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Advancing New Zealand's Supercritical Geothermal Opportunity

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ABSTRACT

Aotearoa New Zealand is investigating its supercritical geothermal opportunity. Long-term, the challenge is to go beyond conventional geothermal systems, using scientific, technological, regulatory, market and societal solutions that together, will de-risk and accelerate New Zealand's supercritical development. To support this goal, a national supercritical strategy is being designed. This strategy will build on the scientific understanding of New Zealand's supercritical resources, leverage international experience, and propose specific work streams to facilitate utilisation of these earth energy resources.

The Strategy is expected to have three phases each spanning a decade:

- 2020-2030: Research and preparation for exploration drilling
- 2030-2040: Exploration drilling, pilot scale trials and feasibility demonstration
- 2040-2050: Sector-wide deployment

In this way, the Strategy aims to advance from today's understanding to deployable technology by 2040. Sector-wide deployment by 2050 will be aligned with New Zealand's aspirations to be "carbon zero" by 2050. Action Plans will assist in implementation of the Strategy, and Action Groups will drive implementation in specific workstreams.

1. INTRODUCTION

Tapping into deeper supercritical resources to access significant reserves of higher temperature (400 ºC – 600 ºC), sustainable, renewable geothermal energy is not a new idea. Yet, present levels of understanding are insufficient to offer industry-ready solutions for New Zealand.

The supercritical geothermal opportunity for New Zealand is being assessed through a 2019-2024 Government-funded research programme; *Geothermal: The Next Generation* (Chambefort et al, 2019; 2020). Geoscience research includes theoretical evaluation and identification of supercritical resources at temperatures between 400 ºC to 600 ºC and depths down to about six kilometres. Complementary engagement, regulatory and market research activities are proposed, seeking to de-risk exploratory drilling and ultimately technology deployment.

This paper overviews this research programme, the NZ Supercritical Strategy ("the Strategy") development process, and the approach to engagement with stakeholders across the geothermal industry, academia, research, regulatory, business, Māori, the finance sector and government entities. New Zealand's supercritical journey is already underway: www.geothermalnextgeneration.com

2. NEW ZEALAND'S SUPERCRITICAL OPPORTUNITY

2.1 Government Drivers: Low-Carbon Energy Sector

The New Zealand Government is committed to accelerating the use of renewable low-carbon emission energy. New Zealand's 2050 carbon emissions target was identified by the Climate Change Commission in 2020 as ~20 Mt CO_2e (CCC, 2020), moving from a current level of ~80 Mt CO_2e (Figure 1). This ambitious target will move New Zealand to "zero carbon" by 2050.

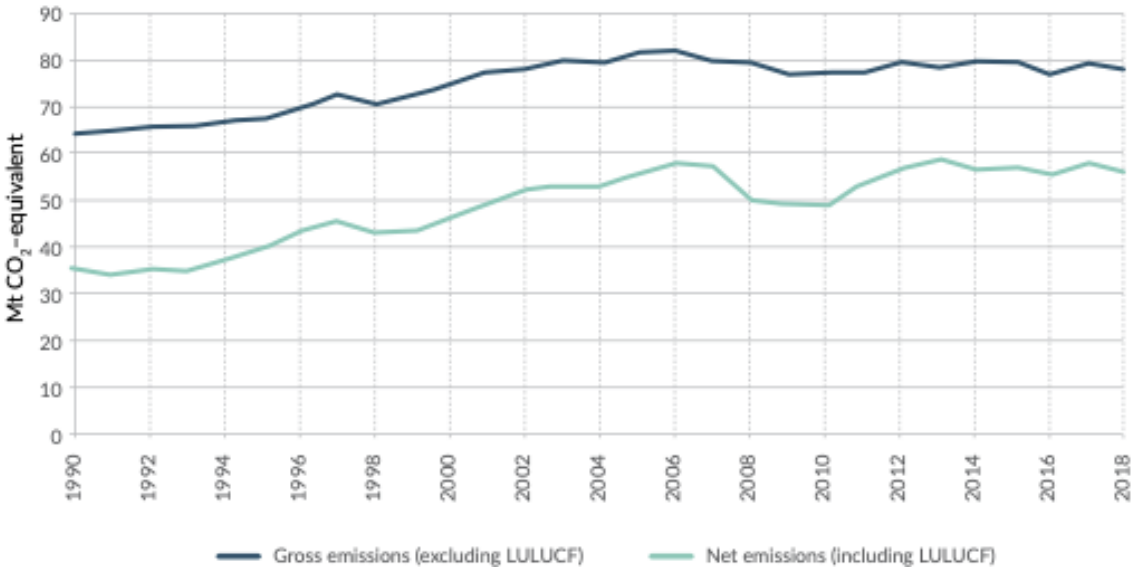

Figure 1: New Zealand's gross and net emissions from 1998 to 2018. Greenhouse gas emissions are measured in megatonnes of CO2 equivalent (Mt CO2-e). [Source: MFE, 2020]

