)). Workstreams include Geo40, which is expanding silica sol production to a commercial production operation using geothermal water from the Ohaaki Geothermal Field. Central Government announced in July 2019 (Jones 2019) that it is to invest NZ$15M to assist Geo40 with the construction of a larger commercial production plant. The extracted silica is to be sold in bulk for use in the manufacture of consumer goods. The commercial plant will see Geo40 process 6,700 tonnes per day of separated geothermal water, which follows on from the success of the commercial demonstration plant that processed about 850 tonnes per day of water. The extraction of other minerals is also being explored from the silica-reduced separated geothermal water.

Climo et al (2020b) identifies other workstreams that could usefully be established in further developing minerals extraction from geothermal waters in New Zealand.

5.3 Direct Use Data

An update of the New Zealand Direct use data is included in Appendices Table 3 and Table 5. The data is based on WGC 2015 data (Carey et al 2015) with an update of the industrial use data (i.e. the largest energy use change and better quality energy data from measurement based records). Energy data of smaller and moderate commercial size use is imperfect with the numbers being approximations calculated using consent data, local knowledge and assumptions on utilisation.

The data from the NZ Country update papers to the last three WGC conferences is summarised in Table 2.

Table 2: NZ Annual Direct Use Energy Summary table. Data from Harvey et al 2010, Carey et al 2015 and Table 5 in Appendix for 2020.

WGC Conference	Direct Use PJ / annum		
	Total	Industrial	Other
2010	9.5	6.1	3.4
2015	8.5	5	3.5
2020	TBC	TBC	3.5

Overall there has been some changes in annual energy utilisation in the industrial sector whilst little or no change is observed in other sectors over the decade since 2010.

Climo et al (2020c) provides a review of New Zealand's Direct Geothermal Use data identifying strengths and weaknesses in the data. For national scale reporting, the current level of accuracy in the geothermal direct use dataset is likely adequate because (i) the geothermal direct use contribution is small (less than 2% of the national consumed energy use dataset), and (ii) this geothermal data is dominated by a few large industrial users who adequately monitor their energy use.

For reporting and resource management (e.g. at a field-scale or regional scale), more robust data would allow for improved quantitative analyses of heat energy used, the number of existing installations, trending and for estimating future trends. This is time- and cost-intensive and it is necessary to have clear benefits from collecting and maintaining such data against the intended use. It is not practical, nor affordable, to collect highly detailed data on all operations on a national scale, and to maintain temporal data on either a continuous or even semi-continuous basis. The total geothermal energy consumed data for New Zealand is expected to be accurate to within an error margin of +/-20% using the approach that is currently used (though trends will be real if these are assessed in a consistent manner). It is unlikely that significant additional effort to reduce that error margin would produce material benefit.

GNS Science has been supporting a web-based searchable spatial geothermal use application with the aim of providing information on where geothermal resource use, including geothermal heat pumps, has occurred in New Zealand.

6. GEOTHERMAL GROUND SOURCE HEAT PUMPS AS OF 31 DECEMBER 2019 (TABLE 4 IN APPENDICES)

The growth in uptake of geothermal heat pumps in New Zealand, measured through estimated annual use, is show in Table 3.

Table 3: NZ Geothermal Heat Pump Summary table. Data from Harvey et al 2010, Carey et al 2015 and Appendices in this paper

WGC Conference	Geothermal Heat Pumps TJ / annum
2010	40
2015	70
2020	400

The increase that has occurred between 2015 and 2020 is driven by the rebuilding of commercial infrastructure in the Christchurch Central Business District post the devastating 2011 earthquake. A number of commercial facilities have adopted aquifer water energy systems using the productive ground water aquifers that exist under the city. The systems being installed are all based on water to water heat pumps. Seward and Carey (2020) provides information on activity occurring in Christchurch and discusses four specific installations in more detail.

