Regional Energy Transition Accelerator – Bay of Plenty – Geothermal Energy Assessment

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ACRONYM LIST

ATES	Aquifer thermal energy storage
ASHP	Air source heat pump
BOP	Bay of Plenty
BOPRC	Bay of Plenty Regional Council
BTES	Borehole thermal energy storage
CA	Climate Adaptation Act
COP	Coefficient of performance
DHW	Domestic hot water
DSIR	Department of Scientific and Industrial Research
DTES	District Thermal Energy Systems
EECA	Energy Efficiency and Conservation Authority
ETS	Emissions Trading Scheme
GHGs	Greenhouse gas emissions
GHX	Ground heat exchanger
GSHP	Ground source heat pump
IEA	International Energy Agency
MBIE	Ministry of Business Innovation and Employment
NBA	Natural and Built Environment Act
NTGA	Ngāti Tūwharetoa Geothermal Assets
NIFS	North Island Fault System
NST	Norske Skog Tasman
PE	Polyethylene
RETA	Regional Energy Transition Accelerator
RMA	Resource Management Act
RTE	Renewable Thermal Energy
SPA	Spatial Planning Act
TVZ	Taupō Volcanic Zone
UTES	Underground Thermal Energy Storage
VRV	Variable refrigerant volume
VRF	Variable refrigerant flow
WSHP	Water source heat pump
WRC	Waikato Regional Council

UNIT LIST

Barg	Bar gauge
CO_2e	Carbon dioxide equivalent
d	Day
GJ	Gigajoule
km^2	Square kilometre
kW	Kilowatts
kW_{th}	Kilowatts thermal
kWh	Kilowatt-hour
L	Litre
m	Metre
MJ	Megajoule
MVA	Megavolt-amperes
MW	Megawatts
MW_e	Megawatts electric
MW_{th}	Megawatts thermal
NZD	New Zealand Dollar
PJ	Petajoules
s	Second
t	Tonne
°C	Degree Celsius

ABSTRACT

The Regional Energy Transition Accelerator (RETA) project driven by the Energy Efficiency and Conservation Authority (EECA) aims to develop an understanding of what is needed to decarbonise each region in New Zealand. The objective is to develop a well-informed and coordinated approach for regional decarbonisation by understanding unique region-specific opportunities and barriers when developing regional energy transition roadmaps. It is EECA's intention to make available the information required to optimise the choice of sustainable energy options in the transition away from fossil fuels. The scope of this work is a geothermal assessment specific to the broader Bay of Plenty (BOP) region.

The region is known for its natural geothermal phenomena like hot springs, geysers and boiling mud in Rotorua, and for different uses of this resource, such as therapeutic hot bathing pools in Tauranga and Rotorua, and industrial applications in Kawerau. The region encompasses high temperature systems at Rotorua and Kawerau (>150°C), and low temperature systems (<150°C) at Tauranga and Awakeri, and near ambient temperature groundwater resources across the region.

This is the first RETA that includes geothermal energy. As requested by EECA, the Reporoa Geothermal Field, located in the Waikato region, is also included in this assessment.

The report introduces the reader to the key concepts of geothermal energy use for heat supply and various applicable regulatory regimes, including relating to geothermal greenhouse gas emissions and the Climate Change Response Act 2002 and regulations. Analysis of data from these identifies that significant operational greenhouse gas emission reductions (compared with natural gas providing heat for the same duty) can be achieved using geothermal and ground source heat pump (GSHP) technologies.

The report identified the selection of four sites for geothermal assessment from the 54 sites EECA had information on in the BOP. The detailed assessments have been presented to EECA, with summary information on each site presented in this report. The assessments are bespoke solutions for each site. This is a usual characteristic of geothermal solutions because of the near unique combination of the available resource and the application requirements at a given site.

Geothermal solutions are well suited to providing baseload energy because of the capital-intensive nature of the plant and equipment required. Peak loads can be accommodated with these requiring additional capital for the geothermal plant or alternative energy supply plant installed to meet the requirements beyond the baseload. The geothermal assessments identify that GSHP and geothermal technologies have an important part to play in decarbonisation of the BOP region and that GSHP technologies using ambient temperature groundwater also have application widely across New Zealand.

The findings include:

- Geothermal solutions have the potential to achieve operational greenhouse gas emission reductions of between 80% and 100%, excluding grid electricity associated emissions, when compared with natural gas, providing the geothermal solution can meet the heat supply temperature requirements of the application.
- For the four site applications analysed, geothermal solutions achieve significant carbon emission reductions.

- GSHPs with the highest coefficient of performance of the systems analysed result in the lowest operational energy requirements, which, in turn, requires the lowest investment in electricity infrastructure for electricity-based solutions.
- GSHPs can enable full retirement of fossil fuelled stationary heat at the Whakatāne hospital (2.1 MWth heating / 1.2 MWth cooling) and the Whakatāne Growers horticultural site (4.8 MWth). The indicative costs of these GSHP solutions are $6.5 and $5.6 million, respectively.
- The two Whakatāne sites were assessed accessing water at 15°C. If a geothermally enhanced aquifer with water at a temperature of 30°C was accessible, a GSHP solution can provide a 50% reduction in annual energy usage compared with air sourced heat pump solutions and a 30% reduction relative to a 15°C GSHP solution.
- Use of the underlying geothermally enhanced aquifer at 45°C with a high temperature GSHP system generating 900 kg/hr of 120°C steam for a fluidised bed drying application at Dominion Salt, Mount Manganui, could replace gas-fired steam generation for this drying application. The indicative cost of this geothermal solution is $5.6 million.
- The assessment of the GSHP application at Dominion Salt highlights possible opportunities for other industrial facilities at or near the Port of Tauranga to utilise the low temperature geothermal resource augmented with heat pump technology. This could include an interconnected energy network between various energy users, both sharing energy and the geothermal energy supply infrastructure.
- At Fonterra Reporoa, culinary-grade steam production using geothermal energy from a high temperature geothermal system could contribute to a major reduction in carbon emissions, even if not entirely displacing all gas-fired processes.

Finally, there is a summary of the key decarbonisation and economic opportunities that geothermal energy presents for the BOP and New Zealand as a whole, with the following recommendations made:

- EECA include GSHP and/or low temperature geothermal in other RETAs to better appreciate the national opportunity.
- Pursue funding for the exploratory activity necessary to enable the Reporoa Geothermal Field to be further investigated as an energy source for industrial use.
- Commission national guidance on consenting processes and subsurface management for GSHP/low temperature geothermal technologies.
- Adopt a drilling insurance scheme, similar to the French model, in New Zealand to de-risk geothermal applications and accelerate the uptake of geothermal in support of decarbonisation targets.
- Undertake further analysis on the opportunities for co-location or shared investment of geothermal deep wells, heat transportation over extended distances, and GSHP/local shared infrastructure in New Zealand.
- Pairing GSHP and high temperature GSHP with low temperature resource should be included in regional economic/energy strategies for Tauranga.
- Commission high temperature heat pump feasibility assessments in the future, especially with the technological and price competitiveness advancements that are occurring.
- Continue to work with geothermal experts and high temperature geothermal resource landowners to assess feasibility of system development on a case-by-case basis.

KEYWORDS

Geothermal, process heat, decarbonisation, greenhouse gas emissions reduction, Regional Energy Transition Accelerator, Bay of Plenty, Energy Efficiency and Conservation Authority, EECA RETA Bay of Plenty, regional energy transition roadmap, ground heat exchangers, ground source heat pumps, high temperature heat pumps

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1.0 INTRODUCTION

1.1 Regional Energy Transition Accelerator Bay of Plenty

The Energy Efficiency and Conservation Authority (EECA) is running the Regional Energy Transition Accelerator (RETA) programme with the aim of developing well-informed and coordinated decarbonisation roadmaps for each region, informed by unique region-specific opportunities and barriers.

EECA contracted GNS Science to provide an assessment of the potential of geothermal energy to decarbonise medium to large energy users, including process heat end-users in the Bay of Plenty (BOP) region as part of RETA 4.8. GNS Science worked with GeoExchange Australia Pty Ltd (GeoExchange) and Dobbie Engineers (Dobbie) who provided expert input into the assessments of the ground source heat pump (GSHP) technology and high temperature geothermal direct use, respectively.

Material prepared for EECA included:

- A general overview of geothermal energy and heat use in New Zealand.
- A summary of the geothermal resources in the BOP region.
- A screening of the EECA identified BOP RETA sites, identifying four sites for detailed analysis.
- Assessment of the four sites for partial or total conversion to geothermal energy, now or in the future. These specific assessments detail the geothermal technology options, systems to deliver geothermal energy to a site and cost estimates.
- A final report for EECA.

GNS Science presented a summary of the findings to the BOP RETA feedback workshop (Appendix 1) organised by EECA and Bay of Connections on 7 November 2023 at the Rydges Hotel, Rotorua.

To distribute the findings more widely, GNS Science prepared this report for public release, which contains a high-level assessment of each site, but excludes any commercially sensitive information. This report has been completed with support from GNS Science's Strategic Investment Fund for New Zealand's Geothermal Future C05X1702.

1.2 Geothermal Energy Overview

Geothermal energy is a renewable and sustainable source of energy that harnesses heat from the Earth that can contribute to reducing greenhouse gas emissions and dependence on fossil fuels, making it an important energy source in New Zealand's transition to a more sustainable and environmentally friendly future energy mix.

Geothermal energy is already a substantial contributor, providing important baseload electricity for New Zealand, amounting to some 18% of the total electricity supply in 2022. Note that this report focuses on geothermal heat use rather than geothermal electricity generation, which is not covered in any detail.

In New Zealand, the Resource Management Act (RMA) distinguishes between geothermal energy and geothermal water:

- *Geothermal energy* is defined as energy derived or derivable from and produced within the Earth by natural heat phenomena; and includes all geothermal water.
- *Geothermal water* is defined as water heated within the Earth by natural phenomena to a temperature of 30°C or more; and includes all steam, water and water vapour, and every mixture of all or any of them that has been heated by natural phenomena.

The extraction of thermal energy from groundwater that is below 30°C is treated by the RMA as a water take, also requiring a discharge consent, with different policy and rules applicable to water at temperatures greater than 30°C.

In this work we consider geothermal energy as the energy in the ground or in water in the ground. We do not regard temperature as a distinguishing factor in our analysis, as we consider that the feasibility of harnessing geothermal energy is contingent upon technological capabilities. The report discusses ambient temperature (<30°C), and low temperature (30–150°C) through high temperature (>150°C) geothermal energy resources and use.

Geothermal utilisation encompasses a range of technologies, each designed to harness the Earth's heat for different purposes and from varying depths and temperatures from within the crust. The choice of technology depends not only on the characteristics of the geothermal resource itself, with underground conditions varying from location to location, but also on the specific energy needs and situational aspects of the application at the facility. Determining the feasibility of converting an existing facility to geothermal is dependent on the location and the specific factors. Geothermal solutions are bespoke, making it difficult to develop useful ‘rule of thumb’ feasibility guidance for geothermal applications.

1.3 New Zealand’s Geothermal Resource

Geothermal energy is available across a variety of geological settings in New Zealand. Factors influencing the characteristics of a geothermal resource are: (1) the heat output and the thermal gradient at the location, (2) the heat transfer mechanism, i.e. convection or conduction, (3) the subsurface permeability characteristics, and (4) the volume of fluids circulating in the rock.

In this study, the geothermal resources variously considered are conventional high temperature geothermal resources, medium to low temperature resources, and ground and groundwater resources at more or less ambient temperature.

1.3.1 High Temperature Geothermal Systems

High temperature geothermal systems (nominally >150°C) are localised and occur where tectonic, structural and hydrological conditions converge to focus and enhance heat and fluid transfer to the surface. In New Zealand, these generally are derived from magmatic sources principally located in the Taupō Volcanic Zone (TVZ), which spans the Waikato and BOP regions, with another high temperature geothermal system at Ngāwhā in Northland (Figure 1.1).

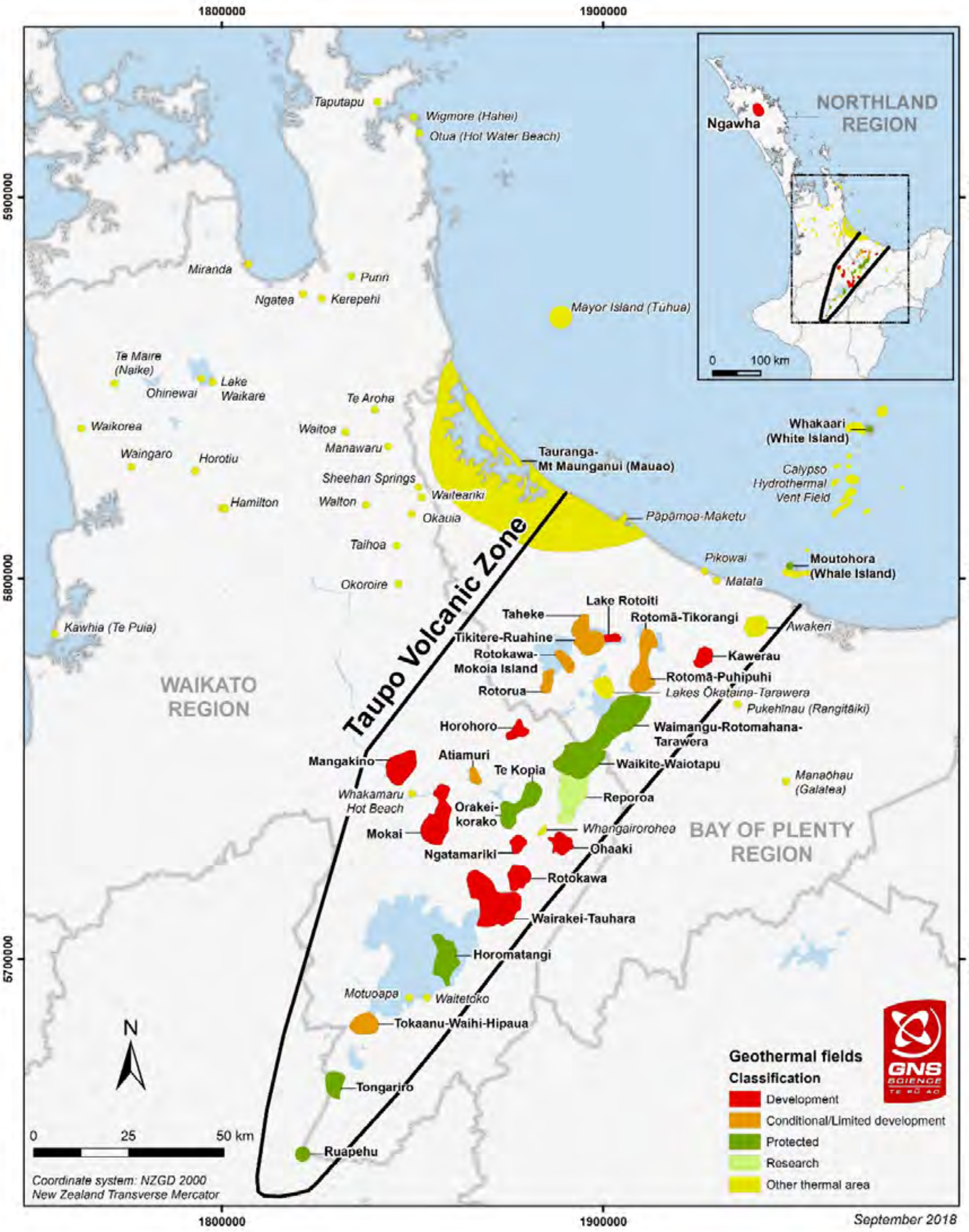

Figure 1.1 Geothermal fields and thermal areas classified by resource management groups – combination of Bay of Plenty Regional Council (BOPRC) and Waikato Regional Council (WRC) classifications. Ngāwhā is shown in the insert.

1.3.2 Thermal Areas and Small Systems

Thermal areas, low temperature resources or small systems are found in the North and South Islands, and are usually related to young volcanism, deep faults or tectonic features. They are represented by the "other thermal area" in Figure 1.1 and the thermal springs in Figure 1.2, which are natural surface expressions of these resources. High temperature springs (>80°C and up to boiling temperature) are concentrated in the TVZ and volcanic areas, lower temperature thermal springs (<80°C) are widespread in the North Island and also along the Alpine Fault in the South Island (Figure 1.2) where plate collision results in rapid uplift of the Southern Alps, with associated elevated thermal gradients (Allis et al. 1979).

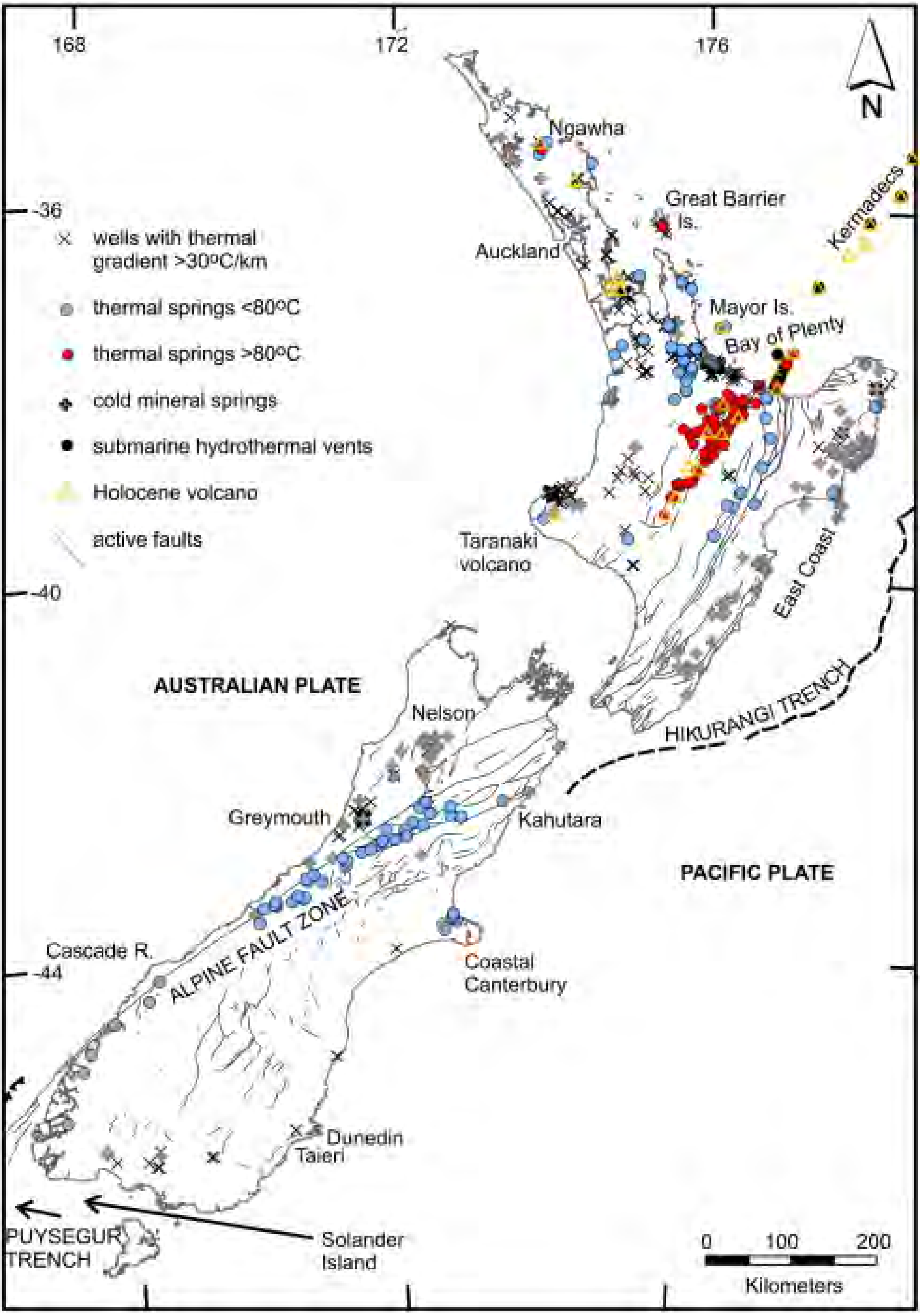

Figure 1.2 Thermal springs in New Zealand (Reyes et al. 2010).

1.3.3 Ground and Groundwater Resources

Natural thermal energy is stored in the Earth's rocks and groundwater systems. The subsurface temperature remains relatively stable year-round compared with the more variable ambient air temperature. Geological and hydrogeological processes influence how this energy is transferred through the subsurface to the ground surface, and at what rates.

Ambient heat flow through the continental crust in New Zealand is around 50–60 mW/m^2, which is consistent with mature continental crust (Allis et al. 1998). Much of New Zealand has higher heat flow than this (Figure 1.3), with the highest heat flow values associated with areas of volcanism, rifting or rapid uplift and erosion (e.g. the TVZ, Ngawha, Taranaki Basin, Murchison, Southern Alps and Dunedin).

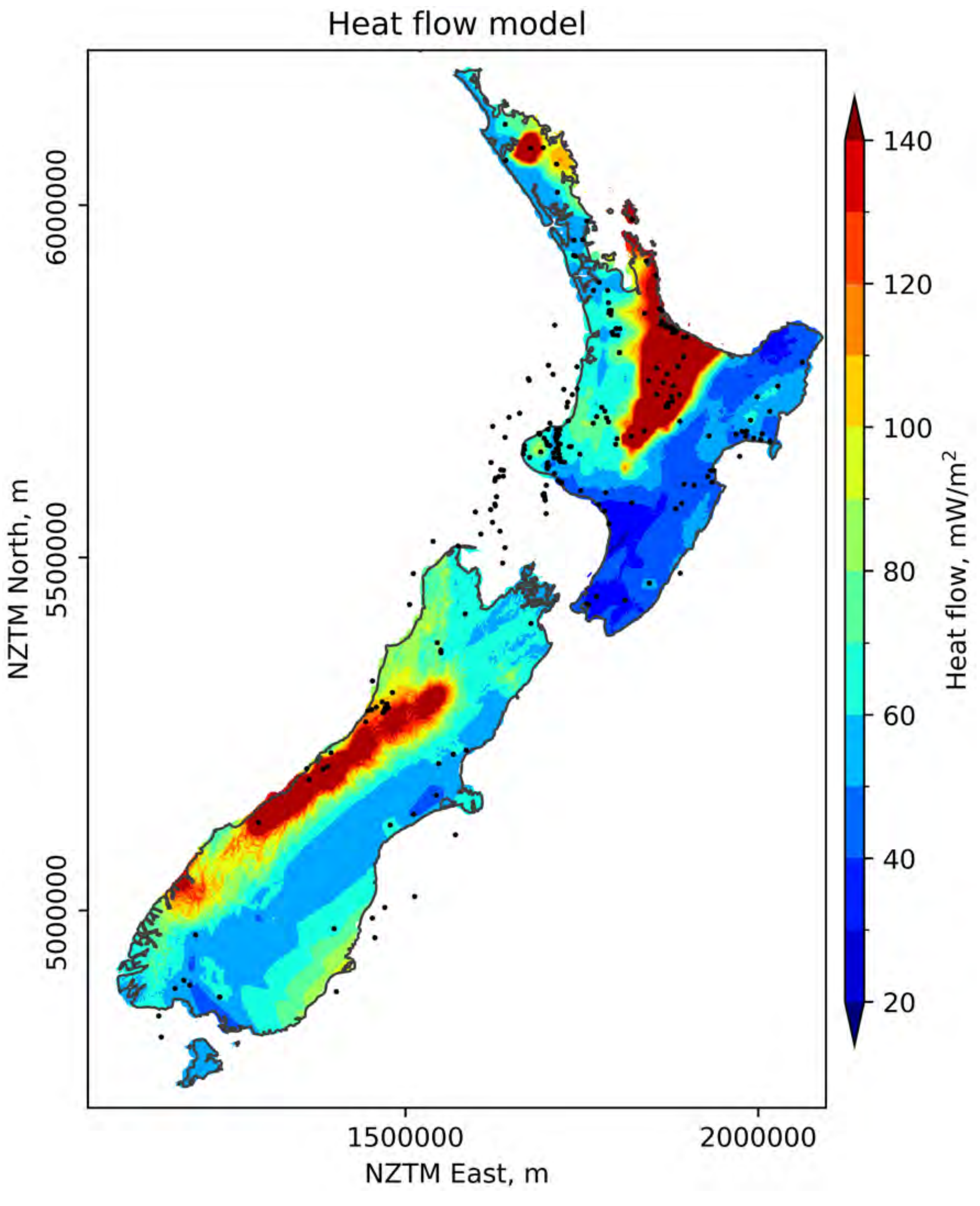

Figure 1.3 Heat flow model map of New Zealand, (Kirkby et al. 2024).