The 2018 recorded greenhouse gas equivalent total carbon emissions from the energy sector (from both supply and use) amounted to ~32,000 ktonnes $CO_{2\text{-}e}$ (MBIE, 2018a). A broad sub-sector breakdown of carbon emissions is shown in Figure 2.

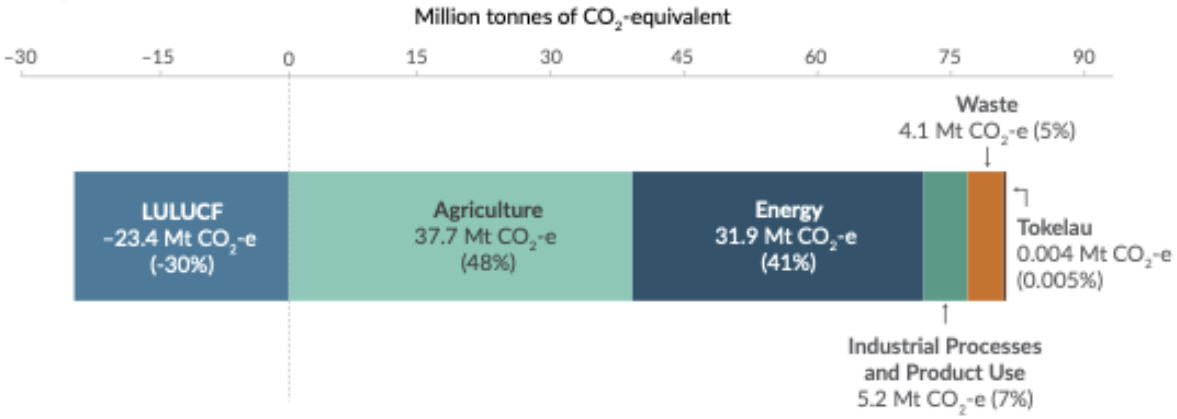

Figure 2: New Zealand emissions profile by sector, 2018. Note: Net emissions from the LULUCF (Land Use, Land Use Change and Forestry) sector are expresed as a negative number because the sector removes more greenhouse gases from the atmosphere than it emits. [Source: MFE, 2020]

The Climate Change Response (Zero Carbon) Amendment Act 2019 (NZ Government, 2019) aims to set a framework for New Zealand's transition to a low emissions and climate resilient economy. Key focus areas are de-carbonisation of the transport sector, coupled with more renewable electricity generation and increasing efficiency of industrial process heat (reducing the consumption of fossil fuels). In December 2020. New Zealand joined 32 other nations in formally acknowledging the global crisis (RNZ, 2020).

New Zealand's electricity supply was 82% renewably generated in 2019, of a total of 156 PJ net generation (MBIE 2019b). Carbon-friendly energy sources, including geothermal, will need to significantly increase their energy contribution in order for New Zeeland to realise its carbon-zero aspiration.

Geothermal energy is currently a strong contributor to New Zealand's renewable energy portfolio. The 2019 data (MBIE, 2019a; 2019b) showed:

- Geothermal energy supplied ~22% of New Zealand's primary energy, that is then converted into an energy form that is consumed (such as electricity or process heat).
- Geothermal energy accounted for 5.5% of all the energy consumed in New Zealand.
- Geothermal generated electricity supplied ~17% of New Zealand's total electricity

However, under current practices and technology, geothermal energy is not zero-carbon — geothermal operations do emit greenhouse gases from the extracted geothermal fluids (MBIE, 2018a). The level of CO_2 in the fluid varies significantly between geothermal fields, and monitoring shows emissions decrease over time as geothermal systems de-gas (McLean and Richardson, 2019).

While operational geothermal CO_2-equivalent emissions are higher than other renewable energy sources, such as wind, hydro or solar energy, geothermal energy can supply critical baseload / non-variable energy supply that is not impacted by climatic conditions (e.g. rainfall, wind, sunlight hours etc). Geothermal emissions are also significantly lower than fossil fuel plants: in the last ten years, as New Zealand's geothermal electricity generation increased and fossil-fuel based generation decreased, the overall emissions intensity of the electricity sector approximately halved (McLean and Richardson, 2019).