7 WELLS DRILLED FOR ELECTRICAL DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES (JANUARY 2015-DECEMBER 2019) (TABLE 6 IN APPENDICES)

Table 6 in the appendices shows the number of wells and fields drilled in New Zealand between Jan 2015 and Dec 2020. The majority of wells are for small scale direct heat use, in fields such as Rotorua and Taupō, and the low temperature system at Tauranga. These wells are typically shallow, 100-300 meters and are used for domestic, municipal and commercial space and water heating, bathing, light industry and horticulture.

There are a number of deep wells installed for existing or new electricity production within Development Systems, including new production and injection wells for the Te Ahi o Maui development at Kawerau, which included the establishment of a new 25MW binary plant, a project between Eastland Generation and Maori land owners. There were also additional wells installed at Kawerau by Mercury and Eastland Generation for the existing electricity plants and by NTGA for mixed electricity/direct heat use, and associated with the expansion at Ngawha.

Well drilling activity costs are a substantial (and growing) portion of total project costs, whether for electricity generation or heat.

8 ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL (TABLE 7 IN APPENDICES)

Personnel in the New Zealand geothermal industry include Government officials (both regional and Central Government), tertiary institutes, Crown research agencies (e.g. GNS Science), consultancies, and development companies. Data for appendix Table 7 has been collected through interviews with representatives of New Zealand companies. While there was major growth in the industry in previous years, this has remained relatively static over the last five years, with a slight decline in recent years. This is due to a static electricity demand resulting in reduction of staffing levels.

It is noted that a number of the New Zealand companies, consultants and academic are also active internationally, bringing a wide range of geothermal expertise and skills to the international market.

9 TOTAL INVESTMENTS IN GEOTHERMAL (US) (TABLE 8 IN APPENDICES)

Recent years have seen a brief pause in intensive geothermal development, but drivers for new investment are now in place.

In an asset transfer, Tuaropaki Trust acquired MBCentury in February 2015. MBCentury continues with its same name but under the direction of its new owner. A second asset transfer involved the purchase of TOPP1 power station by Ngati Tuwharetoa geothermal assets from Norske Skog Tasman.

The main development over the period has been Eastland Generation’s investment at Kawerau in the Te Ahi o Maui 25 MWe binary cycle plant with price quoted at NZ$137 million, in partnership with the Maori land owners Kawerau A8D Ahu Whenua Trust. This was synched to the grid on 1st of October 2018. Eastland also has 100% investment in the Geothermal Developments Limited (KA 24) plant at Kawerau. Eastland Generation is part of the larger Eastland Group which is owned by Trust Tairawhiti and operates on behalf of the people of Te Tairawhiti, the east coast region of the North Island of New Zealand.

The other major new development in progress is Top Energy’s Ngawha 3 development. Three production and three reinjection wells have been drilled by Iceland Drilling, and major earthworks have been undertaken. Ormat is now in the process of building the station and steamfield. Top Energy has indicated a total investment of NZ$180million. Top Energy is owned by a community trust for the benefit of those connected to the electricity network in the area.

Another major investment includes research on hydrogen production being undertaken by Tuaropaki Trust with Obayashi Corporation, for which they established the joint venture vehicle Halcyon Power in 2018.

Geo40 has been established for commercial production of colloidal silica from geothermal fluids. A pilot plant has been operated on the Ohaaki geothermal field in cooperation with Contact Energy.

Figure 5: Geo40’s silica demonstration plant located on the Ohaaki geothermal field

9 PROFESSIONAL TRAINING - GEOTHERMAL INSTITUTE

Geothermal energy training is a very specialised area with few established postgraduate (PG) courses available worldwide. The Geothermal Institute (GI) at the University of Auckland ran a very successful year-long post graduate diploma (PGDip) in geothermal energy technology from 1979 to 2002 (Zarrouk, 2017). The GI had 1300 alumni from more than 50 countries, many now in senior positions and who maintain close relationships with the New Zealand geothermal industry. The GI also trained most New Zealand geothermal experts, keeping New Zealand at the forefront of geothermal research, knowledge and practice worldwide.