Hydrogeological systems are defined as geographical areas with broadly consistent hydrogeological (groundwater) properties, and similar resource pressure and management issues. Systems with the right mix of hydrogeological properties are appropriate for GSHP technology, which can provide both cooling and heating.

1.4 Geothermal Use and Consenting

Geothermal direct use is a broad term used to refer to the use of the energy for heating and cooling applications. Sometimes, the temperature needs to be enhanced; therefore the following definitions provide a useful distinction of geothermal use technology:

- Direct use – the geothermal energy is at a temperature that is useable in the process or facility enabling the geothermal energy to be supplied directly to the facility through heat exchange technologies.
- Indirect use – the geothermal energy is at a temperature below (or above in the case of cooling) the temperature required by the process or application. Equipment (heat pumps, chillers) is used to raise (or lower) the temperature to supply what is required by the application. To differentiate from air source heat pumps (ASHP) commonly used in homes and commercial facilities, we use the term ground source heat pump (GSHP), where the ground is used as the energy source or sink. The in-ground component of these systems can also be referred to as a geothermal or ground heat exchanger (GHX).

Figure 1.4 is a pictorial of generic geothermal use types, including systems that extract and return underground fluids as part of utilising geothermal energy, and the closed-loop systems that extract and return only heat to the underground.

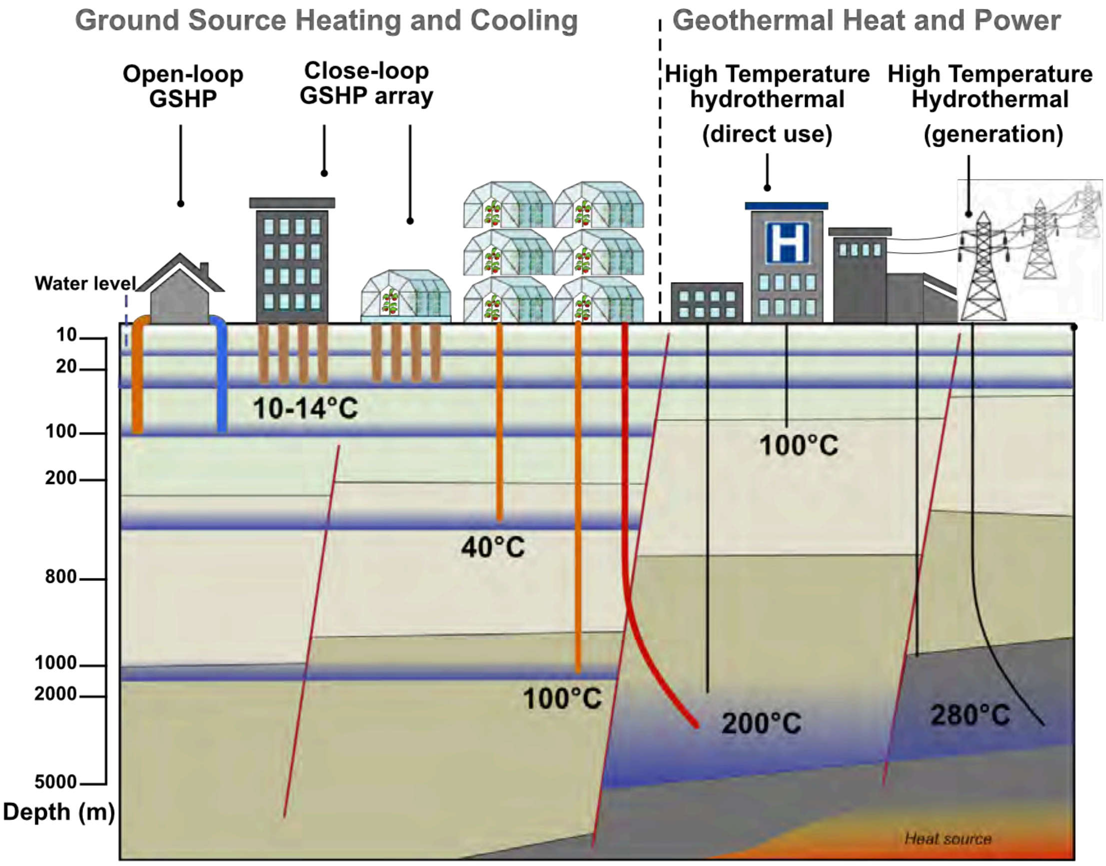

Figure 1.4 Pictorial of generic geothermal use types.

Facility example types and the range of temperatures expected to be required in applications in those facilities are shown in Figure 1.5.

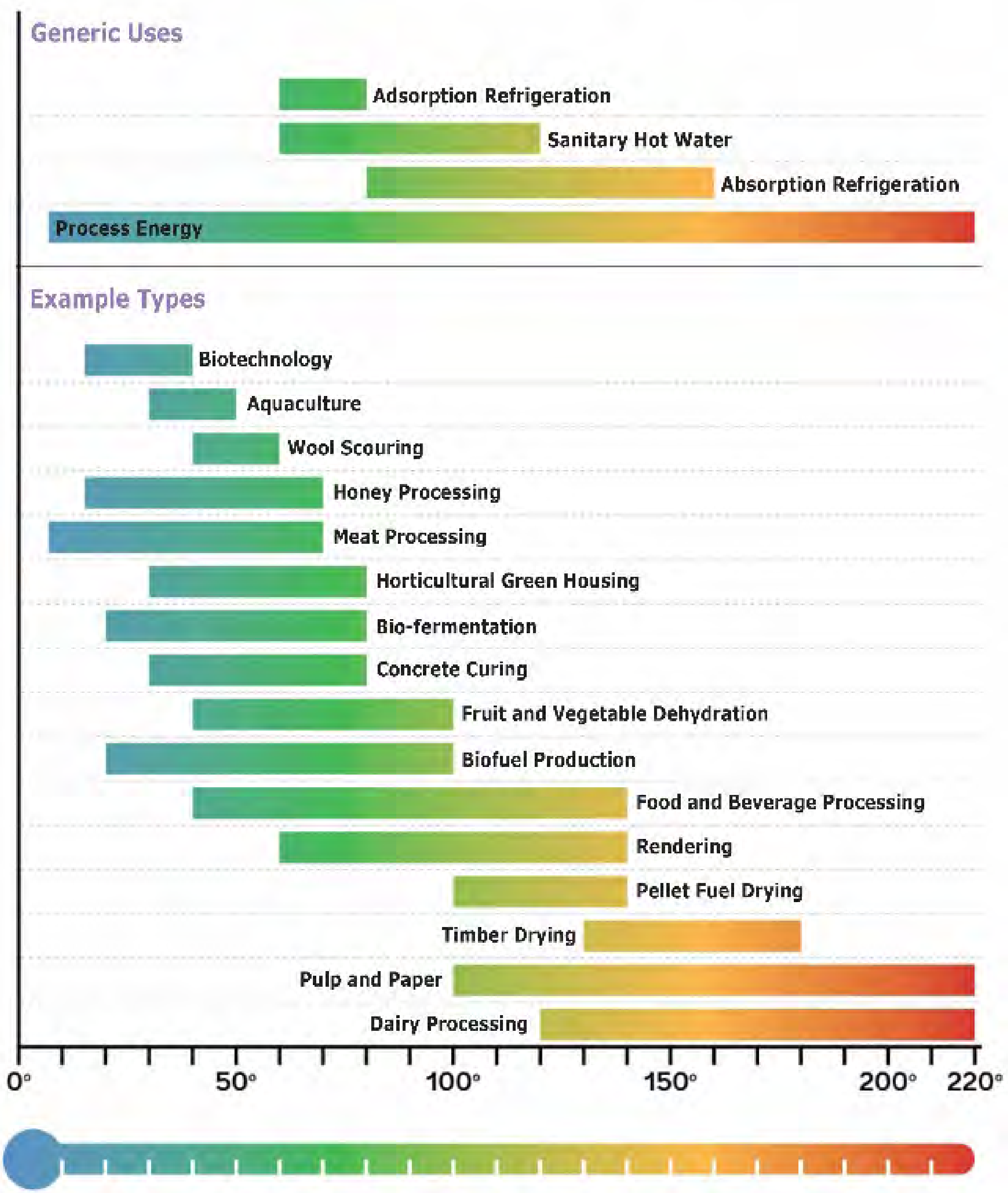

Figure 1.5 Applications of direct geothermal use based on temperature range of energy supply (from Climo et al. 2022).

1.4.1 Current Direct Use in New Zealand

The Ministry of Business Innovation and Employment's (MBIE) *Energy in New Zealand 2023* report estimated that around 7.3 petajoules (PJ) of geothermal energy was used for direct heat in 2022 (MBIE 2023). The uses include drying timber, paper or milk processing, and residential and commercial heating, such as the heated pools in Rotorua. Just under 60% of the 7.3 PJ was used in industrial applications, 33% in commercial and the remainder in residential and agricultural applications. Descriptions of some of the largest industrial applications are included in Sections 2 and 4, with locations variously captured in Figure 1.6.

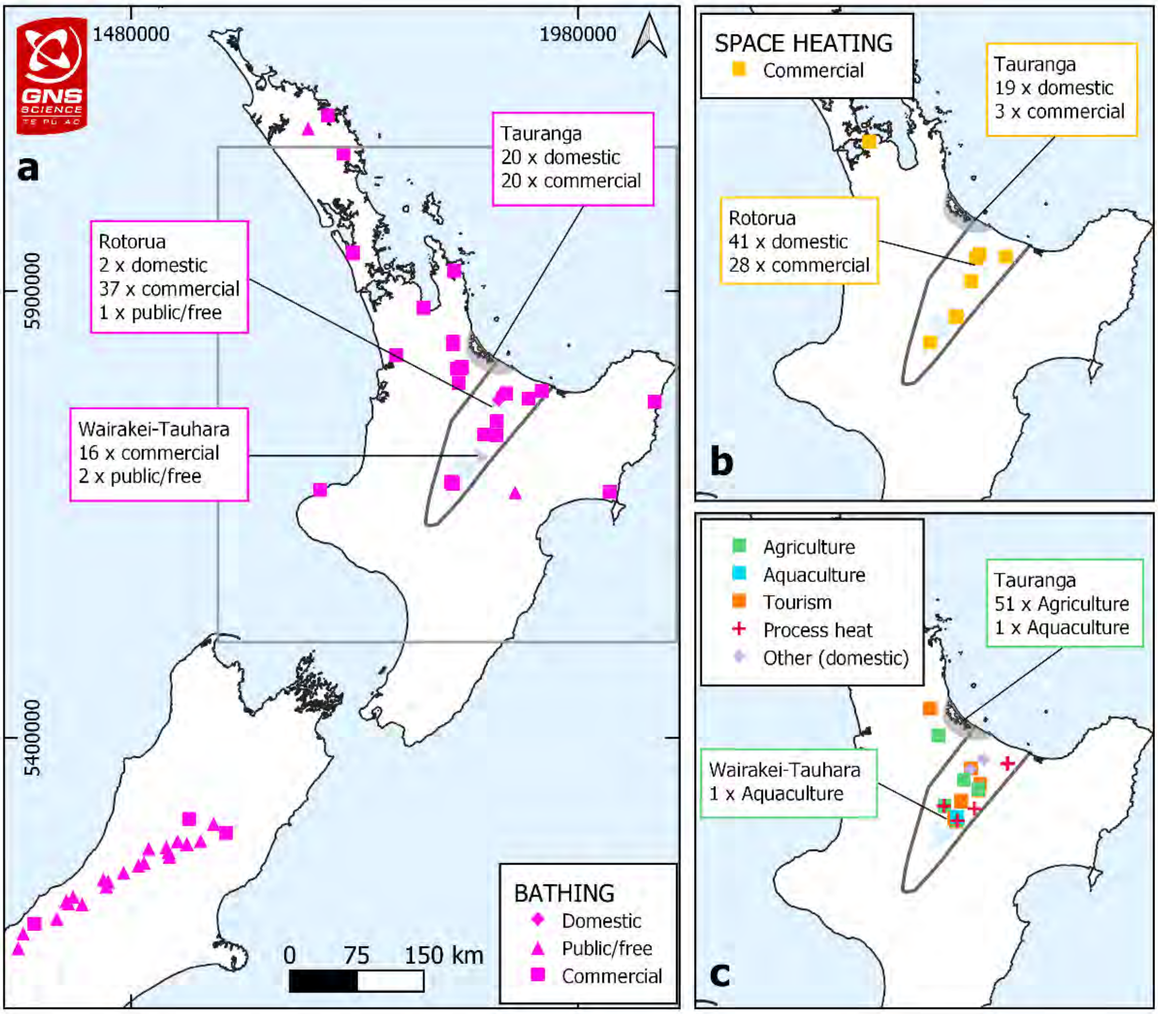

Figure 1.6 Primary uses of geothermal water/heat for (a) bathing, (b) space heating (majority of users for space heating also use for water heating) and (c) other uses, including agriculture, tourism and process heating. Fields with a large number of users are indicated in callout boxes. *'Public/free' includes natural, undeveloped hot springs that may be used for bathing. Figure from Carson and Seward (2023).

1.4.2 Environmental Management and Consents

Regional councils are the governing bodies regulating the management of geothermal energy and its use, with this primarily accomplished through the Resource Management Act (RMA) 1991.

Under the RMA, the taking of geothermal water and energy is prohibited unless:

- Permitted through regional or district plan rules, national environmental standards or granted resource consents; or
- In accordance with tikanga Māori (Māori custom or culture) for the communal benefit of the tangata whenua and does not adversely affect the environment (Kissick et al. 2021).

The main New Zealand geothermal fields have been classified to support their management by the regional councils. The classifications from Waikato Regional Council (WRC) (Table 1.1) and Bay Of Plenty Regional Council (BOPRC) (Table 1.2) are based on a range of aspects, for example: system temperature, existing uses, occurrence of significant geothermal features, their vulnerability, and the level of knowledge/understanding of a system. The classifications dictate the level of development (or lack thereof) permitted in a particular field. The classifications can be changed through processes and procedures that are prescribed in the RMA.

Table 1.1 Geothermal system classification for management by the Waikato Regional Council (WRC), (https://www.waikatoregion.govt.nz/environment/geothermal/classifying-geothermal-systems/).

Category	Characteristics/Development Conditions	Fields
Development systems	Large-scale uses are allowed as long as they are undertaken in a sustainable and environmentally responsible manner.	Horohoro, Mangakino, Mokai, Ngatamariki, Rotokawa, Wairakei-Tauhara.
Limited development systems	Takes that will not damage surface features are allowed.	Atiamuri, Tokaanu-Waihi-Hipaua.
Protected systems	Contain vulnerable geothermal features valued for their cultural and scientific characteristics. Their protected status ensures that their underground geothermal water source cannot be extracted and that the surface features are not damaged by unsuitable land uses.	Horomatangi, Orakeikorako, Te Kopia, Tongariro, Waikite-Waiotapu-Waimangu.
Research systems	Not enough about the system is known to classify it as either Development, Limited Development or Protected. Only small takes and those undertaken for scientific research into the system are allowed.	Reporoa, large systems as yet undiscovered.
Small systems	Isolated springs or sets of springs. These can only sustain small takes and are not suitable for electricity generation.	Warm and hot spring areas in the region.

Table 1.2 Geothermal systems management groups by the Bay of Plenty Regional Council (BOPRC), (https://www.boprc.govt.nz/environment/geothermal/classifying-geothermal-systems).

Management Group	Characteristics/Development Conditions	Fields
Group 1: Protected systems	Numerous significant surface features. Vulnerability to extractive use moderate to high. Surface feature values override extractive values. No potential for extractive use.	Waimangu-Rotomāhana-Tarawera, Whakaari (White Island), Moutohorā Island (Whale Island).
Group 2: Rotorua system	High levels of existing use, both extractive and non-extractive. Numerous Significant Geothermal Features, some with outstanding characteristics where the vulnerability to extractive use is moderate to high. The surface feature values override extractive values. System management that limits extractive uses to avoid, remedy or mitigate adverse effects on the outstanding natural, intrinsic, scenic, cultural, heritage and ecological values. Limited potential for further extractive use.	Rotorua

Management Group	Characteristics/Development Conditions	Fields
Group 3: Conditional development systems	Varying levels of existing use, mainly non-extractive. Some Significant Geothermal Features, where the vulnerability to extractive use is moderate. The values of Significant Geothermal Features have priority over extractive values. System management will provide for use and development, contingent upon the ability to avoid, remedy or mitigate significant adverse effects of development on the Significant Geothermal Features present in these systems. Potential for development of extractive use (heat or fluid).	Rotomā - Tikorangi, Taheke, Tikitere - Ruahine, Rotokawa-Mokoia Island.
Group 4: Development systems	Varying levels of existing extractive use. Few or no Significant Geothermal Features with moderate to low vulnerability to extractive use. System management that provides for extractive use, provided significant adverse effects on Significant Geothermal Features are remedied or mitigated. Potential for development of extractive use (heat or fluid).	Kawerau, Lake Rotoiti (outflow is in the bed of the lake), Rotomā-Puhi Puhi.
Group 5: Low temperature systems	Varying levels of existing extractive use. Few or no Significant Geothermal Features vulnerable to extractive use. System management that provides for extractive use, where the adverse effects of the activity can be avoided remedied or mitigated. Discharge of geothermal fluid must be managed to avoid significant adverse effects on surface water and stormwater.	Tauranga/Mount Maunganui (Mauao), Pāpāmoa/Maketū, Awakeri, Mayor Island (Tūhua), Pukehīnau (Rangitaki), Manaōhau (Galatea).
Group 6: Research systems	This category allows for research into the characteristics of a system in order to enable its reclassification into the appropriate management group. Geothermal takes and discharges are only allowed for investigation purposes and only where it can be demonstrated that there will be no permanent threat to significant geothermal features or to the natural characteristics of the system.	Newly discovered or researched systems that we don't know enough about.

Resource consents for direct use are usually based on a daily volume of water take (in some instances energy take), which is based on the capacity needs of the user, efficiency and potential impacts on the geothermal resource and the surface environment. Consents are also required for the construction of wells, taking or use of geothermal energy, taking or use of heat or energy from material surrounding geothermal water, and discharge of geothermal water (Kissick et al. 2021). For larger-scale commercial or industrial use, the consent process requires thorough assessments and documentation of potential effects, consultation with potentially affected parties and an assessment of the benefits of the utilisation.

Indirect use technologies, such as GSHP, that access groundwater at temperatures below 30°C are covered as a water take within the RMA. There is not a nationally consistent approach to consenting these installations. To date, most of the GSHP-related resource consents over the past decade have been in the Canterbury and Otago regions. As awareness of this technology increases, it may be opportune to standardise processes through the provision of nationally consistent guides and templates, to support councils to appropriately enable GSHP installations.

2.0 GEOTHERMAL PROCESS TECHNOLOGY

2.1 Direct Use

Large geothermal industrial direct-use energy users typically access high temperature geothermal systems. As noted above, New Zealand also has an abundance of lower temperature systems, and these can also be used directly in a range of applications, e.g. drying, fermentation, glasshouse heating (Figure 1.5).

2.1.1 Producing Geothermal Fluid

Wells are drilled into the ground with the deepest wells in New Zealand high temperature geothermal fields being drilled to about 3.5 km.

Geothermal energy production involves the abstraction of fluid from the underground being:

1. Spontaneous well discharge – fluid produced at the surface has both liquid and vapour phases (two-phase; Figure 2.1).
2. Gas supported discharge – fluid produced at the surface is two-phase with gas introduced into the well to decrease the fluid density to the point that the well will discharge (Figure 2.2).
3. Pumped discharge using downhole pumps – fluid produced at the surface is liquid (Figure 2.3).

Spontaneous well discharge is used for geothermal energy production at all the large industrial facilities using geothermal process heat in New Zealand. The gas supported discharge and pumped discharge are used at facilities in New Zealand that have medium/smaller heat load requirements (less than a few megawatts thermal [MWth]). Downhole pumps are used overseas in larger geothermal installations where temperatures are below about 180°C. In New Zealand, pumps are used at smaller facilities, for example the AC Baths in Taupō (Figure 2.3) and the Taupō Hospital.

Additionally, downhole heat exchangers installed inside the well (Figure 2.4) have also been used in some locations in New Zealand where the energy demand requirements are in the 10s of kilowatt range (Figure 2.4).

Figure 2.1 Tauhara wells on discharge. Left: vertical discharge well TH2. Right: well test at Tauhara through a Low-Emission Compact Muffler undertaken in 2022. (Photo courtesy of Western Energy Services Limited).

Figure 2.2 Compressed gas (air at this facility) introduced through hang down tubing to initiate and support the discharge – Plenty Flora, Horohoro (photo courtesy of B. Carey 2014).

Figure 2.3 Downhole pump examples. Left: submersible pump being installed in a well at AC Baths, Taupō. Centre: electric drive motor on a wellhead powering a line-shaft pump at Rittershoffen in France. Right: multistage line-shaft pump and inlet screen in the mast of a drilling rig during pump servicing.

Figure 2.4 Headworks of downhole heat exchanger at the Alpin Motel, Rotorua. The well is 130 m deep with a U-tube loop extracting heat supplying a 40-unit motel and a number of spa pools.

2.1.2 Geothermal Energy Once at the Surface

Once at the surface, the fluids may be separated into liquid and vapour, retained as two-phase or kept as compressed liquid depending on what is delivered at the wellhead and what the heat exchange requirements and arrangements are for the application.

2.1.2.1 Separation of Steam and Liquid

Centrifugal separation is used to separate the vapour from the liquid as illustrated in Figure 2.5. The two-phase mixture is introduced at the side of the vessel. The fluid in the vessel is spinning with the steam moving to the centre of the vessel being extracted at the top through a steam tube. The liquid, being denser, is taken off the side of the vessel at the bottom. The separate phases can then be transported for use.

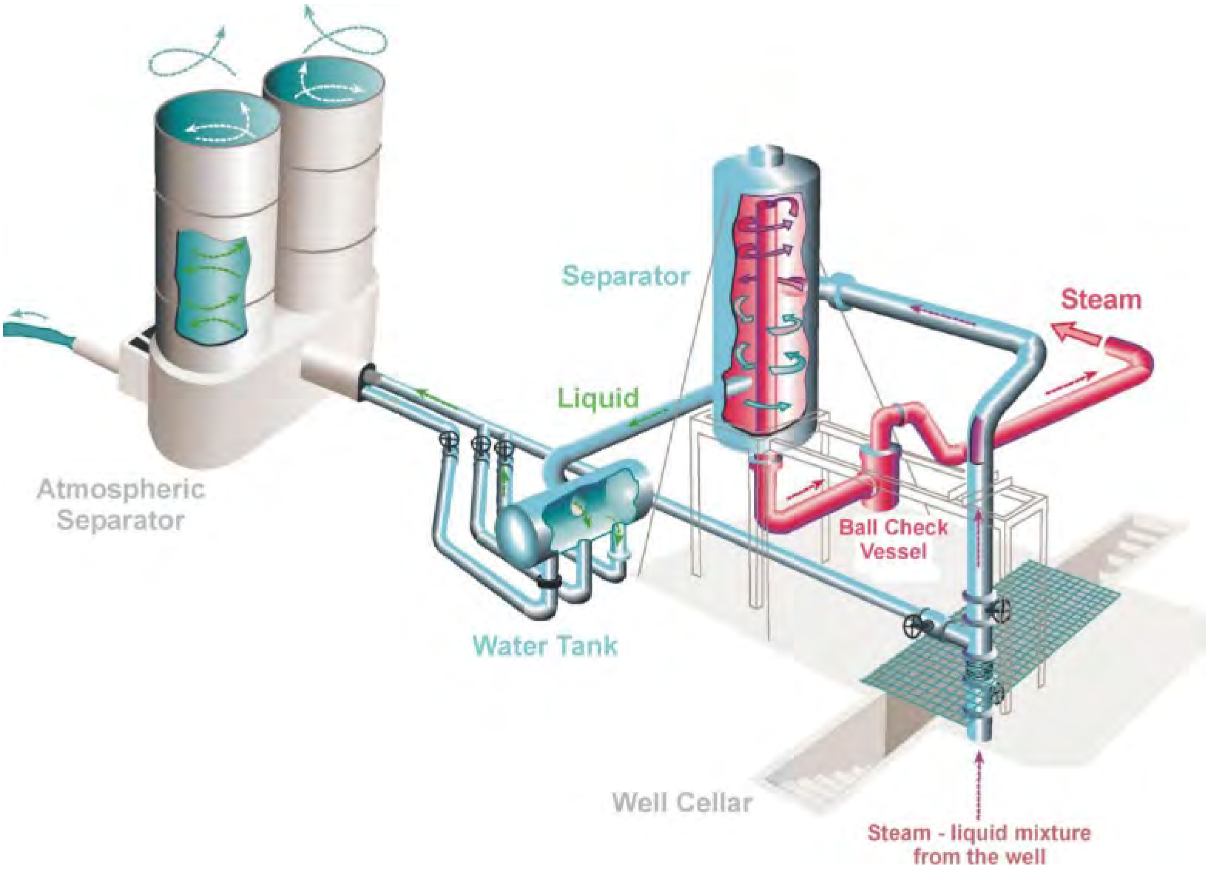

Figure 2.5 Diagram of vertical style separator.