Looking forward, for geothermal to play a key role in the zero-carbon energy New Zealand future, the greenhouse gas emissions from conventional geothermal resources and supercritical development will need to be appropriately managed. Technological solutions do exist, and are already being developed and tested.

2.2 Geothermal Growth Opportunities

The challenge for the geothermal electricity sector is to sustainably use conventional geothermal systems to the fullest possible extent, *and* to go beyond conventional resources, tapping into deeper supercritical heat resources - expected to offer substantial additional energy potential. Voluminous magma resources at temperatures above 750°C form at relatively shallow depths in parts of New Zealand. This provides heat that is transferred and then contained in rocks at supercritical temperatures (Chambefort et al., 2017; 2020). Growth opportunities for New Zealand's hotter, deeper supercritical resources include replacement of the 7 GW electricity currently generated by fossil fuels, as well as large industrial heat and energy uses.

Electricity Generation

New Zealand is seeking 100% renewable electricity by 2030 (ICCC, 2019; NZ Labour Party, 2020). There is some scope for further de-carbonisation of electricity supply using geothermal, and there are significant opportunities for renewable electricity to substitute for fossil-fuel usage through electric transport options and heat supply to the industrial sector.

In NZ Government future projections of energy supply and use, new generation capacity is required with electricity demand projected to grow between 18% and 78 % by 2050. The renewables share of electricity generation increases in all scenarios, projected to increase from 82% in 2017 to around 95% by 2050. Total energy sector greenhouse gas emissions fall significantly across all scenarios (MBIE, 2019c).

This growth assumed electrification of process heat and the energy required to charge electric vehicles, as well as economic growth of 42% - 132% over the period (noting that this report was published prior to the COVID pandemic).

Process Heat Opportunities

New Zealand's existing direct geothermal use spans sectors including tourism, industrial, horticulture, aquaculture, commercial and residential. While bathing is the most abundant operation, process heat demand is the largest direct use of geothermal energy (Daysh et al., 2020).

There is significant scope for geothermal energy to provide a greater contribution to New Zealand's process heat demand. In 2016, around 55% of New Zealand's process heat demand was supplied by burning fossil fuels, and 4% was supplied by geothermal resources (MBIE, 2018b). Geothermal resources can supply heat for new businesses and can also be retrofitted in existing operations to replace fossil fuel supplies. Supercritical resources are a possible opportunity for geothermal to supply significant quantities of heat energy, and at higher supply temperatures than conventional geothermal energy, opening up new industrial applications that have previously not been suitable candidates for direct geothermal use (Climo et al., 2020c).

2.3 Geothermal: The Next Generation

Geothermal: The Next Generation (GNG) is a Government-funded research programme (2019-2024) established to identify what needs to occur for New Zealand to establish hotter and deeper earth resources as a part of the nation's 2050 energy portfolio (Chambefort et al., 2019).

GNG is organised into three research themes: 'Explore' and 'Understand' deliver scientific outputs, whilst 'Integrate' disseminates the knowledge gained and engages with the broader New Zealand and global geothermal communities (GNS Science, 2020).

EXPLORE for future geothermal resources

Using geological and geophysical data from the Taupō Volcanic Zone (TVZ), the structure of the greywacke basement and the influence and location of magmatic bodies will be analysed to identify areas with prospective, drillable supercritical conditions. The research seeks to test the hypothesis that optimal supercritical conditions in the TVZ are found where magmatic heat encounters buried structures above the ductile region, focusing on depths shallower than 10 km. Modelling of thermomechanical and thermochemical processes above large silicic magma and in shear zone will identify the most likely locations of any shallower supercritical resources.

UNDERSTAND the thermochemistry of supercritical resources

Utilisation of supercritical fluids is dependent on understanding the effects of fluid-rock interaction under supercritical conditions, as fluid's properties change at high temperature compare to conventional geothermal systems. The research seeks to define chemical species distribution and fluid-rock interactions, and model behaviour of dissolved and volatile (e.g. non-condensable gas) species influence by active magmatic degassing in the crust, and during fluid extraction and injection (including injection of carbon dioxide and hydrogen sulfide).

INTEGRATE and translate knowledge

A robust understanding of the opportunities and challenges will de-risk future investment and accelerate deployment of supercritical resources in New Zealand. The activities aim to translate supercritical research and inform an engaged stakeholder community for the next generation of geothermal. Informed by expertise from within the project as well as international research group leading supercritical programme, and through external engagement with Māori, multigenerational kaitiakitanga (guardianship) philosophy with respect to resource use will assist in providing the necessary thinking, information and insights that will lead to the development of long term sustainable supercritical projects.