Over 85% of the students attending the course were funded by New Zealand government scholarships and when this funding was stopped in 2003 the course was abandoned. There were similar outcomes for geothermal courses at Pisa, Italy and Kyushu, Japan (Table 4), and University of Nevada (2011-2013) (Zarrouk, 2017). As a result, when restarting the new post graduate certificate (PGCert) in geothermal energy technology in 2007 significant emphasis was given to making the course self-sustaining.

Table 4: History of post graduate geothermal programmes around the world (Zarrouk, 2017)

Institution	Country	Year Started	Year Stopped	Duration (months)	Funding support
International Institute for Geothermal Research, CRN in Pisa,	Italy	1970 1985	1985 1992	9 8	United Nations Development Program (UNDP). UNESCO
Kyushu University	Japan	1970 2016	2001 Continuing	2 – 4 6	The government of Japan (JICA)
Auckland University	New Zealand	1978 2007	2002 Continuing	9 4	UNDP and MFAT Scholarships (varying number over the years) Employer-funded students Self-supported students
UNU-GTP Reykjavik	Iceland	1979	Continuing	6	The government of Iceland and UNU (until 2007) Employer-funded students

9.1 Update on PG Certificate on Geothermal Energy (From 2007)

In 2007 the one-semester (60 points) PGCert course was started with initiative from the academic staff of the Department of Engineering Science with the help of three scholarships (for two years) from Contact Energy Ltd. and one from MBCentury Ltd. These scholarships helped restart the course with student numbers increasing each year as shown in Figure 6.

The course was structured to ensure sustainability with minimum risk and was reduced to a one-semester (19 week) course and divided into separate blocks of about six weeks. This means that students can do the PGCert over two years in six week long blocks plus a one month short project. Currently one full time academic staff (the author) runs the course, with most other lecturers either donating their time or on short-term contracts.

The success of the PGCert course and the strong support from the New Zealand geothermal industry prompted the Ministry of Foreign Affairs and Trade (MFAT) New Zealand government to re-establish a scholarship programme in 2011 as part of New Zealand government aid (NZAID) programme. However a constant stream of self-funded and company sponsored students ensure course sustainability.

Three hundred and thirteen students have completed the PGCert course from 39 countries since 2007. Course numbers have varied through the years with 2014 seeing the greatest number of enrolments at 48 students in total attending (Figure 6).