2.1.2.2 Geothermal Steam

An example of a geothermal steam supply is to the Sequal Lumber facility at Kawerau where up to 30 tonnes per hour of geothermal steam at 7 barg is supplied from Ngāti Tūwharetoa's Geothermal Assets (NTGA) steam supply network to two timber drying kilns at the Sequal site (Figure 2.6).

Figure 2.6 Sawn timber and geothermal timber drying kilns in the middle background, Sequal Lumber, Kawerau.

2.1.2.3 Two-Phase Working Fluid

In a two-phase supply, the geothermal fluid is supplied to the process as a mixture. The geothermal mixture releases heat through heat exchange to a secondary loop that delivers the energy to the facility.

An example of this is the 25 MWth supply at Tenon, Taupō, where geothermal fluid supplied at ~195°C is used to provide heat at 180°C and 150°C through pressurised secondary water systems to the nine kilns drying sawn timber (Figure 2.7).

Figure 2.7 Dobbie Engineers designed the two-phase heat exchanger plant (three heat exchangers) supplying the kilns (to the right) at Tenon, Taupō. (Photo Courtesy of Dobbie Engineers).

The Fonterra Reporoa geothermal conversion, assessed by Dobbie Engineers as part of the RETA BOP workstream, is proposed to use two-phase geothermal heat exchangers to supply the primary energy for the generation of steam for application in the dairy factory.

2.1.2.4 Geothermal Water

Ohaaki Thermal Kilns, at Broadlands, use geothermal water from Contact Energy's Ohaaki geothermal steam field plant to provide energy for drying timber in kilns.

2.1.2.5 Generating Process Steam from Geothermal Steam

Technology developed back in 1988 by Norske Skog Tasman (NST) established a process for treating geothermal condensate to produce feedwater stock that, once vaporised, is used as process steam in the pulp mill.

Geothermal steam is typically oxygen free, has ammonia gas as a minor component and, when condensed, has a very low concentration of dissolved salts, so the condensed geothermal steam used as feedstock at Kawerau did not require deoxygenation as would usually be required for a process feedwater source. The low salts meant that scaling was minor and the residual ammonia was of benefit in providing alkaline conditions to the process steam piping network and equipment.

The process arrangement is shown in Figure 2.8. For the NST process, geothermal steam at 7 barg feeds the vapouriser, producing process steam at 3.5 barg. The condensed geothermal steam feeds the process water preheater with the geothermal fluid being cooled further and then processed to feedwater. In processing, the fluid is fed into a flash tank (FT) and then on into a packed stripping vessel (S), which requires a small supply of degassed process steam introduced to complete the degassing to produce the feedwater.

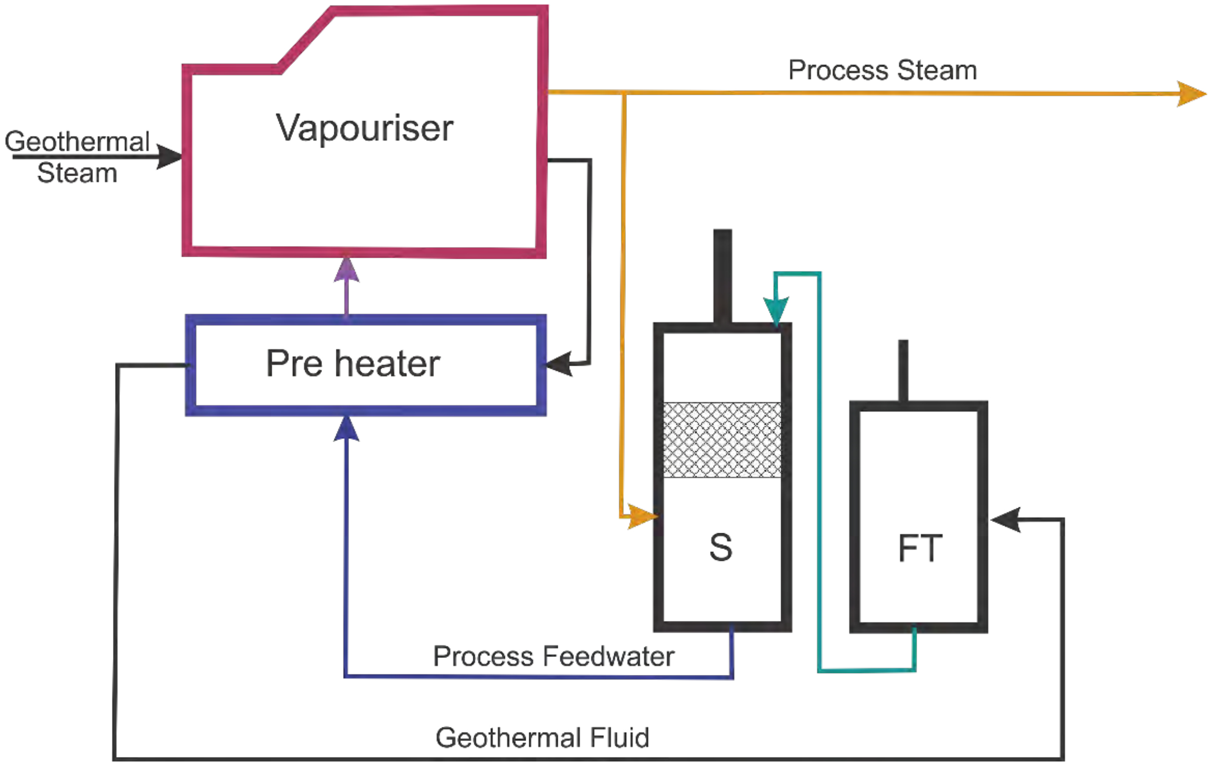

Figure 2.8 Schematic of process steam raising from geothermal steam.

The reboiler technology (Figure 2.9) was adopted by NTGA for supply of reboiled geothermal steam to Svenska Cellulosa AB (SCA, now Essity) in 2010. Geothermal steam at 22 barg generates 16 barg process steam for tissue manufacture in their Kawerau facility.

Figure 2.9 Ngāti Tūwharetoa's Geothermal Assets (NTGA) reboiler, Kawerau. Left: oblique view looking down on the reboiler. Right: reboiler tube bundle.(Photos courtesy of Dobbie Engineers.)

The Miraka Dairy factory adopted the same technology in 2011, using geothermal steam supplied from the Mokai Geothermal Field to produce process steam for milk powder drying. The Miraka heat plant is designed to deliver up to 30 t/hour of 20 barg process steam.

2.1.3 Indicative – Cost Comparison by Fuel Type

Delivered energy costs for different fuel types were assessed in Climo et al. (2022) and have been updated as part of the BOP RETA using more recent data, including some EECA supplied data (Table 2.1). The assessment is for heat energy production for process use and not for the conversion of energy to electricity. The geothermal data in Table 2.1 is for an industrial geothermal steam supply from Kawerau, or Tauhara, where there is geothermal fluid supply infrastructure in place and the geothermal resource conditions are known.

The base fuel price is in the second column (Table 2.1 [from left to right]), the third column is the emissions factors from the Climate Change (Stationary Energy and Industrial Processes) Regulations 2009 and for electricity the 2022 data is from the Ministry for the Environment. The carbon cost is calculated in the fourth column using a unit price of $70 per tonne. The conversion efficiency of the base fuel into delivered heat energy is identified in the fifth column. For the conversion of electricity to process heat, there are two rows in the table, one uses heat pump technology with a coefficient of performance (COP) of 3.5 (second row), capable of producing heat at temperatures generally up to about 80°C. With advances in heat pump technology, the delivery temperature from heat pumps is extended up to ~150°C (at a lower COP). The seventh row is for electrical resistance heating for which temperatures over 1500°C can be attained.

The delivered energy cost is tabulated in the sixth column. For electricity the carbon costs have been calculated but are not added to the delivered energy cost as they are already included in the base cost of the electricity. The data has been sorted on least to greatest total delivered energy cost to a process application (sixth column).

Table 2.1 Indicative industrial process heat costs by fuel type as of December 2023 at a carbon price of $70 per tonne.

Fuel Type	**$/GJ**	**Emissions Factor t CO_2e/GJ**	**Carbon Costs**[1]	**Conversion Factor**[2]	**Total Cost $/GJ Delivered**
Geothermal – Steam	8[3]	0.0073[4]	$0.51	0.83[5]	$10.25
Electricity – Heat Pump COP 3.5	43.34[6]	0.0206[7]	$1.44[8]	3.5[9]	$12.38
Biomass	13[10]	0	$0.00	0.8[9]	$16.25
Gas	11.57[6]	0.0557[11]	$3.90	0.85[9]	$18.20
Coal	9[10]	0.0944[12]	$6.61	0.78[9]	$20.01
Wood Pellets	18[10]	0	$0.00	0.9	$20.00
Electricity – Resistance	43.34[6]	0.0206[7]	$1.44[8]	0.99[9]	$43.78

(1) Carbon units generally at ~$70/tonne through the period September to November 2023. https://www.carbonnews.co.nz/story.asp?storyID=29419 (Accessed 20 December 2023).
(2) Factor applicable for delivery of useable heat energy and not for conversion to electricity.
(3) Nominal Kawerau geothermal steam price.
(4) Kawerau Industrial emissions factor from Climate Change (Stationary Energy and Industrial Processes) Regulations 2009 (SR 2009/285) Version 1 Jan 2023. Geothermal p74 Table 6 Part A – 0.0202 times 1000/2780 to convert to t/GJ.
(5) Using Geothermal steam – computed from geothermal steam (2780 j/g) condensed to 100°C liquid (461 j/g)
(6) MBIE data for 2023 for industrial electricity and for 2022 for gas from energy price data from https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/energy-prices/
(7) Data for 2022 – Ministry for the Environment. 2023a. Measuring emissions: A guide for organisations: 2023 detailed guide. Wellington: Ministry for the Environment, ISBN: 978-1-991077-52-3 Publication number: ME 1764. Table 9 Section 5.2.
(8) Carbon cost associated with electricity is included in the purchase price for electricity. User does not pay this as an additional charge under the Emissions Trading Scheme.
(9) Net calorific values to useable heat provided by EECA – December 2023.
(10) Indicative values provided by EECA – December 2023.
(11) Emissions factor for natural gas (National average) from the Climate Change (Stationary Energy and Industrial Processes) Regulations 2009 (SR 2009/285) Version 1 Jan 2023. p76 Table 10.
(12) Emissions factor for lignite (all other) from the Climate Change (Stationary Energy and Industrial Processes) Regulations 2009 (SR 2009/285) Version 1 Jan 2023. p73 Table 2.

Geothermal as a process energy source is well positioned in terms of its cost per GJ and this is set to further improve as the carbon charges under the Emissions Trading Scheme (ETS) increase into the future. The Climate Change Commission's demonstration pathway has a cost of carbon of $250 per tonne in 2050.

2.2 Indirect Use

In many locations, the temperatures of the ground or groundwater are near ambient, being ~2°C above the average annual ambient air temperature at a given location. These ambient temperatures and somewhat enhanced conditions with temperatures as high as 40°C can be considered for indirect use. Usually, as the temperatures of these sources are not sufficiently hot to heat directly, or sufficiently cold to cool directly, a heat pump is used to meet the temperature requirements of the application.

Similar to an ASHP, a geothermal or ground source heat pump uses the refrigeration cycle to modify the output temperatures. The difference is in the source of the thermal energy, from the air or the ground/groundwater.

GSHPs extract thermal energy from the ground or groundwater and elevate the temperature of the heat to that required in the application. These use ambient ground or groundwater as the source of energy; therefore there is potential for wide geographical application across New Zealand. Thermally enhanced ground conditions (within the range of ~18–40°C) can increase the operating efficiency of the GSHP in heating mode with the downside of reducing the efficiency in cooling mode.

Application temperature requirements met by GSHPs are traditionally less than 80°C. Typically, a GSHP has a COP of ~4–6, whereas a standard ASHP's average COP is of the order of 2–3. As ground or groundwater temperatures are constant year-round, GSHP performance is not susceptible to seasonal variance to the same extent as an ASHP, accounting for the more favourable COP.

2.2.1 Heat Pumps

Heat pumps are the central component of a Renewable Thermal Energy (RTE) system (Figure 2.10) and are its controlling element. Heat pumps can be air, water or ground sourced and deliver thermal energy into the building or industrial site through either water or air. Refrigerant is often used as an intermediary to air delivery in common variable refrigerant volume (VRV) or variable refrigerant flow (VRF) systems.

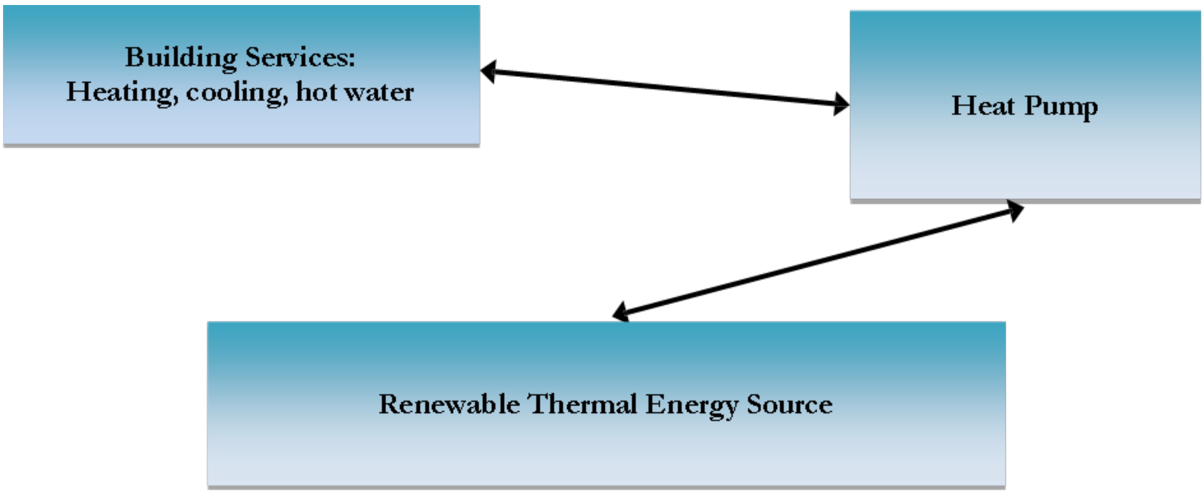

Figure 2.10 Renewable Thermal Energy system. Image courtesy of GeoExchange.

Basic nomenclature follows the format of, for example, air to water heat pump for an ASHP that delivers hot water for hydronic heating, domestic hot water or pool heating.

A ground source (or geothermal) heat pump (GSHP) is an extended range water source heat pump (WSHP) that has been designed to operate over a wider range of source temperatures that are typically present within a closed loop ground heat exchanger (GHX) or where open loop systems have colder or hotter source temperatures.

A brief description of the three main types of GSHP are as follows:

1. A **water-to-air heat pump** is a packaged unit that would be connected directly to the GHX and delivers hot/cool air through designed ductwork (mostly in the ceiling) to indoor zones. Depending on the manufacturer, those units generally have limited supply capacities for domestic hot water (DHW).

2. **Water-to-water heat pumps** connect directly to the GHX and then deliver hot/chilled water to various internal terminals for heating or cooling (buffer or storage tanks are generally required). Water-to-water heat pumps are able to supply all DHW requirements using a separate storage tank, as well as pool/spa heating if required. The inclusion of thermal storage in the form of buffer tanks provides enhanced efficiencies and the potential for generating thermal storage during periods of low electricity costs (e.g. off peak or solar PV). However, this does require additional plant room space.
3. **Water sourced VRF** utilises a refrigerant as a heat transfer medium between a single water sourced condensing unit and either single or multiple indoor units. They are a GHX connected version of the variable refrigerant flow/variable refrigerant volume (VRF/VRV) style systems that are common in conventional systems. The main difference is that the heat pump or condensing unit is located within a plant room rather than externally or in a ventilated space.

2.2.2 Open Groundwater Systems – Aquifer Water

Water is taken from a groundwater source as the energy input or source for a heat pump system.

Open groundwater loops (Figure 2.11) require the presence of a reliable, high-volume and high-quality groundwater source. The three main requirements associated with open groundwater loops are *water quantity*, *water quality* and *water disposal*. Water quantity is important in ensuring the sustainability of the aquifer and the proper ongoing functioning of the system. Water quality is important with respect to the ongoing operational and maintenance costs of the equipment. Water disposal is important as all water extracted from the ground must be disposed of appropriately, which is typically through reinjection back into the aquifer.

Figure 2.11 Open loop groundwater system supply and return well shown. Diagram courtesy of GeoExchange.

There has been a significant uptake in the use of this technology in Christchurch as part of the rebuild after the 2010/2011 earthquakes. Figure 2.12 is a 2021 plan that GNS Science prepared from data it had on the Christchurch installations at that time.

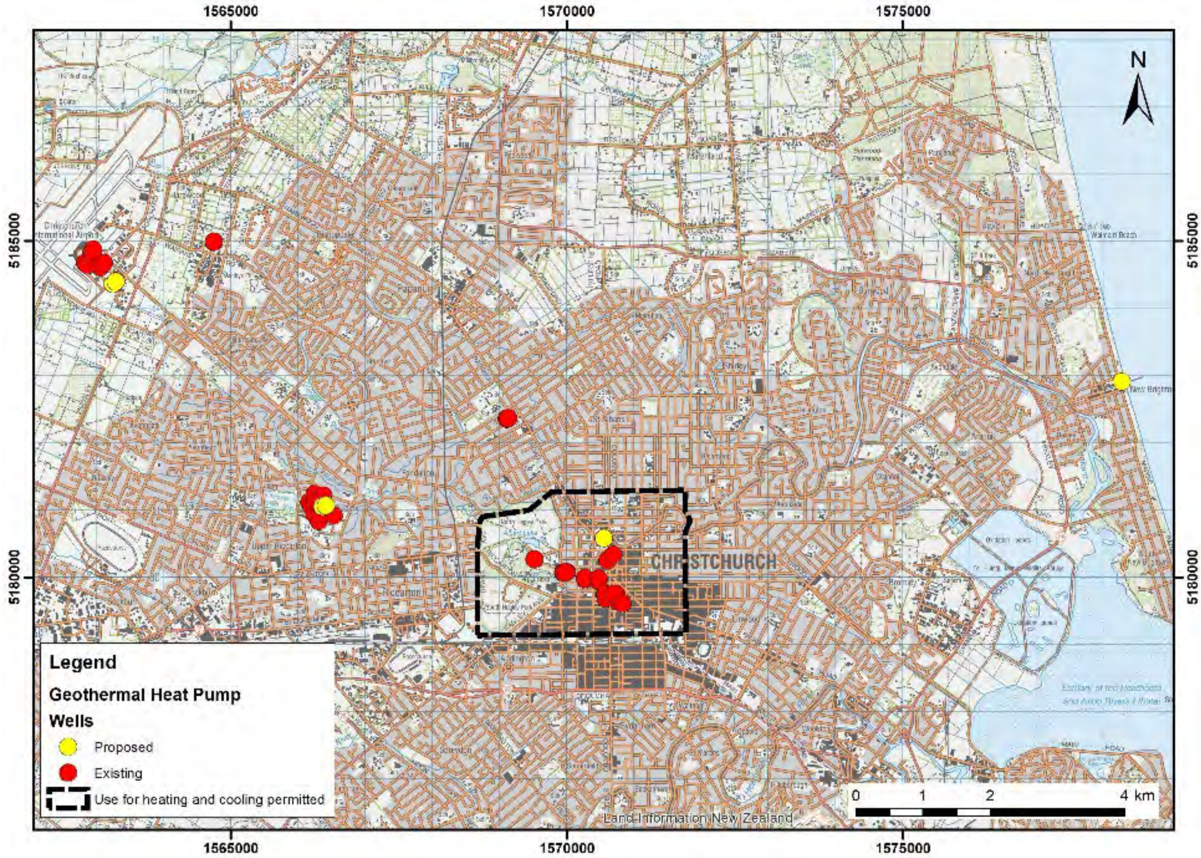

Figure 2.12 2021 geothermal heat pump systems by location in the Christchurch city area.

An example of a retrofit is at the Christchurch Arts Centre where two aquifer water wells supply a heat pump system that has 2.4 MW of heat pump capacity installed. This facility is heat load dominant with only a modest requirement for cooling due to the nature of the buildings and Christchurch's climate. The water temperature in the aquifer is about ~13°C.

A poster on the facility is included in Appendix 2.

A paper by Seward and Carey (2021) discusses four facilities in Christchurch that have adopted open groundwater aquifer systems.

Figure 2.13 shows wells at two Christchurch facilities. The Canterbury Regional Council facility uses a down well electric submersible pump (pump hanging from the crane in the left photo of Figure 2.13) to bring the water to the surface and to keep the system pressurised throughout the entire energy transfer process. The photo on the right is a wellhead at King Edward Barracks, where the wells at this facility are flowing artesian.

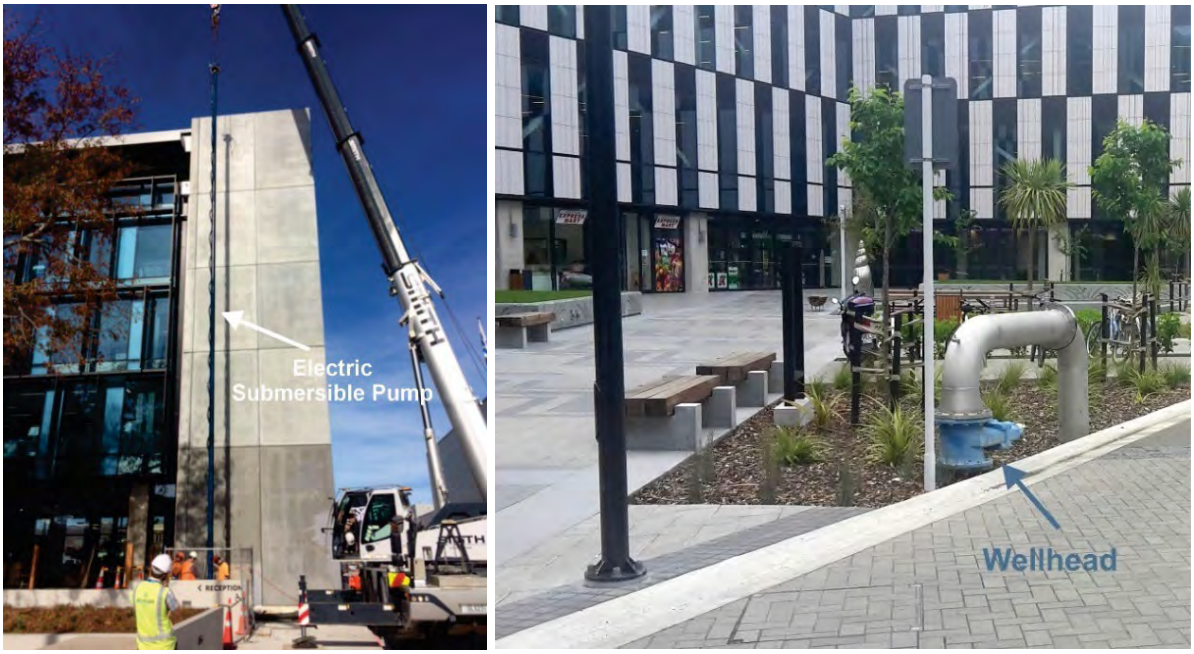

Figure 2.13 Open groundwater system examples in Christchurch. Left: electric submersible downhole pump from Canterbury Regional Council groundwater energy system (hanging from crane). Right: artesian well at King Edward Barracks Christchurch (wellhead valve is the blue valve in the garden).

2.2.3 Ground Based Energy Fields/Ground Heat Exchangers

2.2.3.1 Ground Using a Closed Horizontal GHX

Closed loop horizontal GHXs (Figure 2.14) are common where the relationship between building load and land area is small. For example, a rural residential system is more suitable to a closed horizontal GHX than an inner-city commercial system. A typical soil depth of 2 m is required and they operate more effectively when the soil has a high clay and high moisture content. They should not be located underneath a sealed surface as this prevents appropriate heat exchange in cooling mode.

Figure 2.14 Closed loop horizontal ground heat exchanger (GHX). Image courtesy of GeoExchange.

Photos of different types of horizontal ground heat exchanger installations are shown in Figure 2.15.

Figure 2.15 Horizontal closed loop ground heat exchanger (GHX) – Left: plain tubing in arrangement. Right: slinky tubing arrangement. Both pictures were taken before backfilling.

2.2.3.2 Vertical Probes – Closed Vertical GHX

Closed vertical GHXs (Figure 2.16) are the most common type of GHX due to their suitability to a diverse range of sites and comparatively minimal land area requirements. They are installed by drilling to an average depth of ~100 m, although depths can range from 50–200 m. The installed heat exchanger tubing is typically polyethylene (PE). Vertical GHXs can be installed in most soil/rock types and can be located either underneath or beside a building. Due to the requirement to drill, these are typically the highest cost GHX option.

Figure 2.16 Closed vertical ground heat exchanger (GHX) – Image Courtesy of GeoExchange.

Various arrangements can be used to connect the individual wells as shown in Figure 2.17 (left).

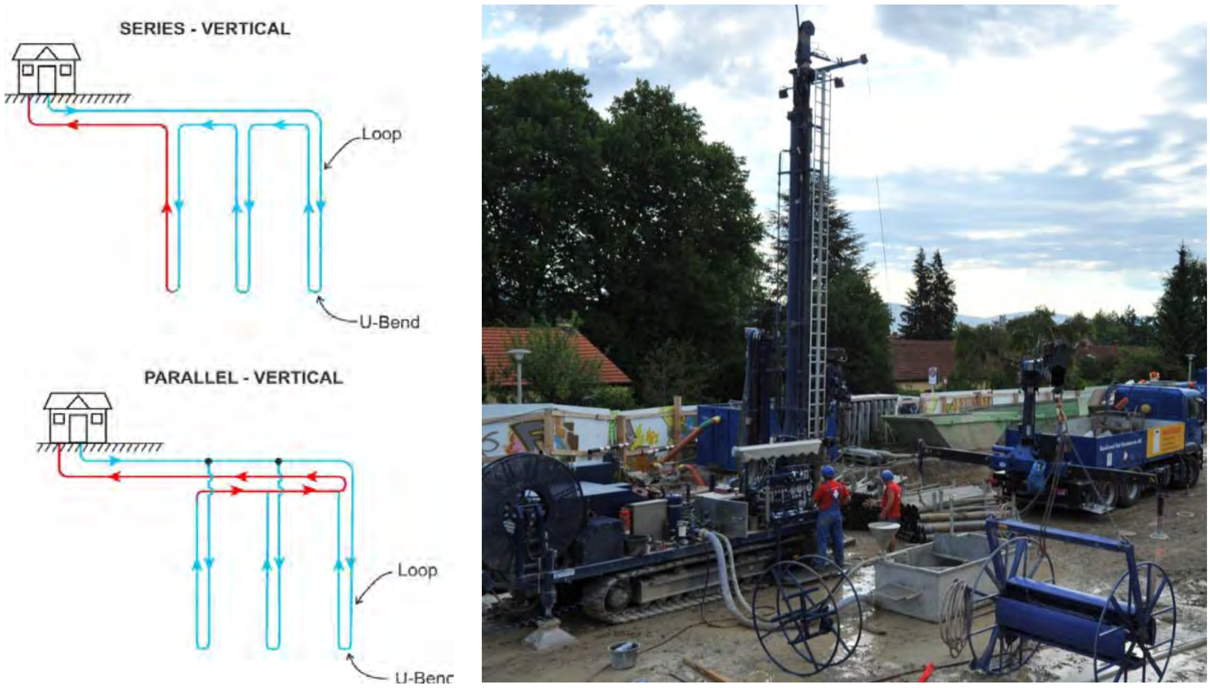

Figure 2.17 Vertical ground heat exchanger (GHX). Left: U-tube series and parallel arrangements. Right: drilling a probe field in Switzerland – 430 probes, each about 220 m deep.

An example of a vertical GHX arrangement is found at the Château Pontet-Canet Winery, which has probe fields used to extract and take heat and cool. An International Energy Agency (IEA) Geothermal case study has been included in Appendix 3.

In New Zealand, vertical probes are currently not common. There is a known installation in a residential house in Queenstown (case study presented in Appendix 4).

2.2.3.3 Energy Piles

Energy piles can perform two functions in supporting the building structurally and providing a GHX for the facility. The only example known in New Zealand is the Lower Hutt Civic Centre (Figure 2.18), which was retrofitted as part of an earthquake strengthening upgrade. Pile cages are fitted with U-looped tubes which transport the heat from the subsurface to the surface, or vice versa if the system is working in cooling mode, refer Figure 2.18 right side. There were 72 piles installed at the Civic Centre as part of the upgrade.

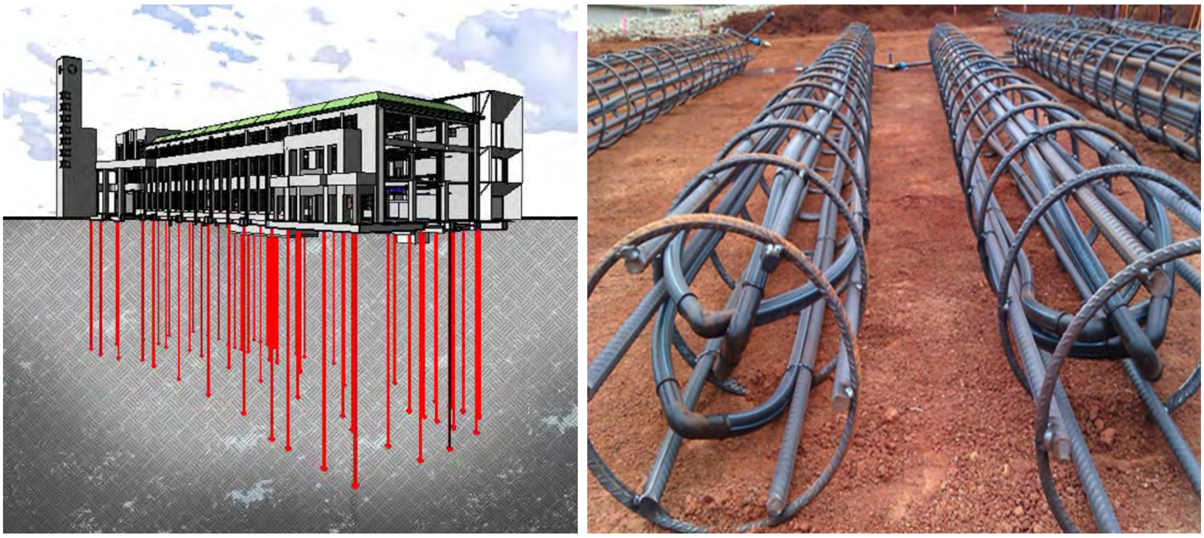

Figure 2.18 Energy piles. Left: schematic of energy piles under the Lower Hutt Civic Centre. Right: 10-m-long pile cages ready for installation at the Civic Centre.

2.2.4 Surface Water Using a Closed Loop

A closed water loop (Figure 2.19) is an option when a suitable water body is located nearby. The minimum requirements for a suitable water body are a minimum water depth of 2 m and sufficient water volume to accommodate the load to be applied. Open or flowing water bodies, such as harbours (e.g. Sydney Opera House case) and estuaries, provide a greater capacity than a closed water body, such as a farm dam or lake. It is possible to use water fountains/sprinklers to increase the capacity of a water body as they increase the heat rejection process.

Figure 2.19 Closed water loop using polyethylene (PE) coils. Image courtesy of GeoExchange.

2.2.5 Hybrid Systems

Hybrid systems use a combination of energy sources at a given site. The adoption of a hybrid system can provide efficiencies and optimisations associated with the spatial or temporal availability of the different RTE sources across the heating and cooling cycles. For example, utilising ground temperatures during extreme weather periods and ambient air on milder days.

With a closed loop GHX, hybrid systems can provide a more thermally balanced GHX, which enhances its performance on a per unit basis while also minimising cumulative impacts of an unbalanced thermal load over time.

2.3 District Thermal Energy Systems (DTES)

A DTES is a heating, cooling and hot water system that is applied over multiple buildings at scales ranging from a school campus to business parks and subdivisions (Figure 2.20). District systems can use either individual thermal sources for each building/lot or a common thermal source that is shared across multiple buildings/lots.

If a per building thermal source is utilised, then the heat pumps will be located within each building. If the thermal source is centralised, then the heat pumps can either be centralised or distributed on a per building basis.

DTES are typically installed and managed as project infrastructure in the same way as other utilities, such as water, sewerage and electricity. Ongoing management of the system is of paramount importance, with a selection of project delivery models that can be adopted ranging from individual ownership to the formation of utility style companies that provide ongoing management and service. Benefits include coordinated environmental management of subsurface resources and shared investment in capital infrastructure, which can lead to the clustering of complementary businesses, e.g. a cooling dominant facility adjacent to a heating dominant facility.

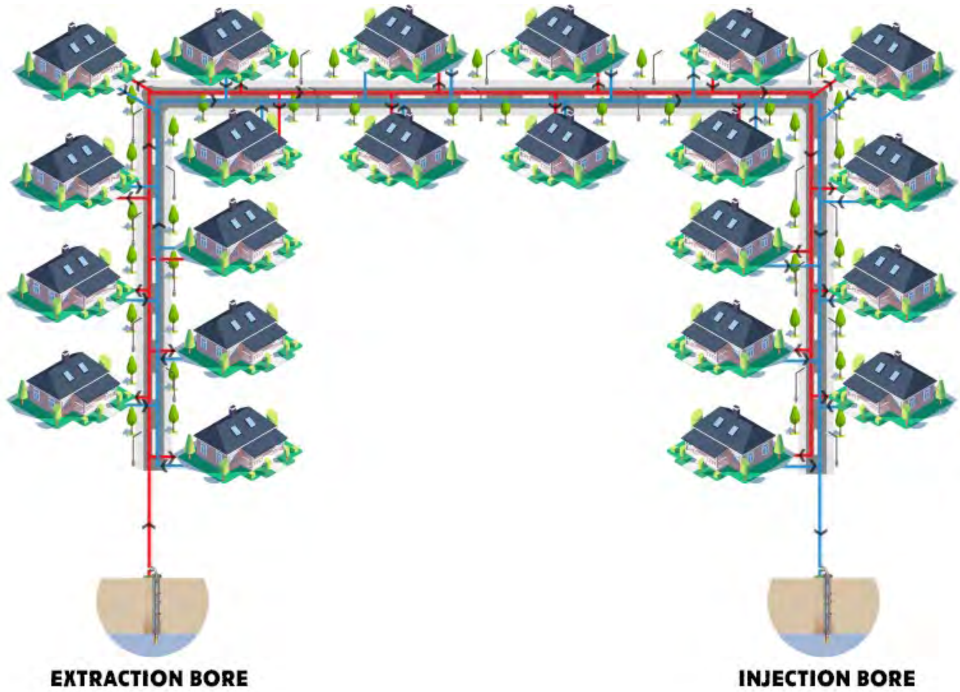

Figure 2.20 Schematic showing district thermal energy system using central energy plant. Image courtesy of GeoExchange.

2.3.1 Diversity, Thermal Sharing and Thermal Storage

In comparison with the conventional approach of an individual heating and cooling system per building, the primary benefits of a DTES are thermal sharing and thermal storage. Thermal storage may not be an element of all DTES but is with most, which include a GHX. Benefits include the potential for smaller thermal sources (i.e. smaller GHX), a more efficient system, reduced primary energy, reduced peak demands (thermal and electrical) and the opportunity for smarter integration with renewable electrical energy.

The original district heating systems are now referred to as early generation DTES. These were typically centralised higher temperature systems that delivered direct heat to buildings. Fifth generation DTES is the term now applied to systems that utilise an 'ambient' loop with various buildings both injecting and extracting heat to the loop and into the GHX at various times.

The concept of diversity is commonly applied across the air conditioning industry to commercial premises and is similar to the zoning concept within a home. That is, as the system is being shared across multiple users, the capacity of the GHX system can be reduced in size as it is unlikely that all users will require the full capacity of the system at any given time. Higher diversity factors are provided to cooling than to heating due to the temporal nature of occupancy during these peaks.

The concept of thermal sharing is one of the strengths of a well-designed DTES. It applies when mixed heating and cooling loads occur either concurrently or over the course of a given period, such as a day, season or year. Concurrent load sharing occurs when different zones and different heating and cooling requirements enable the heat rejected from one area of the system that is in cooling mode to be immediately transferred to an area requiring heating. Higher system efficiencies are common in such instances, as the requirement for both a heating and a cooling system has been replaced by a single load-sharing system.

The most common application and simplest example of load sharing is where the heat rejected from building air conditioning is transferred into a local hot water service or swimming pool.

Thermal sharing with a temporal delay is the basis of underground thermal energy storage (UTES) systems. Sharing can occur over time periods ranging from hourly to seasonally. At the hourly scale, this could be where heat rejected into the ground through the day is used to heat the building overnight. Seasonally, heat rejected into the ground in summer is used to warm the building in winter. Seasonal thermal systems are being developed in a number of locations and in a number of nations in Europe. Examples are, the Heerlen District Energy Scheme case study in the Netherlands, which uses flooded disused coal mine shafts for energy storage, the Château Pontet-Canet Winery case study (Appendix 3) at Pauillac in Bordeaux, France, which uses borehole thermal energy storage (BTES), the borehole thermal energy storage at the ETH Zurich campus at Hönggerberg in Switzerland, and the aquifer thermal energy storage (ATES) system at the Eindhoven University of Technology at Eindhoven in the Netherlands. These technologies are attractive in decreasing the primary energy demand requirements of a facility through the use of thermal energy sharing and storage, and assist in substantially decarbonising building space conditioning.

3.0 GEOTHERMAL ENERGY AND EMISSIONS

3.1 When to Apply an Emissions Factor

There are differences between shallow and deeper geothermal utilisation with the technology used influencing the emissions. High temperature geothermal systems are typically in the liquid state deeper in the underground and on discharge to the surface usually produce a mixture of steam and liquid at the wellhead. Gases are dissolved in the liquid in the geothermal reservoirs and on travelling up to the surface, boiling occurs, causing some partitioning of gases, such as carbon dioxide and methane, into the steam phase. Any facility that has a steam component that is then condensed as part of process energy use will produce gases that need to be processed and reinjected back underground or released to the atmosphere. If released to the atmosphere, the gases are considered contributing to anthropogenic greenhouse gas emissions (GHGs).

Geothermal steam emission factors are low in comparison with fossil fuels (Table 3.1), however, the presence of some gas in the fluids is why geothermal direct use solutions are generically labelled as ‘low carbon’ energy, while some uses in fact will have no associated carbon emissions. Although some geothermal operations emit CO_2 into the atmosphere, the sector is actively working on solutions to curtail these emissions. Currently, there are trials in a number of New Zealand geothermal power stations reinjecting greenhouse gases. The Ngāwhā Generation facilities are reinjecting all of the GHGs produced as part of their operations.

If, in the handling of the geothermal fluid, there is no separation process that produces separate steam and liquid fluid streams, then the fluid state is two-phase. There are separate emissions factors for geothermal two-phase flow under the ETS regulations (Table 6 Part B Climate Change [Stationary Energy and Industrial Processes] Regulations 2009).

If the underground temperatures are below ~180°C so that downhole pumps can be used, keeping the geothermal fluid in a liquid state from the underground through to the wellhead, and the fluid is retained in a liquid state as part of any subsequent process transferring heat to the facility, then there will be no release of steam or GHGs. With no emissions, such geothermal use will not be subject to the ETS.

The nature and type of the facility using geothermal fluids will determine whether any released gases are included in New Zealand’s GHG Inventory. An industrial facility will have accounted emissions whereas a smaller commercial operation, accommodation or residential application will likely not have any emissions accounted.

As emissions from geothermal fields release naturally into the atmosphere, there is discussion in the literature as to the handling of gas releases from geothermal systems. For example, research by O'Sullivan et al. (2021) indicates that over the lifetime of a geothermal system it matters little how the gases are released, irrespective of whether this occurs entirely naturally or as part of a geothermal production operation. There are differences in the timing of the gas releases, but ultimately the modelling suggests that no extra CO_2 is emitted. This raises the question as to whether greenhouse gases released from geothermal systems should in fact be accounted for. However, in this work for EECA the most conservative position is taken that gas, if released from geothermal fluids produced anthropogenically, is to be included and assessed.

The next two sections discuss geothermal emissions under the ETS and New Zealand's GHG Inventory.

3.1.1 Emissions Trading Scheme

The position of the New Zealand ETS/the Climate Change Response Act 2002, and associated regulations, is that emissions from geothermal sources come under the ETS for a **participant's** facility if it is producing **electricity or industrial heat** – Section 54 (1)(a).

Under the Climate Change Response Act 2002, the definition of **industrial or trade premises** means any premises used for any industrial or trade purposes, or any premises used for the storage, transfer, treatment or disposal of waste materials or for other waste-management purposes; but does not include any production land. In this regard, there are facilities from the EECA site matrix that will have greenhouse emissions **accounted** for under the ETS and there will be facilities, such as schools, accommodation facilities, swimming pools and rest homes, which don't. Greenhouses aren't industrial premises; they may be classified as trade premises, however, it is noted that the 12 hectare Mokai geothermally heated greenhouse has a default emissions factor of zero as per Table 6 of the Climate Change (Stationary Energy and Industrial Processes) Regulations 2009.

Geothermal water used to supply energy (provided it is kept in the liquid state) is not included under the ETS as there are no emissions associated with its use.

Appendix 5 contains pertinent aspects of the Act and Regulations, including default emissions factors for steam and two-phase fluids. Appendix 6 contains excerpts from the Climate Change (Unique Emissions Factors) Regulations 2009 (SR 2009/286) in regard to obtaining a Unique Emissions Factor for a geothermal operation, should the operator choose to obtain one if that is more advantageous than using the default factor. The unique factors, once approved, are gazetted in the New Zealand Gazette.

Table 3.1 below provides a comparison of fuel types using various factors, including ETS statutory factors from Tables 2, 6 and 10 from the Climate Change (Stationary Energy and Industrial Processes) Regulations 2009, and the calculated reduction in emissions achieved by using geothermal and GSHP technologies relative to natural gas for the same heat duty application.

Table 3.1 CO_2e emissions factors and computed reduction potential for geothermal (as of 2023).

Fuel Type	t CO_2e/t	GJ/t	t CO_2e/GJ	% Emissions Reduction Per GJ Compared With Natural Gas(7)
Coal (sub-bituminous)	-	-	0.09043(1)	-
Natural gas (national average)	-	-	0.05573(2)	-
Any geothermal steam (default)	0.03(3)	2.78	0.01079	81%
Kawerau – steam	0.0202(3)	2.78	0.00727	87%
Kawerau – NTGA 2020 UEF	0.0106	2.78	0.00381	93%
Rotorua – two-phase	0.0009(4)	0.66	0.00136	98%
Reporoa – two-phase	0.0009(4)	1.15	0.00078	99%
Tauhara – two-phase	0.0009(4)	1.2	0.00075	99%
Mokai – two-phase	0.0009(4)	1.6	0.00056	99%
Mokai Greenhouse – two-phase	0(4)	1.6	0	100%
Any geothermal water	0	0.42(5)	0	100%
Water for GSHP	0	0.06(6)	0	100%

(1) Emissions factor for sub-bituminous coal from the Climate Change (Stationary Energy and Industrial Processes) Regulations 2009 (SR 2009/285) p73 Table 2.

(2) Emissions factor for natural gas (national average) from the Climate Change (Stationary Energy and Industrial Processes) Regulations 2009 (SR 2009/285) p75 Table 10.

(3) Emissions factors from Climate Change (Stationary Energy and Industrial Processes) Regulations 2009 Geothermal p74 Table 6 Part A.

(4) Emissions factors from Climate Change (Stationary Energy and Industrial Processes) Regulations 2009 Geothermal p74 Table 6 Part B.

(5) Liquid water enthalpy at 100°C.

(6) Liquid water enthalpy at about 15°C.

(7) Potential operational emissions reductions achievable using geothermal and GSHP technologies when compared with natural gas, providing the geothermal solution can meet the application temperature requirements.

3.1.2 New Zealand's Greenhouse Gas Inventory

Under the Climate Change Response (Zero Carbon) Amendment Act 2019, the legislation refers in section 5Q (1)(a) to **net accounting emissions** as follows:

> *The target for emissions reduction (the 2050 target) requires that —*
>
> ***net accounting emissions*** *of greenhouse gases in a calendar year, other than biogenic methane, are zero by the calendar year beginning on 1 January 2050 and for each subsequent calendar year; and…*

The definition of net accounting emissions is as follows from p5 of the Net Zero 2019 Act:

> ***net accounting*** *emissions means the total of gross emissions and emissions from land use, land-use change, and forestry (**as reported in the New Zealand Greenhouse Gas Inventory**), less…*

The following is an extract from p101 of the New Zealand Greenhouse Gas Inventory (Ministry for the Environment 2023b), which identifies the span of geothermal covered:

> *Geothermal sites whose geothermal steam is not used for energy production have been excluded from the inventory. Operations falling outside the scope of the regulations are not included in the inventory due to a lack of data, methodology and emission factors. Besides this, such sites – rather than using high temperature geothermal steam – use low-temperature hot water, which does not carry high levels of dissolved gases, and any emissions are considered insignificant. Naturally occurring sites do not contribute any anthropogenic emissions.*

3.2 Summary Position – Geothermal Greenhouse Gas Emissions

The question of **accounted** emissions versus emissions not accounted for under the ETS or the New Zealand Greenhouse Gas Inventory has been considered and, in the context of the BOP RETA project work, which is analysing both industrial heat and heat supplied to other facilities, GNS Science have sought to identify emissions more generally than only **accounted** emissions.

4.0 GEOTHERMAL ASSESSMENT

4.1 Regional Energy Transition Accelerator BOP Sites

The sites identified by EECA as candidates for the geothermal assessment are plotted relative to the known geothermal systems in the region (Figure 4.1). The sections that follow provide an overview of the geothermal characteristics at each of the areas where sites were identified:

- Kawerau – High temperature geothermal system.
- Rotorua – High temperature geothermal system.
- Tauranga – Low temperature geothermal system.
- Awakeri – Low temperature geothermal system.
- Whakatāne – Ambient groundwater aquifer(s).
- Opotiki – Ambient groundwater aquifer.
- Reporoa – High temperature geothermal system.