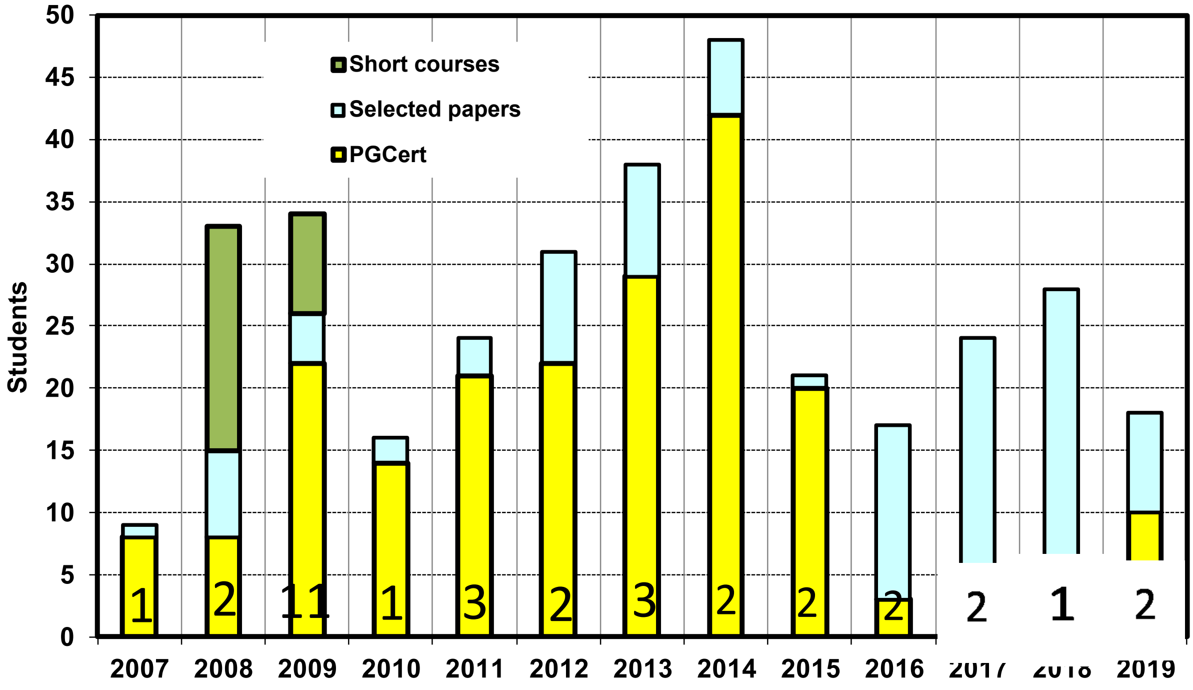

Figure 6. Annual number of student's enrolment in the PGCert, selected papers and short courses. The numbers within the yellow bar indicates the number of domestic students attending the full PGCert course each year.

In recent years, there has been a decline in the number of students completing the full PGCert degree (Figure 6) due in part to the strong interest in the interfaculty Master of Energy (taught) program where students carry the credit from doing the geothermal papers (courses) toward this degree. Students from the Master of Energy program also carry six months research project on geothermal topics.

The Geothermal Institute have also been running several professional vocational training courses in New Zealand, Germany, Indonesia, Chile, Japan, Kenya and Iceland.

CONCLUSION

Despite some slowing in the industry, the over 1000MW of installed geothermal electricity generation capacity contributes approximately 18% of national electricity, and will continue to be critical in the move to a zero carbon economy. There has been establishment of a new 25 MWe binary plant in Kawerau, and some expansion at Ngawha is underway. There is also a developing emphasis on the direct use of geothermal energy, including industrial direct heat use (e.g. milk production, wood processing), as well as commercial and domestic uses (including geothermal heat pumps). Much of this work is being facilitated through collaborative projects, including the Geoheat Strategy. This New Zealand remains at the cutting edge of geothermal technology, implementation and management.

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APPENDICIES

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 2019	1,032	7,474	1,562	7,430	5,381	25,000	0	0	biogas 33 wood 40 wind 689 solar 68	biogas 255 wood 287 wind	8,805	42,650
Under construction in December 2019	32	254	0	0	20	93	0	0	wind 135	408	187	755
Funds committed, but not yet under construction in December 2019	-	-	-	-	-	-	0	0	-	-	-	-
Estimated total projected use by 2020	1,064	7,728	1,562	6,675	5,401	25,093	0	0	965	3,154	8,992	42,650

Note that demand has been steady so increased renewable energy capacity/generation will reduce fossil fuel generation

TABLE 2 **UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2019**

1) N = Not operating (temporary), R = Retired, C = Consented. Otherwise leave blank if presently operating.

2) 1F = Single Flash B = Binary (Rankine Cycle)
2F = Double Flash H = Hybrid (explain)
3F = Triple Flash O = Other (please specify)
D = Dry Steam