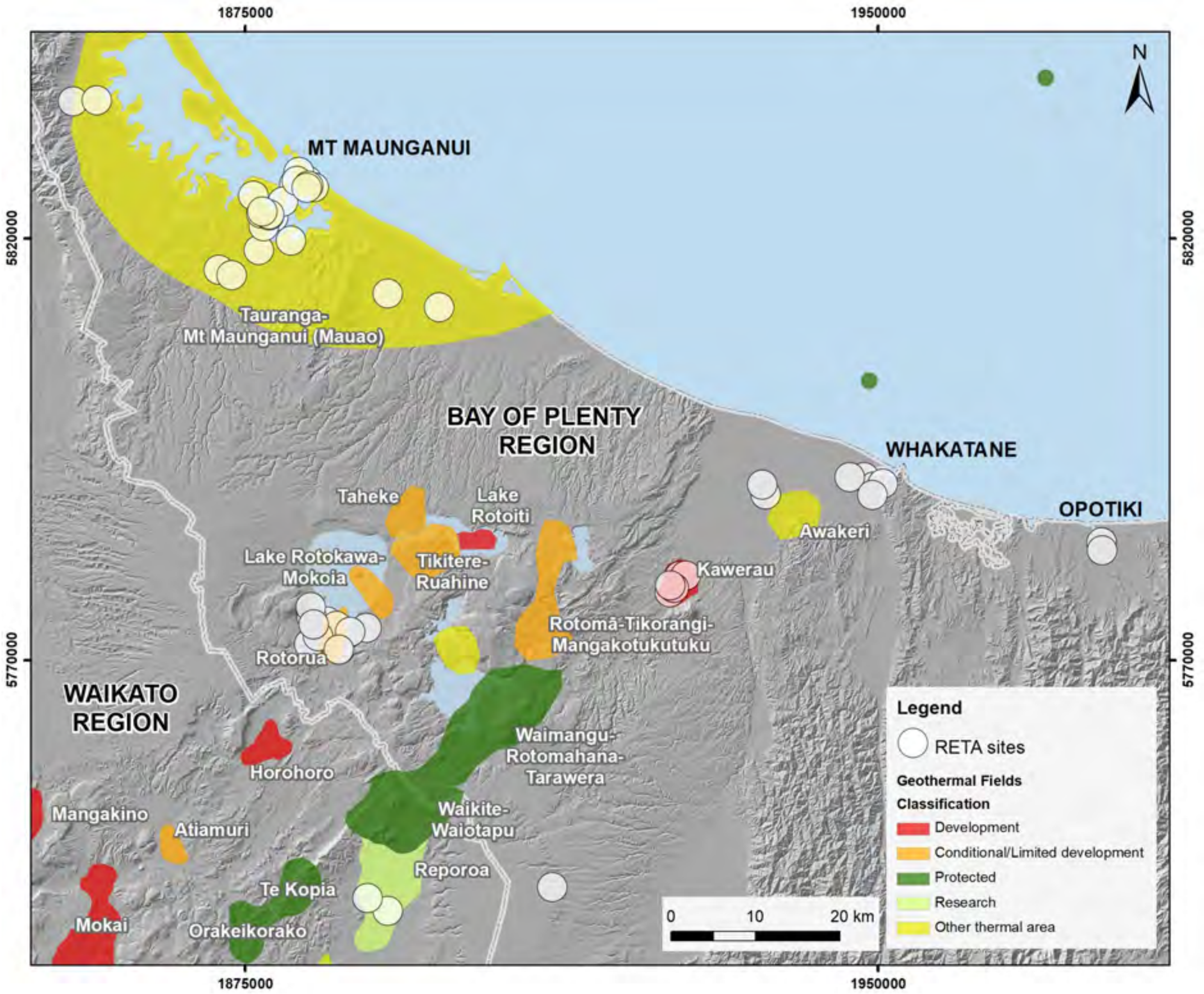

Figure 4.1 Location of the Energy Efficiency and Conservation Authority Regional Energy Transition Accelerator Bay of Plenty sites, relative to known geothermal systems.

4.2 Kawerau Geothermal Field

The Kawerau Geothermal Field is located ~15 km inland from the BOP coastline, immediately east of Kawerau township. It is the most north-easterly of the major high temperature geothermal systems located in the TVZ (Figure 1.1). At the surface, the Tarawera River runs through the centre of the field, with its flood deposits having formed much of the near-surface geology. The Kawerau surface manifestations are mostly concentrated in a 2 km^2 area. The geophysical resistivity surveys reveal a more extensive geothermal reservoir at depth (Allis 1997) as shown in Figure 4.2.

More than 75 wells have now been drilled in the field for various purposes, although no more than 20 have been in production at any one time, with many of the older wells now used as monitor wells. Production from older wells is mostly from around 1 km depth, while a number of the more recent wells produce from deeper into the greywacke basement.

Downhole temperatures recorded in the field range from 250–310°C. A large and productive geothermal resource is present at Kawerau with a number of companies drawing on the resource for both process heat use and electricity production. The four major consent holders include Mercury NZ Limited, Ngāti Tūwharetoa Geothermal Assets Limited (NTGA), Geothermal Developments Ltd (Eastland Generation) and Te Ahi O Māui Partnership.

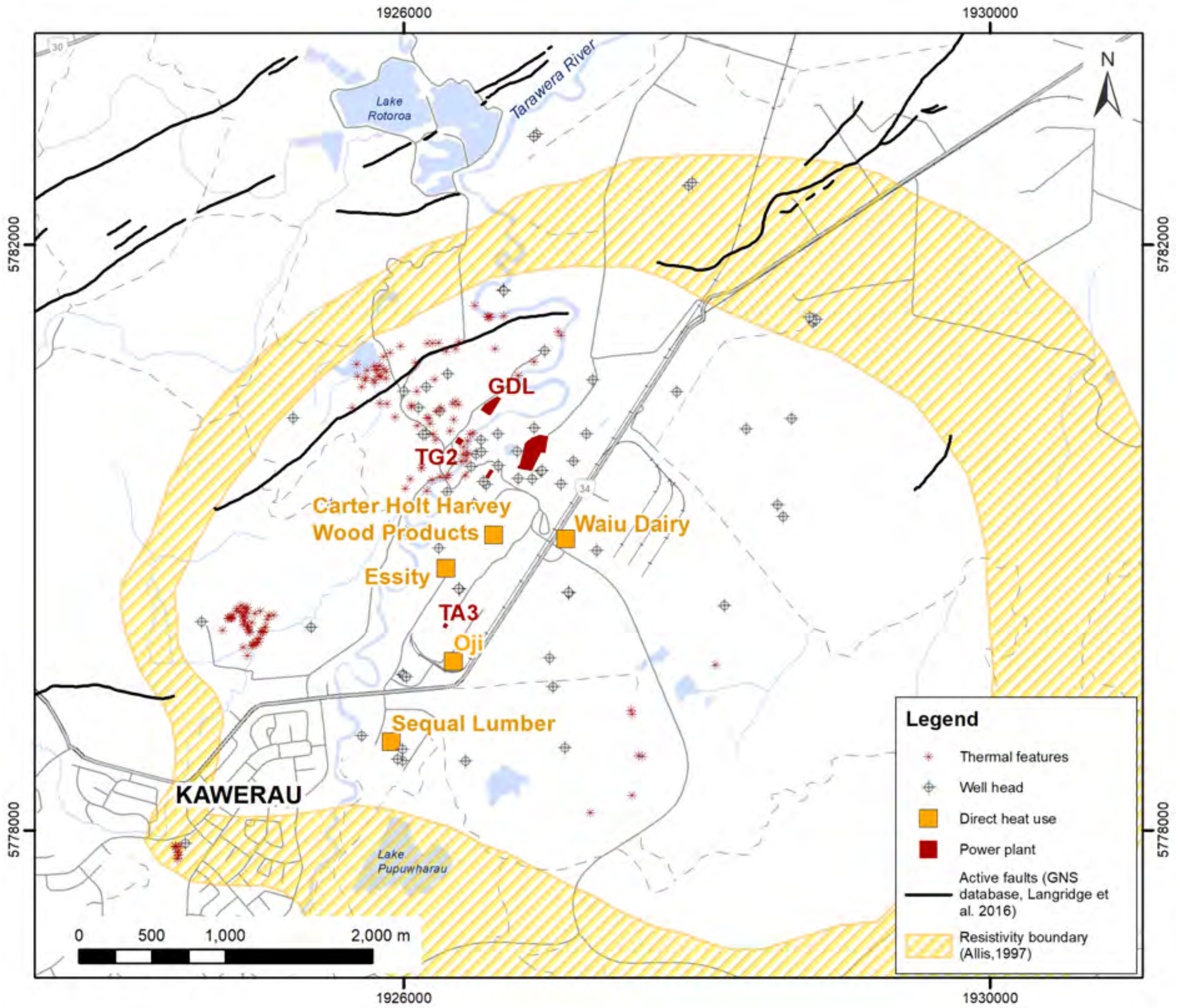

Figure 4.2 Kawerau Geothermal Field layout.

4.2.1 Kawerau Industrial Energy Supply

Geothermal energy was initially supplied to the Tasman Pulp and Paper Mill in 1957 as process heat. With time, other businesses have developed as part of the broader Kawerau industrial estate and have embraced process energy sourced from the geothermal resource. The businesses now include Oji Fibre Solutions, Carter Holt Harvey, Sequal Lumber, Essity, Norske Skog Tasman and the Waiū Dairy Factory (Figure 4.2).

The geothermal field currently supplies about 5 PJ per annum of energy through contracts between NTGA and the businesses taking the energy. The energy to the businesses is primarily supplied as steam under longer-term supply contracts. The geothermal system operates at three steam pressures, namely 7, 10 and 22 bar. The 7 and 10 bar geothermal steam is supplied to meet user requirements, whilst the 22 bar supply is used as the primary energy and fluid source for a reboiler operated by NTGA. The reboiler generates process grade steam (often referred to as clean steam) at 16 bar, which is supplied to Essity, Waiū and Oji Fibre Solutions.

The use of geothermal energy supporting the Kawerau industrial estate has significantly contributed to the decarbonisation of energy from this site. From 1957–2023, some 100 million tonnes of geothermal steam has been produced from the Kawerau Geothermal Field that has been used directly to supply the industrial estate. Calculating the CO_2e emitted using the Kawerau default factor of 0.0202 t CO_2e/t steam (Climate Change [Stationary Energy and Industrial] Regulations 2009) gives ~2 million tonnes of CO_2e emitted from the 100 million tonnes of steam. The energy in the steam equates to some 278,000 TJ. If this energy was supplied by natural gas the associated CO_2e emissions would have been some 15 million tonnes. The CO_2e emissions reduction from Kawerau industries through using geothermal energy over the period 1957–2023 equates to some 13 million tonnes CO_2e if natural gas was the fuel replaced.

Individual businesses have adopted different approaches, and two sites that are in the BOP RETA site list at Kawerau are discussed in more detail immediately below.

Essity, and its predecessors SCA and Asaleo Care, have been using process steam produced from geothermal steam since 2010, when NTGA installed a reboiler (Moore 2011) to supply saturated process steam at 16 bar gauge for the tissue manufacturing process. This geothermal generated process steam replaced steam generated by a natural gas fired boiler. By shifting to geothermal, Essity reduced its annual CO_2e emissions in 2010 by 17,000 tonnes (Moore 2011), which represented about 40% of its annual emissions at the time. In 2022, Essity announced it was further reducing its CO_2e emissions by redesigning the natural gas fired drying hood and Yankee drum by converting one of its two paper drying machines to fully utilise geothermal. This is the first in the world for a tissue paper machine to be fully powered from geothermal rather than natural gas. The annual CO_2e emissions reduction projected from the project is some 6,400 tonnes. The project cost is NZD 15.5 million (2022 costs).

The second paper machine could be converted in time once the geothermal powered machine has been proven in operation. This second conversion would further reduce Essity's emissions by an additional 6,400 tonnes per annum.

Oji Fibre Solutions (Oji) process around 1.25 million cubic metres of wood a year, converting it into unbleached kraft pulp (for the manufacture of paper and tissue) and fibre cement pulp (used for the production of building products). Oji Kawerau is the largest user of geothermal energy for process heat at any site in New Zealand. In 2021, about 21% of the mill's annual energy requirements of 8.3 PJ was met from geothermal energy (1.81 PJ [Oji Fibre Solutions 2022]).

In 2019, Oji embarked on a $63 million transformation project at the Kawerau site, eliminating the use of coal through increased use of geothermal energy. Previously, to provide steam for process heat requirements, Oji burnt coal, waste oil and wood residues (biomass) in a boiler. Investing in a steam line from NTGA secured a continuous supply of process quality steam from the NTGA reboiler facility. The modifications directly reduced CO_2e emissions from Oji's Kawerau site by 10,000 tonnes per annum and indirectly avoided a further 10,000 tonnes per annum of emissions through wood residues no longer required at Kawerau being transported and used as biofuel at the Oji Kinleith Mill, Tokoroa. Operational savings of $4 million per annum were achieved.

Oji are experienced users of geothermal energy and they will understand the opportunities for further decarbonisation at their site. The GNS Science team have no insight into future projects that might benefit from geothermal energy at the Oji Kawerau site.

4.2.2 Future Development

NTGA have indicated that they could supply an additional 6 PJ per annum of geothermal process heat available as steam at 7 barg and, as solutions are developed to utilise hot geothermal water, there is an additional 8 PJ per annum of thermal energy that could be utilised at 130°C. The current indicative price for steam is $12–$18 per tonne per hour ($4.3–$6.5 per GJ).

The **Fonterra Edgecumbe** facility is located 19 km from the Kawerau Geothermal Field. In New Zealand, this sort of distance has not yet been traversed by a pipeline supplying geothermal energy. The longest supply lines known were installed in the Wairakei Geothermal Field before the Te Mihi power station was built, with some pipelines traversing some 5 or 6 km from the wellhead to the Wairakei Power Station. In France and the Netherlands, medium (250 mm) and large diameter (500 mm), respectively, low-heat-loss pipelines have been installed with temperature losses as low as 3.8°C over 15 km (refer to Appendix 7 for details on the pipeline supplying the Beinheim starch plant) and 1°C over 8.5 km at operating temperatures of 170°C and 135°C, respectively (Ravier et al. 2017, Appendix 8).

With innovation in design (such as Ravier et al. 2017) and moving away from more traditional New Zealand cross-country geothermal pipeline design, the engineering of low-heat-loss pipelines (supply and return) could substantially extend the geographical reach of the geothermal energy supply from high temperature geothermal fields in New Zealand. However, there needs to be a change in the New Zealand approach to geothermal pipeline design for this to occur.

The natural gas use at the Edgecumbe Fonterra site is 738 TJ per annum, opening up potential reduction using the Kapuni natural gas factor of 53.40 t CO_2e/TJ (Climate Change [Stationary Energy and Industrial Processes] Regulations 2009, Table 10) of some 39,400 tonnes per annum. If geothermal energy from Kawerau is supplied to the Edgecumbe factory, the quantum of these emissions could be substantially reduced. If the reduction achieved through the system design developed by Dobbie Engineers for the Fonterra Reporoa facility is applied, then site emission reductions greater than 60% could be anticipated.

NTGA have indicated that they consider that a geothermal supply from Kawerau to Fonterra Edgecumbe, augmented with developing technologies, will be viable in less than a decade. GNS Science is of the view that innovation studies in low-heat-loss energy transmission pipelines (delivery and return) and system integration studies looking at the best approach for supplying and using geothermal energy in the Edgecumbe facility could see this occur sooner.

4.3 Rotorua Geothermal Field

The Rotorua Geothermal Field is located near the southern margin of the Rotorua caldera, formed by a ~225,000-year-old eruption. As defined by surface activity, shallow wells and resistivity measurements, the geothermal field covers ~12 km^2 (~20–28 km^2 at 500 m depth) and extends beneath Rotorua City and northwards under Lake Rotorua (Bibby et al. 1992). The Rotorua Geothermal Field has boiling conditions at <100 m. Geothermal surface features are concentrated in three main areas, which are Whakarewarewa-Arikikapakapa, Ohinemutu-Kuirau Park and Government Gardens-Ngapuna (Figure 4.3).

Since the 1920s, more than 1000 drillholes have penetrated the shallow resource below the city, with ~96% of the bores being less than 200 m deep. The extraction was originally uncontrolled, and most of the spent geothermal water was discharged to waste. Over-exploitation of the geothermal resource without the return of the fluid back into the reservoir resulted in a decline of many and failure of several surface features in the 1970s.

A change in management policy led to a 1987–1989 borehole closure programme, with a ~60% reduction in the quantity of fluid extracted and a 1.5 km exclusion zone focused around the Pohutu Geyser (Figure 4.3). In 1999, the Rotorua Geothermal Regional Plan was approved, and included enhancement and allocation of the resource, managing and controlling adverse effects on the field and protecting surface features. After this change in management, there has been some recovery of the reservoir and ongoing recovery of surface features. The management approach of the Rotorua geothermal resource is currently under review (Doorman et al. 2022).

Along with tourism focussed around the geothermal surface features, the Rotorua resource is utilised for space heating, including the Rotorua Hospital, Rotorua museum, motels and large hotels (e.g. Novotel Lakeside Rotorua), mineral pools, mud pools and swimming pools heated with geothermal energy (e.g. Wai Ariki Hot Springs and Spa, QE Health, Polynesian Spa and the Rotorua Aquatic Centre), as well as other light commercial uses, such as greenhouse heating.

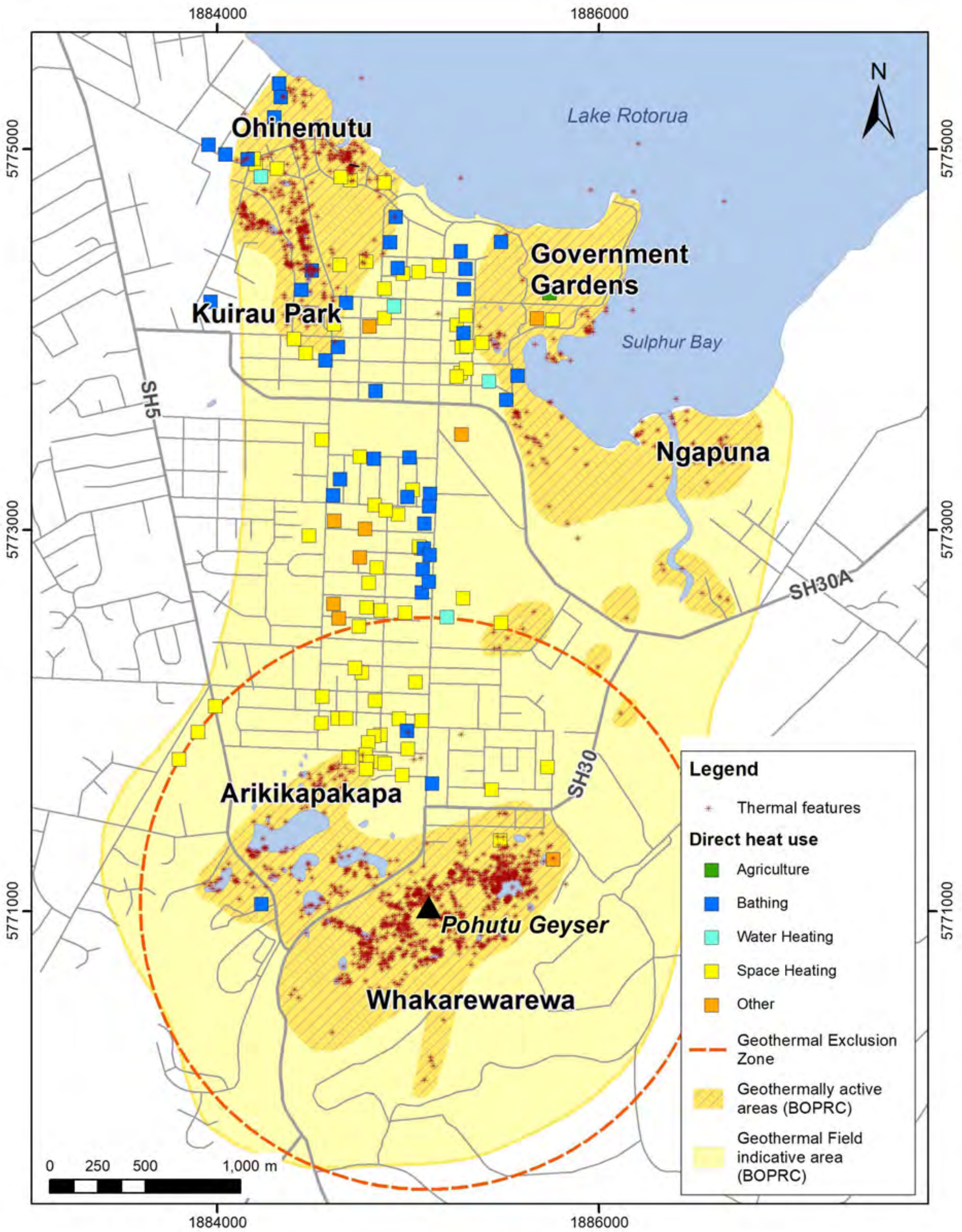

Figure 4.3 Rotorua Geothermal Field layout.

4.4 Tauranga Geothermal Field

The Tauranga Geothermal Field is an extensive low-enthalpy warm-water system with a surface extent of around 875 km^2. It extends over 60 km from Katikati-Waihi Beach in the north-west to Te Puke-Maketu in the east (Figure 4.4), with the dominant heat expression lying near Tauranga city.

The Tauranga Geothermal Field has few natural surface features. There are warm springs/seeps with temperatures ranging from 23–47°C. The thermal regime of the area is dominantly conductive with the warm aquifer temperatures varying between 30°C and 70°C at depths of between 200 m and 600 m.

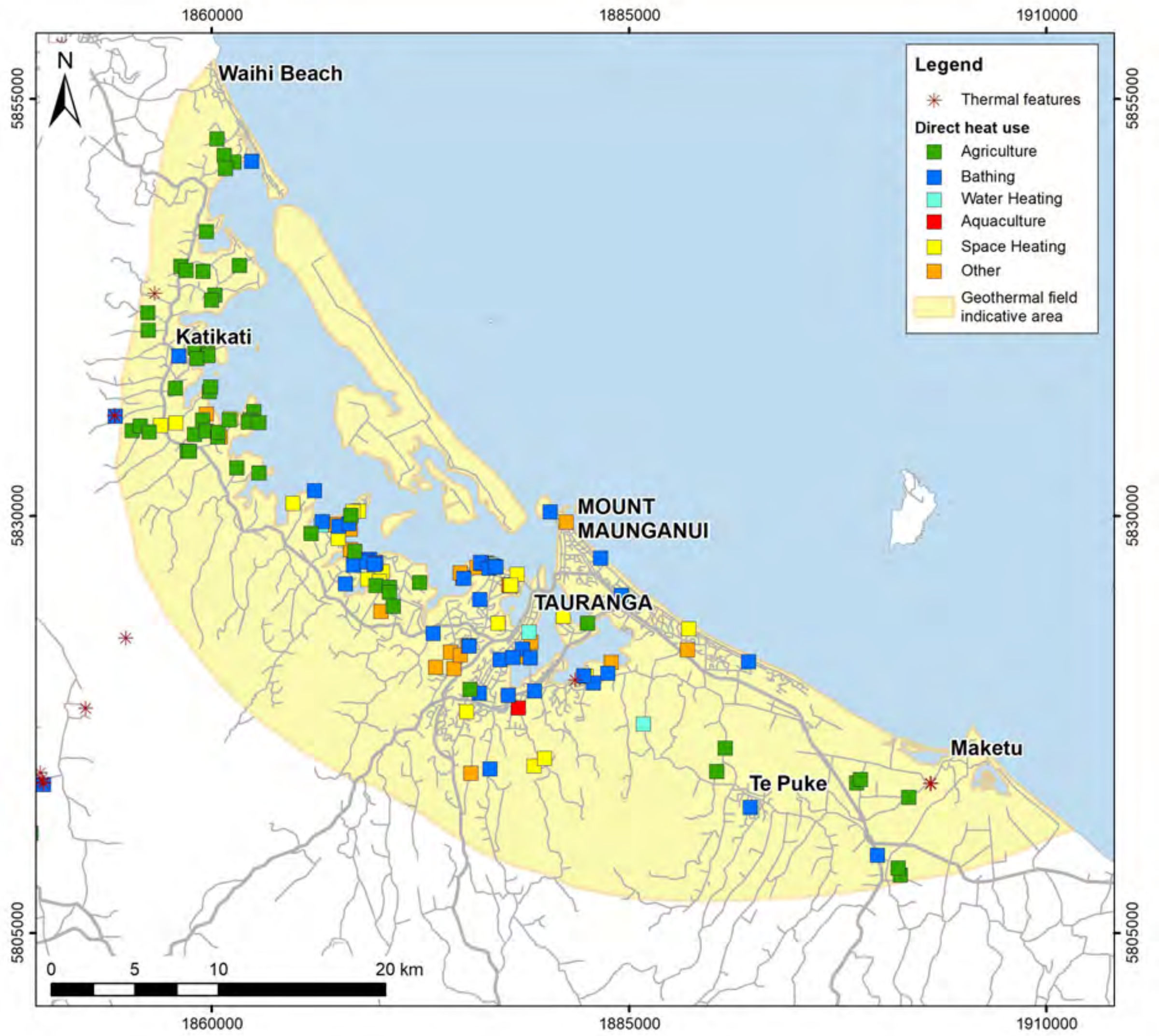

Figure 4.4 Map of the Tauranga Geothermal Field and known current geothermal users.

The Tauranga Geothermal Field is part of BOPRC Management Group 5. It is an area where the long-term management of the system requires consideration of it as both a geothermal resource and groundwater resource. It is used in its geothermal capacity for heat (all water >30°C as per the geothermal water definition of the RMA), and the same aquifer is used by freshwater users.

An average of 26,000 tonnes of geothermal water is extracted from the Tauranga Geothermal Field per day (Zuquim et al. 2022) being used for heating, cooling, tropical fisheries, bathing and greenhouses (Figure 4.4). The largest single user (about 10%) is the Baywave TECT Aquatic and Leisure Centre.

Around 25% of the geothermal water take is for ‘non-geothermal’ uses, such as irrigation and frost protection.

Across all users, only about 16% of the take is reinjected (Zuquim et al. 2022).

4.4.1 Te Puke – Maketū Area

The Te Puke – Maketū area has a low-resistivity anomaly zone, some hot springs and a thermal anomaly.

- The low-resistivity zone in Maketū reflects the presence of highly conductive seawater at shallow depths, not necessarily the presence of geothermal fluids (Stagpole and Bibby 1998).
- The Maketū peninsula is a horst bounded by north-east striking normal faults. These faults most likely act as conduits for the hot fluids to rise to the surface and feed the springs.
- A 134-m-deep well produced fluid at 41.7°C.

Further subsurface investigation is needed to better characterise the nature and the extent of the geothermal resource of the Maketū area, as it could be a promising area for low temperature geothermal direct use.

4.5 Awakeri Geothermal Field

The Awakeri Geothermal Field (Figure 4.1) is located halfway between Whakatāne and Kawerau. Hot springs occur in that area near a major north-east trending basement fault bounding the Whakatāne Graben. It is believed the hot water circulates from depth along this fault. Two bores drilled in the 1940s confirmed the presence of a hot water aquifer at depths of 50–80 m. Subsequent investigations of the resource include drilling a number of shallow bores and geophysical surveys.

Temperatures measured from the Awakeri boreholes range from 56–70°C, with the hottest temperature measured closest to the hot springs. The average temperature of the fluid discharged from the pools is ~38–53°C, depending on the inlet temperature. The fluids are weakly mineralised, neutral, chloride-bicarbonate waters.

This site is too far away from Whakatāne to supply any lower temperature heat users on the EECA site list there and, although only a few kilometres from the Fonterra Edgecumbe site (on the BOP RETA site list), the temperature conditions in the Awakeri resource are considered too low to be particularly useful for a higher temperature (>200°C) dairy factory heat supply. However, they are likely suitable for lower temperature applications, such as greenhouses, if these were located close by the field.

4.6 Whakatāne

Whakatāne is located on the coast, 90 km east of Tauranga. It is outside of any geothermal fields and there are no known thermal anomalies in the area. The closest geothermal area is Awakeri, located about 8 km to the south-west.

It sits on the eastern edge of the Rangitaiki Plains, which cover an extensive area between the coast and the surrounding hills and ranges. It is a low-lying flood plain that has been extensively drained to accommodate agricultural developments.

The area is structurally complex, being at the convergence of the North Island Fault System (NIFS) and the TVZ. The Whakatāne Fault and the Edgecumbe Fault are two of the most active faults in this area.

The Whakatāne hills represent ancient sea cliffs of the greywacke basement. Downfaulting to the west deepens the basement surface. It is overlain by a sequence of marine sediments, alluvial and volcanic deposits that thicken towards the west under the plains.

Energy use in the area will rely on the ambient temperature groundwater resource. There are two aquifers in the area:

- A shallow, unconfined aquifer in highly heterogeneous subsurface sediments down to c. 70 m depth, and
- A deeper aquifer in deep sediments and fractured ignimbrite to depth of c. 400 m.

Further detail on the regional and local groundwater aspects at the sites analysed in the Whakatāne area can be found in Hodges et al. (1991).

4.7 Ōpōtiki

Ōpōtiki is located on the coast east of Whakatāne. It is outside of any geothermal areas and there are no known thermal anomalies in that area. Development in the area will rely on ambient-temperature ground and groundwater resources.

4.8 Reporoa

Although not in the BOP administrative region, EECA have requested that information be provided on the Reporoa Geothermal Field as a possible source for energy to the Fonterra Reporoa dairy factory.

The field sits above the Reporoa Caldera (Figure 4.5). Thermal manifestations are present locally, including hot and boiling springs and pools, steaming ground, seepages, sinter and mud pools.

Scientific investigations undertaken in the 1960s by the Department of Scientific and Industrial Research (DSIR) at Reporoa included geological, aero-magnetic (regional), gravity, resistivity and seismic reflection surveying, spring flow-rate and temperature measurements, with the manifestation fluids being chemically analysed and identified as neutral chloride-bicarbonate waters (Mongillo and Clelland 1984). In 1966, the Ministry of Works and Development drilled a ~1340-m-deep well, identified as Reporoa 1 (Glover and Ellis 1967). Downhole information and other data, including chemical analyses, were obtained from the well. The maximum measured temperature was 255°C at the relatively shallow depth of ~950 m (Glover and Ellis 1967). The well was discharged for a short period of time in October 1966.

Bibby et al. (1994) consider resistivity signatures between the Reporoa and Waiotapu Geothermal Fields, identifying that from these geophysical signatures Reporoa is likely to be a separate geothermal field. The resistivity boundary zone for Reporoa is shown in Figure 4.5.

More recent work by Pauline and Kaya (2019) simulated geothermal production and injection from the Reporoa Geothermal Field with different electrical power generation scenarios up to 30 MW_e. The model grid included the southern part of the Waiotapu Geothermal Field. One of the scenarios modelled was for a 10 MW_e electrical generation facility with very minimal effects computed over a 30-year life. A 10 MW_e electrical facility requires about 100 MW of thermal energy. This is about the primary geothermal energy required for the supply to the Fonterra Reporoa dairy factory per the preliminary design for the site.

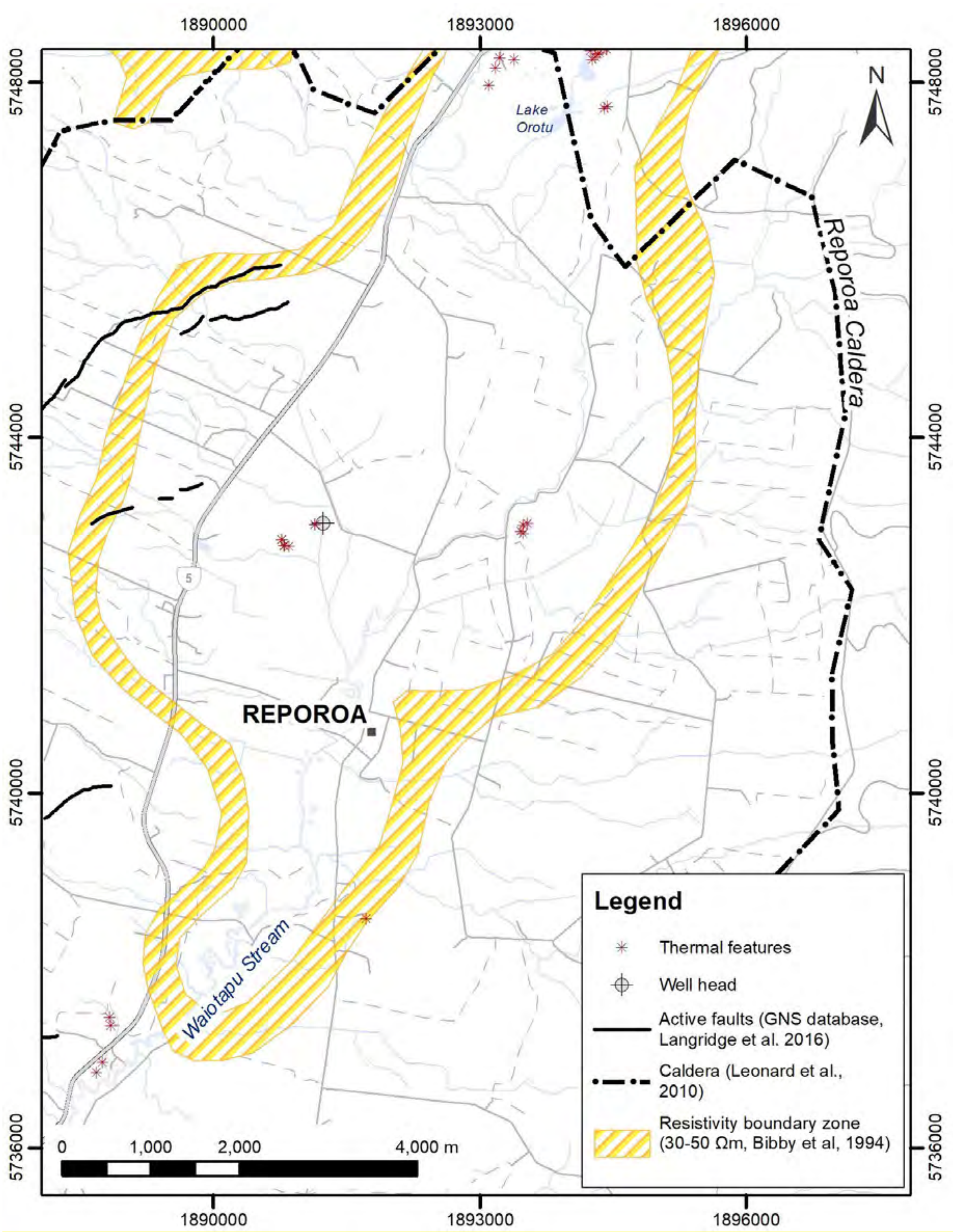

Figure 4.5 Reporoa Geothermal Field as defined by the resistivity boundary zone. The northern part of the Reporoa Caldera is shown on the figure (dashed line) as is the well site RP-1 (circle with cross hairs). The GNS Science active faults are from Langridge et al. 2016.

Before the Reporoa Geothermal Field is used as an energy source, additional exploratory work will be required to confirm the presence of utilisable geothermal energy. In particular, the geophysical surveying should be extended to include magnetotellurics that cover the likely reservoir depth with associated inversion modelling looking down to a depth of about 5 km. Shallower (<300 m) SKYTEM, transient electromagnetic data is understood to be available now and will provide valuable insights on the structure of the shallow part of the field, including potential fluid flow pathways and interconnectivity between the surface features, groundwater aquifer(s) and the geothermal reservoir. The new datasets should be combined with existing geoscientific information, reviewed and reinterpreted using current analytical techniques. The work should include a geological review and preparation of a system specific geological model, a review of the geophysical data, gravity, magnetics, resistivity and magnetotellurics. Additional data capture could be expected as part of those reviews, which, after acquisition, would be modelled and analysed. Resampling of the surface manifestations and re-analysis of their chemistry is also recommended.

The inferences will then need to be tested by drilling additional exploratory wells. The siting of these wells will depend mostly on the outcome of the magnetotellurics analysis. A minimum of two wells should be considered, with each of these drilled to a depth of about 3 km to provide good depth coverage in exploring the system, whilst also being readily drillable using techniques and equipment now commonly used in high temperature geothermal systems in New Zealand.

Under the Waikato Regional Plan (Waikato Regional Council 2012), Reporoa is categorised as a Research Geothermal System. The plan rules provide opportunity to undertake scientific activity on a research field but no larger scale utilisation until a plan change is worked through.

The regional plan describes the reasons for the research categorisation as:

- Several surface outflows vigorously depositing sinter, and
- May be hydrologically linked to Waikite-Waiotapu-Waimangu Geothermal Field.

It is understood that the primary reason for Reporoa being classified as a Research Geothermal Field by the WRC was because of a possible link to the surface features of the Waikite-Waiotapu-Waimangu areas. Concerns were that if a significant pressure change occurred in Reporoa this might influence the outflow from Waiotapu. It is interesting to note the opinion of Bibby et al. (1994) that any such linkage is incompatible with the resistivity signatures between the two geothermal fields.

The hydrological linked influence is premised on the basis that a pressure change at Reporoa might propagate to Waiotapu. If the Reporoa development strategy adopted is full injection then the pressure change theory between Reporoa and the other fields driving the research categorisation for Reporoa is of less relevance. Full reinjection has been demonstrated at Ngatamariki, where all but ~2% of the fluids are being returned to the reservoir, which, as a consequence, has seen very little pressure change.

Ahead of Reporoa being used for larger scale energy production, a plan change would be required to move the field to the development or the limited development category, depending on the volumes of fluid to be extracted and injected. The proposed exploratory work suggested above would bring more insights on the nature of possible connectivity, if any, between the two geothermal fields and provide some of the supporting evidence for the application documentation for the plan change. This plan change process could be expected to take up to about 24 months, once the application documentation is prepared.

Changing a system categorisation is not insurmountable and, by way of note, the Ngatamariki Geothermal Field is a Waikato geothermal field that has moved from unclassified/research to development. This change occurred as part of input to the original proposed Waikato Regional Plan (Waikato Regional Council 2012).

5.0 ASSESSED SITES FOR GEOTHERMAL ANALYSIS

Four sites covering a range of characteristics were to be assessed as part of the GNS Science/EECA contract with the outcomes, where possible, being applicable to other facilities and other regions in New Zealand. A shortlisting process was undertaken.

5.1 Shortlisting

EECA identified 30 sites for consideration for geothermal energy supply assessments from the 54 EECA RETA BOP site list. Through discussion, GNS Science, GeoExchange, Dobbie Engineers and EECA reduced this to four:

- Whakatāne Hospital: GSHP technology, ~15°C ambient aquifer water.
- Whakatāne Growers: GSHP technology, ambient aquifer water.
- Dominion Salt – Mount Maunganui: GSHP technology, ~45°C aquifer water.
- Fonterra Reporoa: High temperature geothermal direct use, 260°C geothermal water.

These sites cover a range of different operations at locations with different geothermal resource, or water source temperatures and characteristics. The four study sites are shown in Figure 5.1.

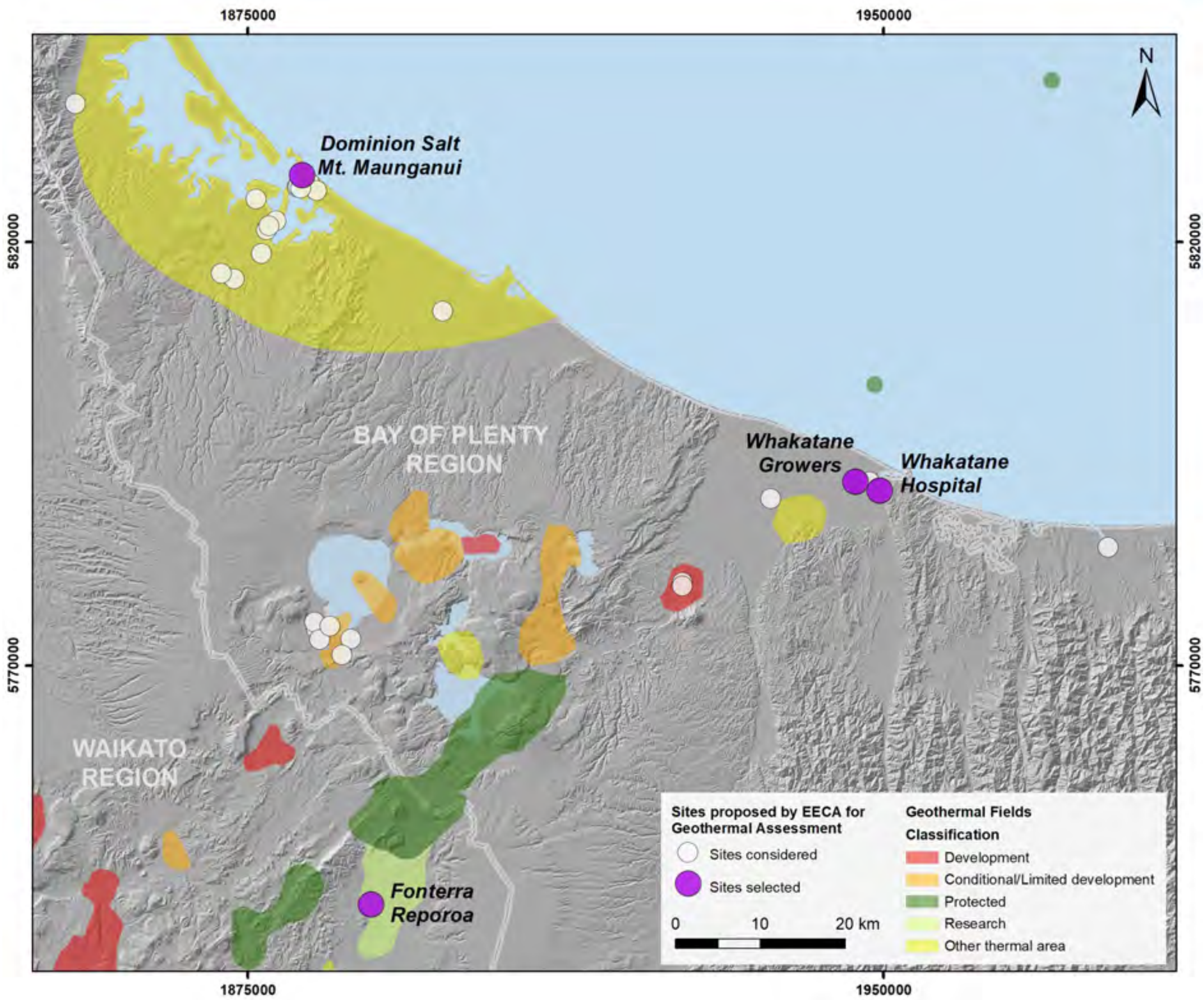

Figure 5.1 Location of the four sites selected for geothermal assessment.

5.2 Site Study Remarks

GeoExchange prepared the Mount Manganui and the two Whakatāne assessments, Dobbie Engineers assessed the surface plant required for the Reporoa assessment and GNS Science provided material on the underground resources. The studies are of a preliminary nature with the material prepared to enable comparisons to be made with other technologies that might reduce carbon emissions that have been prepared by other contributors as part of the BOP RETA.

EECA undertook to prepare the comparative analysis with other energy sources (e.g. biomass, electricity).

The material presented in this report is not to be relied upon for progressing conversion of a site to geothermal energy. Detailed engineering design and costings will be required prior to finalising any system that might be being considered for installation at a given site.

If the reader is looking for more detailed information on the sites assessed, please address your request to EECA.

5.3 Whakatāne Hospital

Whakatāne Hospital sits atop a shallow and deeper aquifer system. The shallow unconsolidated aquifer was considered unlikely to be able to provide sufficient flow, would likely have mounding issues on reinjection and had poor water quality. The deeper Matahina aquifer was considered as the better source of renewable thermal energy, and the aquifer yield is expected to be able to satisfy the entire estimated site heating and cooling demand. Three abstraction wells and four injection wells are expected to be required.

Although the primary intent of the assessment is to replace the gas boiler, a ground heat exchanger (GHX) typically operates more efficiently when it has a combination of heating and cooling, especially when simultaneous. As such, the cooling option has been incorporated into the analysis, and the GSHP was modelled to provide 100% of the heating and cooling requirements, replacing the existing gas boilers and air-cooled chillers.

GSHPs can provide a direct replacement in the existing plant room for both the gas boilers and the existing chillers of the new buildings. This approach also ensures compatibility with the building's current infrastructure.

The Whakatāne Hospital was assessed using groundwater at ambient temperature (~15°C) as the energy source/sink for an open loop GSHP that provides for 100% of the heating and cooling requirements. The site is a complex of old and new buildings with a peak heating requirement of 2.1 MW_{th} and peak cooling requirement of 1.2 MW_{th}. Annual energy for heating is 3.6 GWh and cooling is 2.2 GWh. The GSHP system would require a peak flow of 60 L/s of 15°C water to be abstracted and returned to the Matahina Formation aquifer. Compared with an ASHP system, the GSHP solution would reduce the peak electrical load by more than 35% and annual electrical energy input by more than 40%. The capacity of the electrical supply to the hospital is adequate to support the GSHP solution.

Table 5.1 summarises the capital cost estimate for the GSHP solution. The costs are indicative only, as final design has not been completed.

Table 5.1 Indicative cost estimate for an ambient aquifer water ground source heap pump (GSHP) solution to replace the boilers and air chillers at Whakatāne Hospital.

Cost Item	Total	Comments
Decommissioning of existing plant.	$300,000	-
Drill test bore to 350 m, includes coring.	$299,646	Includes 30% contingency.
Drill and complete remaining six bores and install three pumps.	$1,490,173	Includes 30% contingency.
Connect bores to plant room.	$400,000	-
Supply and Install GSHPs in New Building.	$1,080,000	Manufacturer estimate plus 50% installation for piping, electricals, etc.
Supply and install WS VRF in Old Buildings.	$1,575,000	-
Professional fees (9%).	$463,034	Engineering, regulatory, site supervision and project management.
TOTAL	$5,607,853	-

5.4 Whakatāne Growers

Like the nearby hospital, Whakatāne Growers sits atop a shallow and deeper aquifer system. The deeper Matahina aquifer (~270 m) has been considered as the better source of renewable thermal energy as the shallow aquifer is unlikely to provide sufficient flow, and would likely have mounding issues on reinjection and has poor water quality.

Testing of groundwater conditions is required to confirm whether 100% of site heating needs can be achieved from the deeper Matahina Formation aquifer. This will inform whether a 100% GSHPs solution is possible or whether supplementary heating will be required from an additional source.

The following analysis is based on the assumption that 100% of site heating needs can be met by GSHP.

Whakatāne Growers is a 3.2 hectare covered crop facility, with four glasshouses, with an assessed peak energy requirement of 4.8 MW_{th}.

The GSHP solution uses four 1.2 MW heat pumps using a peak flow of 60 L/s of 15°C water to be abstracted and returned to the Matahina Formation aquifer. Three abstraction wells and four injection wells are expected to be required. Wells are approximately 350 m deep.

The GSHPs would be located in the existing boiler room, and thermal storage would also be located in the boiler room with connections to the existing reticulated heating pipe network.

The capacity of the electrical supply to/at Whakatāne Growers would need to be uprated with a new ~3 MVA feed. Costs to upgrade this electrical infrastructure at the site have not been included in the capital cost estimates tabulated in Table 5.2. The costs are indicative only, as final design has not been completed.

Table 5.2 Indicative cost estimate for an ambient aquifer water ground source heat pump (GSHP) solution to replace the boilers at Whakatāne Growers.

Cost Item	Total	Comments
Decommissioning of existing plant and equipment.	$200,000	-
Drill test bore to 350 m, includes coring.	$658,266	Includes 30% contingency.
Drill and complete remaining six bores and install three pumps.	$2,626,149	Includes 30% contingency.
Connect bores to plant room.	$400,000	-
Supply and Install GSHPs.	$2,160,000	Manufacturer estimate plus 50% installation for piping, electricals, etc.
Professional fees (9%).	$526,000	Engineering, regulatory, site supervision and project management.
TOTAL	**$6,570,415**	-

In order to model the advantages that might accrue if available water source temperatures were slightly elevated, such as might be found in the broader Tauranga area for a similar facility to the Whakatāne Growers' covered crop facility in a similar climate environment, water temperatures up to 30°C were assessed, with the percentage savings in energy to operate the system relative to an ASHP or a GSHP operating off a 15°C source computed and tabulated in Table 5.3. There are also savings in the capital cost of an installation, as the number of ground source heat pumps required reduces as the source temperature increases to 30°C.

Table 5.3 Percentage energy savings for ground source heat pump (GSHP) systems using slightly elevated water temperatures relative to an air source heat pump (ASHP) or a GSHP using 15°C water.

Heat Pump Type (Source Temperature)	System COP	Energy Savings Relative to ASHP	Energy Savings Relative to GSHP (15°C)
ASHP (Whakatāne Growers)	2.0	-	-
GSHP (15°C) (Whakatāne Growers)	2.77	28%	-
GSHP (20°C)	3.2	38%	14%
GSHP (25°C)	3.6	44%	24%
GSHP (30°C)	4.0	50%	31%

Significant savings accrue with the increase in temperature from 15°C up to 30°C.