3) Electrical installed capacity in 2019

4) Totals exclude retired plant

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
Wairakei			4	R	4 HP - BP	34			
			9		2 IP- BP				
	Wairakei	1958-63			4 LP - C	157	115	915	
					3 MP - C				
		1996	1		1 LP- BP	2			
	Wairakei Binary	2005	2		B	15	10	80	
	Poihipi	1996	1		D	55	55	390	
	Te Mihi	2014	2		2F	166	166	1385	
Kawerau	Tasman BP	1966	1	R	1BP	10			
	Tasman BP	2004	1		1 BP	5	5	44	
	TG1	1989	2	R	B	2.4			
	TG2	1993	1	R	B	3.5			
	KA24	2008	1		B	8.3	8.3	30	
	Kawerau	2008	1		2F	100	100	800	
	TOPP1	2013	1		B	23	23	180	
	Te Ahi O Maui	2018	1		B	25	25	200	
Reporoa	Ohaaki		1	R	1 HP - BP (	11			
		1989	1	R	1F	47			
			1	R	1 HP - BP (	11			
			1		1F	47	37	300	
Rotokawa	Rotokawa	1997	4		H (1F, B)	29	29	270	
	Rotokawa Extension	2003	1		B	5	5		
	Nga Awa Purua	2010	1		3F	140	140	1,000	
Northland	Ngawha	1998	2		B	10	25	200	
	Ngawha 2	2008	1		B	15			
	Ngawha 3	2020	1		B				31.5
	Ngawha 4	?	1	C	B				31.5
Mokai	Mokai 1	1999	6		H (1F, B)	55	55	930	
	Mokai 2	2005	5		H (1F, B)	39	39		
	Mokai 1A	2007	1		B	17	17		
Tauhara	Te Huka	2010	2		B	26	26	190	
	Tauhara II	?		C					250
Ngatamariki	Ngatamariki	2013	4		B	82	82	650	
Rotoma	Rotoma-Tikorangi	?		I					35
Rotoiti	Tikitere	?		I					40
Total			51			1,032	962	7,564	388

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF JULY 2019 (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. (°C) - outlet temp. (°C)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

4) Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

5) Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% of capacity all year.

Note: please report all numbers to three significant figures.

Locality	Type[1]	Maximum Utilization					Capacity[3]	Annual Utilization		
		Flow Rate	Temperature (°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		24	22			0.2	22	6	0.95
Auckland	B, H		50-65	30			2.6	17	57	0.69
Waikato	B, O, H, D, G, I, F						148		3,130	0.67
Bay of Plenty (misc)	B, O, H, D, G, F						65		1,239	0.60
Bay of Plenty (Kawer	I						204	400	5,300	0.82
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	1.00
Canterbury	B		52	24			0.5	4	8	0.50
West Coast	B		55-60	36			0.4	5	6	0.50
TOTAL							421		9,748	0.73

TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF JULY 2019

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. (^{o}C) - outlet temp. (^{o}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. (^{o}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 JULY 2019

1) Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)]x0.004184
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 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

3) Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^6 W)
Note: the capacity factor must be less than or equal to 1.00 and is usually less,
since projects do not operate at 100% capacity all year

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]	62	578	0.30
District Heating [4]			
Air Conditioning (Cooling)	-	-	-
Greenhouse Heating	24	366	0.48
Fish Farming	17	196	0.36
Animal Farming	0	2	0.50
Agricultural Drying[5]	-	-	-
Industrial Process Heat[6]	304	6,220	0.65
Snow Melting	-	-	-
Bathing and Swimming[7]	58	1,375	0.75
Other Uses (irrigation, frost protection, geoth. tourist park)	33	992	0.95
Subtotal	499	9,729	0.62
Geothermal Heat Pumps	>20	390	
TOTAL	519	10,119	

4) Other than heat pumps, includes water heating
5) Includes drying or dehydration of grains, fruits and vegetables
6) Excludes agricultural drying and dehydration
7) Includes balneology

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2015 TO JULY 2019 (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	Monitor	
Exploration[1)]	(all)	0	0	0	0	0
Production	>150° C	12	0	2	0	23.353
	150-100° C	0	20	0	0	1.91
	<100° C	0	21	0	5	6.975
Injection	(all)	7	8	0	0	7.58
Total		19	49	2	5	0

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 Progra
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2014	59.0	128.0	40.5	0.0	0.0	410.5
2019	67.0	130.0	46.0	0.0	0.0	390.0

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2019) US$

Period	Research & Development Incl.	Field Development Including Production	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
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	0	60	0	55	100	0