5.5 Dominion Salt

Dominion Salt, Mount Manganui, is an industrial facility that includes steam for use in a cogeneration system and for direct supply to two fluidised bed dryers. The site is complex and the focus of the geothermal assessment was only for the steam supply to the dryers, which would require a 720 kW_{th} high temperature heat pump to generate 900 kg/hr of 120°C steam. The dryers were assumed to be operational 24/7, with the operations only interrupted for maintenance.

Dominion Salt overlies part of the Tauranga low temperature geothermal aquifer, with aquifer water temperatures of ~45°C at a depth of about 300 m. The Waiteariki Ignimbrite aquifer unit was assessed to supply 20 L/s at 45°C for the Dominion Salt application with the fluid returned to the aquifer at 37°C. A heat pump with a COP of 2.8 was selected for the application requiring 253 kW of electrical input. Table 5.4 summarises the capital cost estimate for the ground source high temperature heat pump (GSHTHP) solution. The estimates are indicative only, as final design has not been completed.

Table 5.4 Indicative cost estimate for a ground source high temperature heat pump (GSHTHP) using low temperature geothermal aquifer water (~45°C) as an application to replace the natural gas generated steam supplying two fluidised bed salt dryers at Dominion Salt.

Cost Item	Total	Comments
Decommissioning of existing plant.	$200,000	-
Drill test bore to 350 m, includes coring.	$596,647	Includes 30% contingency.
Drill and complete remaining four bores and install two pumps.	$1,697,604	Includes 30% contingency.
Connect bores to plant room.	$250,000	-
Supply and install HTHPs.	$2,025,000	Manufacturer estimate plus 50% installation for piping, electricals, etc.
Professional fees (9%).	$429,233	Engineering, regulatory, site supervision and project management.
Total	**$5,198,484**	-

It is understood that cogeneration is a common operating approach for industries at the Port of Tauranga and so decarbonisation by reducing/removing gas from the industrial area needs to consider electrical energy (cogeneration) as well as thermal energy (boilers). Grid upgrades will need to consider compensating for the cogeneration electrical capacity lost as well as the increase in electrical demand required for the heat pumps replacing gas-fired boilers. High GSHP efficiency optimises capital investment in the electrical infrastructure.

The assessment of the GSHP application at Dominion Salt highlights possible opportunities for other industrial facilities at or near the Port of Tauranga to utilise the low temperature geothermal resource augmented with heat pump technology. This could include an industrial park/energy scheme that interconnects various energy users, both sharing energy and the energy infrastructure. A study of this opportunity is recommended.

5.6 Fonterra Reporoa

Reporoa is a high temperature geothermal system categorised as research under the Waikato Regional Plan. Downhole information and other data, including chemical analyses were obtained from an exploratory well drilled in 1967. The maximum measured temperature was 255°C at the relatively shallow depth of ~950 m.

The research rule framework associated with Reporoa includes a discretionary activity rule 7.6.3.6 (Waikato Regional Council 2012) with associated assessment criteria that enables consent to be applied for further exploratory and testing activity:

- The take of geothermal energy or water from a Research Geothermal System of up to 10,000 tonnes per day or

- Discharge of water and associated naturally occurring contaminants into water, or onto or into land, arising from the taking of geothermal water from within a Research Geothermal System; that is undertaken for the purpose of scientific investigation or enhancement of the geothermal system or associated surface features is a discretionary activity (requiring resource consent).

Additional scientific and exploratory activity is required to better inform the energy potential / supply opportunities and to provide supporting information for a plan change to a development category that would be required to supply energy to a nearby industrial facility. Exploration activities are estimated at ~$18.5 million with an additional $0.75 million allocated for the plan change work. A period of three to four years should be adequate for the exploratory work, with the plan change work commencing at year three and taking about two years to complete.

The geothermal assessment by Dobbie Engineers for Fonterra Reporoa was to provide geothermal generated steam at a maximum of 36 tonnes per hour at 14 barg (198°C). This would cover a significant portion of the site's existing thermal demand. The design uses two-phase geothermal equipment to generate culinary grade process steam that is delivered to the site.

The capital costs for the surface plant and piping systems (excludes wells in the geothermal field) is estimated at $24 million with annual plant operational/maintenance costs of $1.5 million. GNS Science estimated that an additional $24 million should be allocated for additional production and injection wells. Periodic well maintenance and possibly well replacement work will also need to be undertaken over time.

6.0 BAY OF PLENTY RETA WORKSHOP

GNS Science, along with sub-contractors Yale Carden (GeoExchange) and Greg Moore (Dobbie Engineers), attended the BOP RETA feedback workshop organised by EECA and Bay of Connections on 7 November 2023 at the Rydges Hotel, Rotorua. GNS Science presented a summary of the outcomes from the Geothermal workstream. The presentation delivered at the workshop is included in Appendix 1.

A number of attendees expressed a strong interest in the findings from the geothermal work during the open floor discussion. GNS Science expects to see further enquiries from process heat end-users as well as local economic development agencies in the region looking to further investigate the potential of geothermal energy in decarbonisation of the BOP region.

7.0 SUMMARY REMARKS AND RECOMMENDATIONS

Material documented in this report identifies that geothermal heat and GSHP technologies compared with fossil fuels (natural gas fired) performing the same heating duty have the potential to reduce operational emissions by between 80% to 100%. These calculations exclude any emissions associated with grid electricity used in the application.

At the industrial scale for a geothermal steam supply at a location such as Kawerau, or Tauhara, where energy supply infrastructure is in place, geothermal energy can be delivered at ~$10 per GJ, including a $70 per tonne cost of carbon. Geothermal is the lowest cost fuel in these circumstances. This position only improves with time as the cost of carbon under the ETS increases.

Four geothermal site specific assessments were completed in the broader BOP region as part of the BOP RETA.

The Whakatāne Growers, Whakatāne Hospital and Dominion Salt steam boiler feasibility assessments realised very high levels of carbon reductions using GSHP solutions. The GSHP assessments for each site resulted in the lowest electrical energy requirement to deliver the required heat, along with the lowest peak electrical load required, so minimising facility electrical and grid investment. These result in operational efficiencies and reduced annual operational costs compared with likely other electrification alternatives, notably ASHP or electric boilers.

The design to replace natural gas fired clean steam with culinary grade steam produced using geothermal energy for the same application using the Reporoa Geothermal Field resulted in a substantial reduction in emissions for that application. It is, however, not feasible to transition 100% of operational gas-fired functions at the Reporoa factory to geothermal sources, with ~30% of the gas use remaining. Therefore, overall, the geothermal conversion would reduce the site's annual carbon emissions by more than 60%. However, before the Reporoa Geothermal Field is used as an energy source, additional exploratory work and a regional plan change will be required to move the field to a development category.

The low temperature geothermal resource in and around Tauranga represents an opportunity that has not been fully realised. The combination of elevated groundwater temperatures and GSHP technologies, as demonstrated in the Dominion Salt assessment and the computed scenarios of the Whakatāne Growers site using a 30°C geothermally enhanced water temperature, highlights the significant operational efficiencies achievable compared with either ASHP or GSHP using ambient (15°C) temperature groundwater. These energy efficiency opportunities could further attract economic investment to the region, especially for sectors such as the covered crop growers. While not featured as a case study in this report, direct use of geothermal fluid at 60–70°C range temperatures merits consideration for the right sort of venture. The development of a regional strategy around the ambient/low temperature resource, while ensuring effective environmental management, presents a noteworthy opportunity.

In response to global demands for electrification, high temperature heat pump technology tailored for industrial applications is progressing at accelerated pace. Presently available equipment is capable of attaining temperatures of up to ~150°C. A 120°C output temperature was used as part of the Dominion Salt assessment with results showing real promise for this type of technology. It is recommended that revisiting such assessments in the future would be useful particularly with the rate that technological advancements are occurring.

Although GSHP typically require a higher initial capital investment when compared with other alternatives, the substantially reduced operating costs, particularly in comparison with ASHP, result in more favourable return on investment with relatively short payback times. The advantages extend further, as, from a business operator's perspective, the enhanced efficiency of a GSHP installation can avoid/reduce the cost of electrical transformer and other electrical load/capacity upgrades, while eliminating the reliance on fuel transportation and storage, and mitigating potential supply challenges. On a regional scale, the broader adoption of GSHP technologies offers benefits by alleviating/reducing load pressure on the regional/local electrical network infrastructure.

The report does not delve into regional strategies that involve the aggregation of businesses around shared drilled geothermal resources or shared GSHP technology within district-wide/ shared energy schemes. However, these approaches merit thorough consideration. For instance, the capital investment at Reporoa becomes more palatable if the owner generates another revenue stream by becoming an energy provider to other industry. District schemes represent an economic opportunity for authorities to proactively support essential infrastructure and energy supplier roles, similar to NTGA at the Kawerau Geothermal Field. A similar model could work with low temperature geothermal and GSHP as a local energy scheme. This is presented as an opportunity for the Port of Tauranga in the conclusion of the Dominion Salt assessment. Such investments could create a sustained revenue stream for the region whilst also significantly contributing to regional decarbonisation efforts, thereby fortifying the economic vitality of the region. In the absence of public sector investment, this opportunity could be explored by private investors, especially iwi.

Deep drilling for geothermal resources represents a substantial capital investment, and the inherent risks associated with drilling for resource stand as an obstacle to direct use. This is not unique to New Zealand; numerous European nations have successfully embraced an insurance scheme, originally pioneered in France during the 1970s, to address the risks linked to drilling operations. The French scheme has directly contributed to the growth of geothermal direct use investment, and adopting an almost identical scheme in New Zealand is considered to hold significant promise. With the insurance scheme and other subsidies available in many European nations, geothermal energy is an attractive prospect for several compelling reasons, including the pursuit of energy independence for geopolitical and economic security, cost-effectiveness in ongoing operations and the unwavering reliability associated with these renewable energy sources. Geothermal energy is available 24/7 and is impervious to weather conditions. Consequently, a surge of investment in this sector is underway in Europe, with a projected 58% increase from current development, translating to an estimated USD 7.4 billion in capital expenditure between 2022 and 2030, in both the public and private sectors. Notably, many subsidised drilling initiatives in Europe target depths of 2–3 km for temperatures that are readily accessible at less than 500 m in New Zealand.

There is great potential for expansion of activity at the Kawerau Geothermal Field, as there is more land and more heat available for industrial process use. Further to this, technology to transport geothermal fluid many kilometres without significant temperature loss is advancing and becoming cost effective, therefore it is feasible to consider that geothermal energy from Kawerau could be cost effectively piped to Fonterra’s factory in Edgecumbe within the next 10 years. In fact, piping fluid to available land in a radius around a single well/geothermal production site is a model to consider in the near future. As New Zealand reduces its reliance on coal and gas, the utilisation of geothermal high temperature heat for industrial processes becomes increasingly attractive. This transition presents an opportunity for government leadership in exploring and initiating drilling activities in lesser-known geothermal fields.

The provision of a stable supply of high temperature heat will remain a consistent and vital demand. Once the exploration drilling phase is successfully de-risked, it opens the door for private green investors or iwi stakeholders to take on the development of these geothermal sites, facilitating a sustainable and greener energy future. It is noteworthy that New Zealand's geothermal electricity generators have made significant progress in carbon reinjection into reservoirs, so new geothermal facilities can be designed operationally as effectively carbon zero by deploying gas reinjection techniques.

Obtaining consent for a high temperature installation constitutes a substantial investment, both in terms of time and financial resources. The process of obtaining consent for such installations is often intricate, varying between regional authorities, each bearing unique associated risks. Proactive and early engagement with iwi is strongly encouraged. Māori-owned development of facilities using high temperature geothermal resources has proven to be a successful and sustainable model, and it is advisable for local and national governments to provide support for such initiatives. In contrast, GSHP and low temperature geothermal projects, while not exempt from due process, do not encounter the same level of complexity in the consenting phase. That said, it is also not a straightforward process and differences in process and outcome exist between regional authorities. Crucially, the geographical potential for using these technologies extends widely across the nation. Therefore, it is recommended that national guidance on the opportunity and consenting processes, that include best practices for subsurface and groundwater energy management, be established to facilitate the uptake, standardising and, in doing so, de-risking the uptake of these GSHP technologies.

7.1 Recommendations

- EECA include GSHP and/or low temperature geothermal in other RETAs in order to better appreciate the national opportunity.
- Pursue funding for the exploratory activity necessary to enable the Reporoa Geothermal Field to be further investigated as an energy source for industrial use.
- Commission national guidance on consenting process and subsurface management for GSHP/low temperature geothermal technologies.
- Adopt a drilling insurance scheme, similar to the French model, in New Zealand to de-risk geothermal applications and accelerate uptake in support of decarbonisation targets.
- Undertake further analysis on the opportunities for co-location or shared investment of geothermal deep wells, heat transportation over extended distances and GSHP local shared infrastructure in New Zealand.
- Include pairing GSHP and high temperature GSHP with the low temperature geothermal resource in regional economic/energy strategies for Tauranga.
- Commission future high temperature heat pump feasibility assessments, especially in view of the rate of technological change and price competitiveness occurring.
- Continue to work with geothermal experts and high temperature geothermal resource landowners to assess feasibility of system development on a case-by-case basis.

8.0 REFERENCES

Allis RG. 1997. The natural state and response to development of Kawerau Geothermal Field, New Zealand. *Transactions (Geothermal Resources Council)*. 21:3–10.

Allis RG, Henley RW, Carman AF. 1979. The thermal regime beneath the Southern Alps. In: Walcott RI, Cresswell MM, editors. *The origin of the Southern Alps*. Wellington (NZ): Royal Society of New Zealand. p. 79–85. (Bulletin / Royal Society of New Zealand; 18).

Allis RG, Funnell RH, Zhan X. 1998. From basins to mountains and back again: NZ basin evolution since 10 Ma. In: Arehart GB, Hulston JR, editors. *Water-rock interaction: proceedings of the 9th International Symposium on Water-Rock Interaction: WRI-9*; 1998 Mar 30 – Apr 3; Taupo, New Zealand. Rotterdam (NL): A.A. Balkema. p. 3–9.

Bibby HM, Dawson GB, Rayner HH, Bennie SL, Bromley CJ. 1992. Electrical resistivity and magnetic investigations of the geothermal systems in the Rotorua area, New Zealand. *Geothermics*, 21(1–2):43–64. https://doi.org/10.1016/0375-6505(92)90067-J

Bibby HM, Caldwell TG, Risk GF. 1994. Resistivity evidence for an independent geothermal field at Reporoa, In: Soengkono S, Lee KC, editors. *Proceedings of the 16th New Zealand Geothermal Workshop 1994*; Auckland, New Zealand; Auckland (NZ): University of Auckland, Centre for Continuing Education. https://www.geothermal-energy.org/pdf/IGAstandard/NZGW/1994/Bibby.pdf

Carson L, Seward A. 2023. Update of direct geothermal energy use inventory and management for New Zealand. In: *Proceedings 45th New Zealand Geothermal Workshop*; 2023 Nov 15–17; Auckland, New Zealand. Auckland (NZ): University of Auckland. https://www.geothermal-energy.org/pdf/IGAstandard/NZGW/2023/103.pdf

Climate Change Response Act 2002. https://www.legislation.govt.nz/act/public/2002/0040/latest/DLM158584.html

Climate Change Response (Zero Carbon) Amendment Act 2019. https://environment.govt.nz/acts-and-regulations/acts/climate-change-response-amendment-act-2019/

Climate Change (Stationary Energy and Industrial Processes) Regulations 2009: (SR 2009/285). https://www.legislation.govt.nz/regulation/public/2009/0285/latest/DLM2394207.html

Climate Change (Unique Emissions Factors) Regulations 2009: (SR 2009/286). https://www.legislation.govt.nz/regulation/public/2009/0286/51.0/DLM2378401.html

Climo M, Carey B, Miller F. 2022. Action Plan 2022 – 2023: Geoheat Strategy for Aotearoa NZ. [Place unknown] (NZ): New Zealand Geothermal Association. 23 p.

Doorman P, Camburn F, Scholes P, Zuquim M. 2022. Nga Wai Ariki o Rotorua changing the way we manage the Rotorua Geothermal System. In: *Proceedings 44th New Zealand Geothermal Workshop*; 2022 Nov 23–25; Auckland, New Zealand. Auckland (NZ): University of Auckland. https://www.geothermal-energy.org/pdf/IGAstandard/NZGW/2022/011.pdf

Glover RB, Ellis AJ. 1967. Chemistry of Hole 1 Reporoa (RP-1). Taupō (NZ): Department of Scientific and Industrial Research, Chemistry Division. Report CD 118/12.

Hodges S, O'Brian C, O'Shaughnessy B, Wilson A. 1991. Rangitāiki Plains groundwater resource evaluation. [Whakatāne (NZ)]: Environment Bay of Plenty. 140 p. Unpublished Technical Publication 2

Kirkby AL, Funnell RH, Scadden PG, Seward AM, Sagar MW, Mortimer N, Sanders F. 2024. Towards a New Zealand heat flow model. In: Proceedings, 49th Workshop Geothermal Reservoir Engineering; 2024 Feb 12–14; Stanford, California. Stanford (CA): Stanford University. Report SGP-TR-227. 6 p.

Kissick D, Climo M, Carey B. 2021. *An overview of New Zealand's Geothermal Planning and Regulatory Framework.* Taupō (NZ): Traverse Environmental Ltd.

Langridge RM, Ries WF, Litchfield NJ, Villamor P, Van Dissen RJ, Barrell DJA, Rattenbury MS, Heron DW, Haubrock S, Townsend DB, et al. 2016. The New Zealand Active Faults database. *New Zealand Journal of Geology and Geophysics*. 59(1):86–96. https://doi.org/10.1080/00288306.2015.1112818

[MBIE] Ministry of Business, Innovation & Employment. 2023. Energy in New Zealand 2023 – 2022 calendar year edition: comprehensive information on and analysis of New Zealand's energy supply and demand. Wellington (NZ): MBIE. 55 p.

Ministry for the Environment. 2023a. Measuring emissions: a guide for organisations: 2023 summary of emission factors. Wellington (NZ): Ministry for the Environment. https://environment.govt.nz/publications/measuring-emissions-a-guide-for-organisations-2023-emission-factors-summary/

Ministry for the Environment. 2023b. New Zealand's Greenhouse Gas Inventory 1990–2021. Wellington (NZ): Ministry for the Environment. https://environment.govt.nz/publications/new-zealands-greenhouse-gas-inventory-1990-2021/

Mongillo M, Clelland L. 1984. Concise listing of information on the thermal areas and thermal springs of New Zealand. Wellington (NZ): Department of Scientific and Industrial Research. 228 p. (DSIR Geothermal Report; 9).

Moore G. 2011. Ngati Tuwharetoa Geothermal Assets clean steam supply to SCA Hygiene Australasia's Kawerau tissue mill. In: *Proceedings 33rd New Zealand Geothermal Workshop*; 2011 Nov 21–23; Auckland, New Zealand. Auckland (NZ): University of Auckland. https://www.geothermal-energy.org/pdf/IGAstandard/NZGW/2022/011.pdf

Oji Fibre Solutions. 2022. Sustainability Report 2021/22. Auckland (NZ): Oji Fibre Solutions. https://cdn.sanity.io/files/gz4vq3tx/production/f94f8793b8f2bbec79a365f86b7e94ad884a53db.pdf

O'Sullivan M, Gravatt M, Popineau J, O'Sullivan J, Mannington W, McDowell J. 2021. Carbon dioxide emissions from geothermal power plants. *Renewable Energy*. 175:990–1000. https://doi.org/10.1016/j.renene.2021.05.021

Pauline R, Kaya E. 2019. Modelling geothermal power generation from the Waiotapu – Waikite – Reporoa Geothermal Fields. In: *Proceedings 41st New Zealand Geothermal Workshop*; 2019 Nov 25–27; Auckland, New Zealand. Auckland (NZ): University of Auckland. http://www.geothermal-energy.org/pdf/IGAstandard/NZGW/2019/086.pdf

Ravier G, Harders V, El Aoud M. 2017. Rittershoffen geothermal heat plant: first geothermal heat plant for industrial uses worldwide. Woluwe-Saint-Lambert (BE): Euroheat & Power. English edition.

Reyes AG, Christenson BW, Faure K. 2010. Sources of solutes and heat in low-enthalpy mineral waters and their relation to tectonic setting, New Zealand. *Journal of Volcanology and Geothermal Research*. 192(3–4):117–141. https://doi.org/10.1016/j.jvolgeores.2010.02.015

Seward A, Carey B. 2021. Geothermal heat pumps role in rebuilding Christchurch's commercial business district. In: *Proceedings World Geothermal Congress 2020+1;* 2021 Apr – Oct; Reykjavik, Iceland. The Hague (NL): International Geothermal Association. https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2020/29004.pdf

Stagpoole VM, Bibby HM. 1998. Electrical resistivity map of the Taupo Volcanic Zone, New Zealand: nominal array spacing 500 m, 1:250,000 [map]. Lower Hutt (NZ): Institute of Geological & Nuclear Sciences. 1 map. (Institute of Geological & Nuclear Sciences geophysical map; 11).

Waikato Regional Council. 2012. Waikato regional plan. Hamilton (NZ): Waikato Regional Council. 7, Geothermal module. p. 7-3–7-101.

Zuquim M, Zarrouk SJ, Janků-Čápová L. 2022. Tauranga geothermal system – an overview. In: *Proceedings 44th New Zealand Geothermal Workshop*; 2022 Nov 23–25; Auckland, New Zealand. Auckland (NZ): University of Auckland. https://www.geothermal-energy.org/pdf/IGAstandard/NZGW/2022/013.pdf

APPENDICES

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APPENDIX 1 GEOTHERMAL AVAILABILITY AND COST WORKSTREAM, BAY OF PLENTY RETA WORKSHOP PRESENTATION

Appendix 1 is provided as the **GNS SR2024-02 Appendix 01 – GNS RETA BOP presentation_final.pdf** file attachment in the PDF.

APPENDIX 2 OPEN GROUND WATER SYSTEM AT THE CHRISTCHURCH ARTS CENTRE

Appendix 2 is provided as the **GNS SR2024-02 Appendix 02 – Green Energy Christchurch Arts Centre 31_10-2017. pdf** file attachment in the PDF.

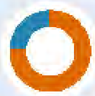
APPENDIX 3 CHÂTEAU PONTET-CANET WINERY – FRENCH CASE STUDY

Link to the Château Pontet-Canet Winery case study.

Château Pontet-Canet Winery

CLIMATE ZONE
Average monthly temperature
3°C - 26°C

ENERGY SYSTEM



76%
Heating Energy
24%
Cooling Energy

Château Pontet-Canet classified Bordeaux Grand Cru since 1855

The winery owner's brief was to integrate the energy needs of the buildings using shallow geothermal energy sourced locally from within the vineyard. An very important aspect is the notion of "terroir" (from the earth) ensuring provision, for the long term, of sustainable ecological energy. The main challenge was to feed the different buildings with their specific energy needs: rooms for seasonal workers, offices, the castle, premises for staff, the wine cellars, the wine maturation processes, the reception and the stables.

The cumulative area of the buildings connected to the geothermal installation is 5850m². The maximum heating requirement occurs in October (292 kW) and the main cooling requirement (154 kW) occurs in summer (July and August). The total annual energy production is 1228 MWh supplied 100% from the geothermal resource using heat pumps.

An enthusiastic owner sustainably using geothermal energy at his vineyard to heat and cool the facility.

In Brief

Location
Pauillac, a famous village North of Bordeaux, near the Gironde estuary, France.

Heat pumps
663 kW - 3 compressors each with 221 kW heating capacity and 158 kW cooling capacity.

Site details
Two closed loop geothermal systems comprising:

- 67 vertical probes arranged in three groups, in the vineyard, servicing the winery.
- 6 vertical probes servicing the residential housing zone.

Annual Energy
Heating 841.7 MWh
Cooling 292.3 MWh
Sanitary hot water 94 MWh

Economics
Total CAPEX (2017): 1,144,000€

Savings of 60,000€ per year compared to propane gas solution.

Aerial view of the winery.

Location of the 74 vertical probes in four zones.

Drilling the vertical probes (left). Installing the polyethylene loops (lower right). Trenches for connecting pipes (top right).

"One of 40 geothermal installations providing energy to the wine sector in France"

The project has a sophisticated centralized plant room connecting the facilities to the energy source. Energy management is implemented via computer from several workstations controlling 3 chillers, the simultaneous production of heating and cooling, and the centralized production of sanitary hot water.

Three geothermal probe fields provide the energy:

- 3 groups cover all the energy needs.
- 2 groups are active in winter.
- 1 group in summer.
- Probe groups (zones) are operated alternately.
- Hot or cold water depending on what is required to be produced and distributed.
- The sensor field receives hot, chilled or a mixed temperature water depending on the circumstances.

The energy production is from:

- 3 TRANE CGWH chillers / heat pump units each with cooling capacity of 158 kW and heating capacity of 221 kW.
- 3 air handling units and their distribution networks.
- 61 tanks, separately, able to be heated or cooled.
- Numerous radiators and fan coil units.

The installation has been operational since 2017 with the expected performance in line with the design for this closed loop geothermal system. A monitoring program measures the evolution of underground temperatures with time along with the performance of the heat pumps.

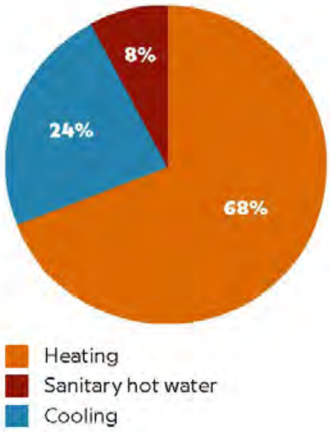
The investment in the energy part of this project was 1,144,000€, corresponding to 4000€ per kW installed. The Heat Fund managed by ADEME, the Agency of the Ministry of Energy Transition subsidized the installation with a grant of 429,000€ (37% of the investment).

The payback time of the investment compared to a gas solution is 12 years including the government support.

Further Information

Click the link below
Château Pontet-Canet Winery.

Annual energy production (delivered energy) is 1,228 MWh.



AFPG
French Association of Geothermal Energy Professionals
77 rue Claude Bernard – 75005 Paris
www.afpg.asso.fr

www.iea-gia.org

APPENDIX 4 VERTICAL PROBE INSTALLATION IN QUEENSTOWN

This architecturally designed home is heated with a vertical ground source heat pump.

Queenstown Family Home Heated from 120 m Underground.

Ground source heating was a natural choice as a heating solution when Ian Adamson designed his family's energy efficient home in Queenstown.

Ian Adamson installed a ground source heating system in his new family home near Dalefield in 2011.

As an architect, Ian has a unique insight into the construction industry, and knew what he wanted to achieve when building his own home.

He says it was vital to ensure that his family were warm and comfortable all year round, but sustainability and environmental considerations were equally as important.

The home was designed to be as energy efficient as possible. High levels of insulation are a feature of the home, well beyond minimum specifications set in the building code.

It has also been designed to take advantage of a sheltered northerly aspect, with concrete slabs acting as thermal mass areas by gaining and storing the sun's energy.

Given the focus on energy efficiency during the design phase, when it came to a heating solution, ground source heating was a natural choice.

KEY BENEFITS:

- Vertical system requires very small installation area
- Maintains high heating efficiency even when air temperatures are low
- All rooms in the home are heated evenly
- Low running costs, noise and visual impact

KEY FEATURES:

- System installed in 2011
- 2 x 120 m deep bore holes, closed loop system
- 11 kW system providing hot water to underfloor heating pipes and hot water for domestic use
- Heated area: 280 m²
- 5kw photovoltaic solar system installed on the roof in 2014 to provide greater efficiency

Queenstown Home with 120-m-deep vertical probes.

Water is circulated in small iron pipes adjacent to the plants to provide heat to the plants.

"WE LIKE THAT WE ARE USING A FULLY RENEWABLE RESOURCE BY ACCESSING LATENT ENERGY FROM THE GROUND."

Ground source heating remains highly efficient, even when outside air temperatures plummet.

"The extremes of our climate here in Queenstown and a belief in sustainability have strongly influenced our decision to run with ground source heating," Ian says.

"We wanted a highly efficient heating solution with low operating cost and without the hassle of chopping wood or ordering diesel or wood pellets. Ground source heating was a good fit. We also like that we are using a fully renewable resource by accessing latent energy from the ground."

While the site was large enough to install a horizontal captor field, Ian opted for a vertically installed, closed loop system.

"The benefit of a vertical system is that we were able to install without any major disruption to existing landscaping, it didn't affect our construction schedule and hasn't tied up a large area of land.

"I was initially concerned about the drilling process and resulting mess, however it was the complete opposite with the rig in and out in six days, complete with holes grouted. All slurry was collected and removed from site."

The system consists of two bores, 12 metres apart, drilled to a depth of approximately 120 metres.

A 'U' shaped pipe was installed in each bore before they were sealed and capped.

A water/glycol solution is circulated through these pipes to gain heat from the earth. As the site is not over an aquifer and there is no risk of groundwater contamination, resource consents from the local council were not required for this project.

Having been through a few winters, Ian and his family are impressed with their heating system.

"We have moved from a smaller house where you tend to heat spaces you are occupying, to now running the entire house at 20°C, with bedrooms around 18°C. The system is completely self regulating and hassle free."

Ian says choosing an installer was an important decision in the process. He engaged Heated Ltd. to install an 11 kw Bosch system.

"It is a big investment, so we wanted it done right. We liked that our installer has a direct association with the manufacturer of the heat pump unit. We had the confidence that it would be installed right the first time.

In 2014, Ian installed a 5kw photovoltaic solar system on the roof, to provide even greater energy efficiency in his family home.

A drilling rig is needed on site to install a vertical ground source system.

Ian Adamson
Home owner and Architect

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New Zealand requires reliable, renewable energy sources into the future. The Government is supporting GNS Science in fostering increased use of renewable resources. By 2025, the Government's Energy Strategy aims for direct use of geothermal energy to account for more than 12 PJ/year.

For more information visit our website:
www.gns.cri.nz/earthenergy
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GNS

APPENDIX 5 EXTRACT FROM THE CLIMATE CHANGE RESPONSE ACT 2022

Below are extracts of pertinent parts of the Climate Change Response Act 2022 and associated Regulations.

A person must comply with regulations 19 and 20 (text below) if the person, in any year, is a participant under section 54(1)(a) of the Climate Change Response Act 2002 in respect of the activity in Part 3 of Schedule 3 of the Climate Change Response Act 2002 of using geothermal fluid for the purpose of **generating electricity or industrial heat**.

Regulations 19 and 20 of the Climate Change (Stationary Energy and Industrial Processes) Regulations 2009 – Version 1 January 2023.

19 Collection and recording of information for purpose of calculating emissions from using geothermal fluid

(1) The following information must be collected and recorded in relation to each class of geothermal fluid used in the year for the purpose of generating electricity or industrial heat:

(a) for a class referred to in Part A of Table 6 of Schedule 2, or a class defined in a unique emissions factor approval that relates to a plant that uses, or makes a particular use of, geothermal steam, the total number of tonnes of geothermal production steam used by the person in the year; and

(b) for a class referred to in Part B of Table 6 of Schedule 2, or a class defined in a unique emissions factor approval by reference to a plant that uses, or makes a particular use of, geothermal fluid that does not relate to steam production, the total number of tonnes of 2-phase geothermal fluid used by the person in the year.

(2) For the purposes of subclause (1)(a), geothermal production steam used—

(a) includes non-condensable gases and steam vented from system emergency vent facilities; but

(b) does not include—

(i) fugitive steam released during well testing or well bleeding; or

(ii) steam released from the disposal of spent geothermal fluid; or

(iii) steam released from unused but maintained production wells.

20 Method of calculating emissions from using geothermal fluid

(1) Emissions in relation to each class of geothermal fluid referred to in regulation 19(1)(a) that is used for the purpose of generating electricity or industrial heat by the person in the year must be calculated in accordance with the following formula:

$$E = A \times EF$$

where:

A is the number of tonnes of geothermal production steam of the class used by the person during the year, as recorded under regulation 19(1)(a)

E is the emissions for the class of geothermal fluid used in tonnes

EF is;

(a) in relation to a class of geothermal fluid listed in Part A of Table 6 in Schedule 2 for which no unique emissions factor is in force, the emissions factor for the class of geothermal fluid from that Table; and

(b) in relation to a class of geothermal fluid defined in an approval to use a unique emissions factor, the unique emissions factor for that class.

(2) Emissions in relation to each class of geothermal fluid referred to in regulation 19(1)(b) used for the purpose of generating electricity or industrial heat by the person in the year must be calculated in accordance with the following formula:

$$E = A \times EF$$

where:

A is the number of tonnes of 2-phase geothermal fluid of the class used by the person during the year, as recorded under regulation 19(1)(b)

E is the emissions for the class of geothermal fluid used in tonnes

EF is;

(a) in relation to a class of geothermal fluid listed in Part B of Table 6 in Schedule 2 for which no unique emissions factor is in force, the emissions factor for the class of geothermal fluid from that Table; and

(b) in relation to a class of geothermal fluid defined in an approval to use a unique emissions factor, the unique emissions factor for that class.

(3) An emissions return submitted by a person who is required to comply with this regulation must record the person's total emissions from the activity of using geothermal fluid for the purpose of generating electricity or industrial heat in the relevant year, calculated by adding together the emissions for each class of geothermal fluid used, as calculated under subclauses (1) and (2).

(4) If a person who is required to comply with this regulation is required to submit an emissions return for a period other than a year, this regulation applies with any necessary modifications.

Default Emissions Factors for Geothermal Fluid

Table 6 Geothermal Fluid

Part A

Class Geothermal fluid used by	Emissions Factor	Unit
Kawerau II	0.0202	tCO_2e/t steam
Kawerau Industrial	0.0202	tCO_2e/t steam
Kawerau KA24	0.0202	tCO_2e/t steam
Mokai I and II	0.0053	tCO_2e/t steam
Nga Awa Purua	0.0181	tCO_2e/t steam
Ngawha I and II	0.0930	tCO_2e/t steam
Ohaaki	0.0604	tCO_2e/t steam
Poihipi Road	0.0049	tCO_2e/t steam
Rotokawa I	0.0228	tCO_2e/t steam
Wairakei station site	0.0051	tCO_2e/t steam
Any other plant or process using geothermal steam to produce electricity or industrial heat	0.0300	tCO_2e/t steam

Part B

Class Geothermal fluid used by	Emissions Factor	Unit
Mokai Greenhouse	0.0000	tCO_2e/t2–phase fluid
Tauhara Tenon	0.0009	tCO_2e/t2–phase fluid
Any other plant or process using geothermal fluid to produce electricity or industrial heat through a process other than production of geothermal steam	0.0009	tCO_2e/t2–phase fluid

APPENDIX 6 REGULATIONS ASSOCIATED WITH UNIQUE GEOTHERMAL EMISSIONS FACTORS

Link to Climate Change (Unique Emissions Factors) Regulations 2009.

(b) confirmation that the person or laboratory that carried out the tests referred to in regulation 22(3) holds the certification or accreditation required by that paragraph; and

(c) the calculations done under subclause (3), if relevant, and regulation 23; and

(d) any other information required by the recognised verifier as necessary to provide verification of the unique emissions factor for the purposes of regulation 24.

Regulation 13(1): amended, on 5 December 2011, by section 53(2) of the Environmental Protection Authority Act 2011 (2011 No 14).

Using geothermal fluid

14 Geothermal participant may apply for approval to use unique emissions factor

(1) A geothermal participant may apply to the EPA for approval to use a unique emissions factor when calculating emissions in relation to a class of geothermal fluid in accordance with the Climate Change (Stationary Energy and Industrial Processes) Regulations 2009.

(2) However, a geothermal participant may apply for approval to use a unique emissions factor only if the difference between the unique emissions factor and the default emissions factor that would otherwise apply to the geothermal fluid is more than the estimated uncertainty.

Regulation 14(1): amended, on 5 December 2011, by section 53(2) of the Environmental Protection Authority Act 2011 (2011 No 14).

15 Requirements relating to application for unique emissions factor approval by geothermal participant

A geothermal participant who wishes to apply for approval to use a unique emissions factor in relation to a class of geothermal fluid defined by reference to—

(a) a plant that uses, or a particular use of, geothermal steam, must comply with regulation 16:

(b) a plant that uses, or a particular use of, geothermal fluid that does not relate to steam production must comply with regulation 17.

16 Requirements for applications for unique emissions factor approval for geothermal fluid use calculated by reference to steam production

(1) A geothermal participant who wishes to apply for approval to use a unique emissions factor in relation to a class of geothermal fluid defined by reference to a matter in regulation 15(a) must—

(a) obtain representative samples of the geothermal steam to which the application relates in accordance with either—

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(i) the procedures and standards in—

(A) ASTM E947–83 (Reapproved 2007)— (equipment to be used for the collection of uncontaminated and representative samples from single-phase steam pipelines); and

(B) ASTM E1675–04 for Sampling 2-Phase Geothermal Fluid for Purposes of Chemical Analysis (as applicable to sampling single-phase steam only); or

(ii) the procedures and standards in a published geothermal fluid sampling methodology with accuracy and reliability equivalent to the standards in subparagraph (i); and

(b) have the following tests carried out on each of the samples of the steam by a person or laboratory that is accredited as complying with ISO 17025:2005 by International Accreditation New Zealand, an overseas accreditation agency with whom International Accreditation New Zealand has a mutual recognition agreement, or an overseas accreditation agency recognised under New Zealand's mutual recognition arrangements to carry out the tests:

(i) gas chromatography (to determine CH_4 content); and

(ii) standard chemistry titration analysis methods (to determine CO_2 content); and

(c) measure the tonnes of steam produced per hour at, or downstream of, each separation point, or if the system has multiple steam transmission lines, then at each mix point; and

(d) calculate the emissions factor for each steam separation point or mix point in accordance with the following formula:

$$EF_S = m_{CO2} + (m_{CH4} \times 25)$$

where—

EF_S is the emissions factor for the steam at the separation or mix point expressed as tonnes of carbon dioxide equivalent gases per tonne of steam (tCO_2e/t steam)

m_{CH4} is the mean mass fraction of CH_4 in the steam samples at the separation or mix point as determined by reference to the results of the tests referred to in paragraph (b)(i) and expressed in tonnes of methane per tonne of steam (tCH_4/t steam)

m_{CO2} is the mean mass fraction of CO_2 in the steam samples at the separation or mix point as determined by reference to the results of the tests referred to in paragraph (b)(ii) and expressed in tonnes of carbon dioxide per tonne of steam (tCO_2/t steam); and

(e) calculate the unique emissions factor for the class of geothermal fluid in accordance with the following formula:

$$UEF = [\sum(EF_S \times A) \div \sum A] - EF_R$$

where—

A is the tonnes of steam produced by each separation or mix point per hour as measured in accordance with paragraph (c)

EF_R is,—

(a) if an adjustment for reinjection of steam condensate is claimed, the emissions factor for steam condensate being reinjected as calculated under subclause (2); or

(b) if no adjustment for reinjection of steam condensate is claimed, zero

EF_S is the emissions factor for the relevant steam separation or mix point determined under paragraph (d)

UEF is the unique emissions factor for the class of geothermal fluid expressed in tonnes of carbon dioxide equivalent gases per tonne of steam (tCO_2e/t steam); and

(f) submit the following material to a recognised verifier:

(i) a record of the sampling regime that complies with the procedures and standards referred to in paragraph (a) and, if relevant, a record of the sampling regime that complies with subclause (2)(a); and

(ii) confirmation that the person or laboratory that carried out the tests referred to in paragraph (b) and, if relevant, subclause (2)(b), holds the certification or accreditation required by that paragraph; and

(iii) the test results for the tests referred to in paragraph (b) and, if relevant, the test results for the tests in subclause (2)(b); and

(iv) the estimated uncertainty associated with the unique emissions factor; and

(v) the calculations done under paragraphs (d) and (e) and, if relevant, subclause (2)(c); and

(vi) any other information required by the recognised verifier as necessary to provide verification of the unique emissions factor under regulation 24.

(2) A geothermal participant who wishes to claim an adjustment to a unique emissions factor calculated under subclause (1) to account for the reinjection of condensate from the class of geothermal fluid into a geothermal field must—

(a) obtain representative samples of the steam condensate being reinjected in accordance with the procedures and standards referred to in subclause (1)(a); and

(b) have the tests referred to in subclause (1)(b) carried out on each of the samples of the steam condensate by a person or laboratory that is accredited as complying with that subclause; and

(c) calculate an emissions factor for the reinjected condensate in accordance with the following formula:

$$EF_R = m_{CO2} + (m_{CH4} \times 25)$$

where—

EF_R is the emissions factor for the condensate being reinjected expressed in tCO_2e/t condensate

m_{CH4} is the mean mass fraction of CH_4 in the condensate being reinjected as determined by reference to the results of the tests referred to in paragraph (b) and expressed in tCH_4/t condensate

m_{CO2} is the mean mass fraction of CO_2 in the condensate being reinjected as determined by reference to the results of the tests referred to in paragraph (b) and expressed in tCO_2/t condensate.

(3) The following rules apply to measurement of steam for the purposes of this regulation:

(a) measurement of the steam quantity produced must be undertaken with a venturi flow meter (or other equipment with at least the same accuracy):

(b) the sample port where the samples are collected for the purposes of subclauses (1)(a) and (2)(a) must be located—

(i) immediately after the separation points; or

(ii) if the system has multiple steam transmission lines, at a point where a good mixed sample of the steam can be obtained:

(c) the calculation of steam quantities must be conducted on a continuous basis and in accordance with ISO 5167–1:2003.

Regulation 16(1)(d) formula: amended, on 1 January 2014, by regulation 6(1) of the Climate Change (Unique Emissions Factors) Amendment Regulations 2013 (SR 2013/383).

Regulation 16(2)(c) formula: amended, on 1 January 2014, by regulation 6(2) of the Climate Change (Unique Emissions Factors) Amendment Regulations 2013 (SR 2013/383).

17 Requirements for applications for unique emissions factor approval for geothermal fluid use calculated by reference to non-condensable gas concentrations

(1) A geothermal participant who wishes to apply for approval to use a unique emissions factor in relation to a class of geothermal fluid defined by reference to a matter in regulation 15(b) must—

(a) obtain representative samples of the 2-phase geothermal fluid for which the unique emissions factor is sought in accordance with the procedures and standards in—

(i) ASTM E1675–04 (for Sampling 2-Phase Geothermal Fluid for Purposes of Chemical Analysis); or

(ii) a published geothermal fluid sampling methodology with equivalent accuracy and reliability to the standard referred to in subparagraph (i); and

(b) have the following tests carried out on each of the samples of the 2-phase geothermal fluid by a person or laboratory that is accredited as complying with ISO 17025:2005 by International Accreditation New Zealand, an overseas accreditation agency with whom International Accreditation New Zealand has a mutual recognition agreement, or an overseas accreditation agency recognised under New Zealand's mutual recognition arrangements to carry out the tests:

(i) gas chromatography (to determine CH_4 content); and

(ii) standard chemistry titration analysis methods (to determine CO_2 content); and

(c) calculate the emissions factor for the 2-phase fluid in accordance with the following formula:

$$EF_{fluid} = m_{CO2} + (m_{CH4} \times 25)$$

where—

EF_{fluid} is the emissions factor for the class of 2-phase fluid expressed in tonnes of carbon dioxide equivalent gases per tonne of 2-phase fluid (tCO_2e/t fluid)

m_{CH4} is the mean mass fraction of CH_4 in the samples of the 2-phase geothermal fluid as determined by reference to the results of the tests referred to in paragraph (b)(i) and expressed in tonnes of methane per tonne of 2-phase fluid (tCH_4/t fluid)

m_{CO2} is the mean mass fraction of CO_2 in the samples of the 2-phase geothermal fluid as determined by reference to the results of the tests referred to in paragraph (b)(ii) and expressed in tonnes of carbon dioxide per tonne of 2-phase fluid (tCO_2/t fluid); and

(d) calculate the unique emissions factor for the class of geothermal fluid in accordance with the following formula:

$$UEF = EF_{fluid} - EF_T$$

where—

EF_{fluid} is the emissions factor for the class of 2-phase fluid as calculated in accordance with paragraph (c) expressed in tonnes of carbon dioxide equivalent gases per tonne of geothermal fluid (tCO_2e/t fluid)

EF_T is,—

(a) if an adjustment for reinjection of single-phase fluid is claimed, the emissions factor for reinjected single-phase fluid relating to the class, calculated under subclause (2); or

(b) zero, if no adjustment is claimed

UEF is the unique emissions factor for the class of geothermal fluid expressed in tonnes of carbon dioxide equivalent gases per tonne of 2-phase fluid (tCO_2e/t fluid); and

(e) submit the following material to a recognised verifier:

(i) a record of the sampling regime that complies with the procedures and standards referred to in paragraph (a) and, if relevant, a record of the sampling regime that complies with subclause (2)(a); and

(ii) confirmation that the person or laboratory that carried out the tests referred to in paragraph (b) and, if relevant, subclause (2)(b), holds the certification or accreditation required by those provisions; and

(iii) the test results for the tests referred to in paragraph (b) and, if relevant, the test results for the tests in subclause (2)(b); and

(iv) the estimated uncertainty associated with the unique emissions factor; and

(v) the calculations done under paragraph (c) and (d) and, if relevant, subclause (2)(c); and

(vi) any other information required by the recognised verifier as necessary to provide verification of the unique emissions factor under regulation 24.

(2) A geothermal participant who wishes to claim an adjustment to a unique emissions factor calculated under subclause (1) to account for the reinjection of single-phase geothermal fluid from the class of geothermal fluid into a geothermal field must—

(a) obtain representative samples of the single-phase geothermal fluid reinjected which results from use of the 2-phase geothermal fluid in accordance with the procedures and standards referred to in subclause (1)(a); and

(b) have the tests referred to in subclause (1)(b) carried out on each of the samples of the single-phase geothermal fluid by a person or laboratory that is accredited as complying with that subclause; and

(c) calculate an emissions factor for the reinjected single-phase geothermal fluid in accordance with the following formula:

$$EF_T = m_{CO2} + (m_{CH4} \times 25)$$

where—

EF_T is the emissions factor for the reinjected single-phase fluid expressed in tCO_2e/t fluid

m_{CH4} is the mean mass fraction of CH_4 in the samples of the single-phase geothermal fluid as determined by reference to the results of the tests referred to in paragraph (b) and expressed in tCH_4/t fluid

m_{CO2} is the mean mass fraction of CO_2 in the samples of the single-phase geothermal fluid as determined by reference to the results of the tests referred to in paragraph (b) and expressed in tCO_2/t fluid.

Regulation 17(1)(c) formula: amended, on 1 January 2014, by regulation 7(1) of the Climate Change (Unique Emissions Factors) Amendment Regulations 2013 (SR 2013/383).

Regulation 17(2)(c) formula: amended, on 1 January 2014, by regulation 7(2) of the Climate Change (Unique Emissions Factors) Amendment Regulations 2013 (SR 2013/383).

Combusting used oil, waste oil, used tyres, or waste

18 Waste combustion participant may apply for approval to use unique emissions factor

(1) A waste combustion participant may apply to the EPA for approval to use a unique emissions factor when calculating emissions in relation to a class of used or waste oil, used tyres, or waste in accordance with the Climate Change (Stationary Energy and Industrial Processes) Regulations 2009.

(2) However, a waste combustion participant may apply for approval to use a unique emissions factor only if the difference between the unique emissions factor and the default emissions factor that would otherwise apply to the used or waste oil, used tyres, or waste is more than the estimated uncertainty.

Regulation 18(1): amended, on 5 December 2011, by section 53(2) of the Environmental Protection Authority Act 2011 (2011 No 14).

19 Requirements relating to application for unique emissions factor approval by waste combustion participant

A waste combustion participant who wishes to apply for approval to use a unique emissions factor in relation to a class of used or waste oil, used tyres, or waste that—

(a) consists of or contains non-biomass, may calculate a unique emissions factor for the class in accordance with regulation 20 or the periodic source testing option:

(b) consists of or contains only biomass, must calculate a unique emissions factor for that class in accordance with the periodic source testing option.

APPENDIX 7 RITTERSHOFFEN GEOTHERMAL HEAT PLANT

Appendix 7 is provided as the **GNS SR2024-02 Appendix 07 - Rittershoffen Geothermal Heat Plant.pdf** file attachment in the PDF.

APPENDIX 8 LONG DISTANCE TRANSPORT LOOP EXAMPLE AT RITTERSHOFFEN

Appendix 8 is provided as the **GNS SR2024-02 Appendix 08 - 2017 Ravier et al. ECOGI Pipeline EuroHeat&Power.pdf** file attachment in the PDF.

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