A broad range of supporting studies and initiatives will occur in GNG in parallel to the science programme (some examples below).

Website: A website is the key dashboard to facilitate communication with industry, Māori, land owners, government agencies and others. Visit www.geothermalnextgeneration.com to find out how to get involved.

Inventory: An inventory of New Zealand's supercritical resource potential, assets and infrastructure will focus on potential large-scale projects in prospective geological settings and incorporating international insights.

Market Propositions: Complementary and prioritised market value propositions will be identified for energy suppliers and high energy demand users. This includes data and information needed to build business cases for investment.

Planning Framework: A regulator-industry-Māori geothermal "think-tank" will provide recommendations on the optimal way to regulate the use of supercritical resources. The current planning regime will be considered, along with how this might apply to supercritical resource use. The work will consider how we might optimise the existing (or create a new) planning regime to support sustainable supercritical resource consenting, utilisation and system management.

Publication & Conferences: GNG will publish in peer-reviewed journals, release summary reports, update reports on the website, and communicate through proceedings papers and conference presentations. The New Zealand Geothermal Workshop will have an annual update paper on the GNG programme. For WGC 2020, a forum hosted by GNG will be run in Reykjavík Iceland in May 2021.

One of the activities GNG team is to initiate development of a Supercritical Strategy for Aotearoa New Zealand. However, GNG is just a small part of the overall activity that is required to realise a supercritical future for New Zealand.

3. SUPERCRITICAL STRATEGY DEVELOPMENT

The proposed scope of a New Zealand supercritical strategy focusses on the development of supercritical resources for electricity generation, provision of fuels for transportation (hydrogen) and large-scale industrial process heat supply. This aligns with Government, industry, Māori and local aspirations for economic growth and a sustainable energy future for Aotearoa.

A supercritical heat strategy for New Zealand will accelerate and coordinate utilisation of supercritical resources. The Strategy is expected to have three phases (Figure 3) each spanning a decade:

- 2020-2030: Research and preparation for exploration drilling
- 2030-2040: Exploration drilling, pilot scale trials and feasibility demonstration
- 2040-2050: Sector-wide deployment

The GNG research programme aims to initiate the development of the Strategy and contribute to early-stage research, however the Strategy itself is boarder in scope and longer in duration than GNG. For this reason, the Strategy will be hosted and led by the New Zealand Geothermal Association.

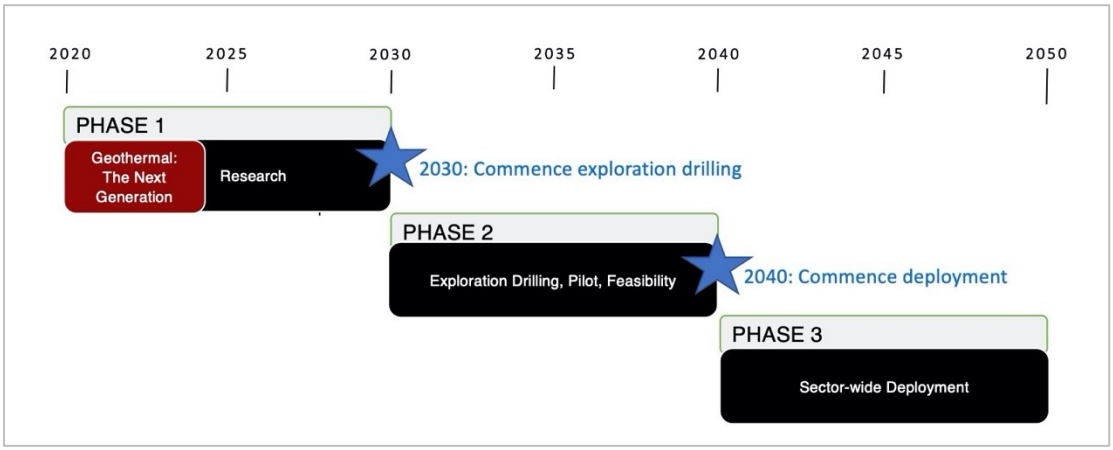

Figure 3: Phases in proposed NZ supercritical strategy.

The Strategy aims to advance from today's understanding to deployable technology by 2040. Sector-wide deployment by 2050 will be aligned with New Zealand's aspirations to be "carbon zero" by 2050. This is an ambitious target, considering that supercritical technology in New Zealand is currently at a low level of readiness (Figure 4).

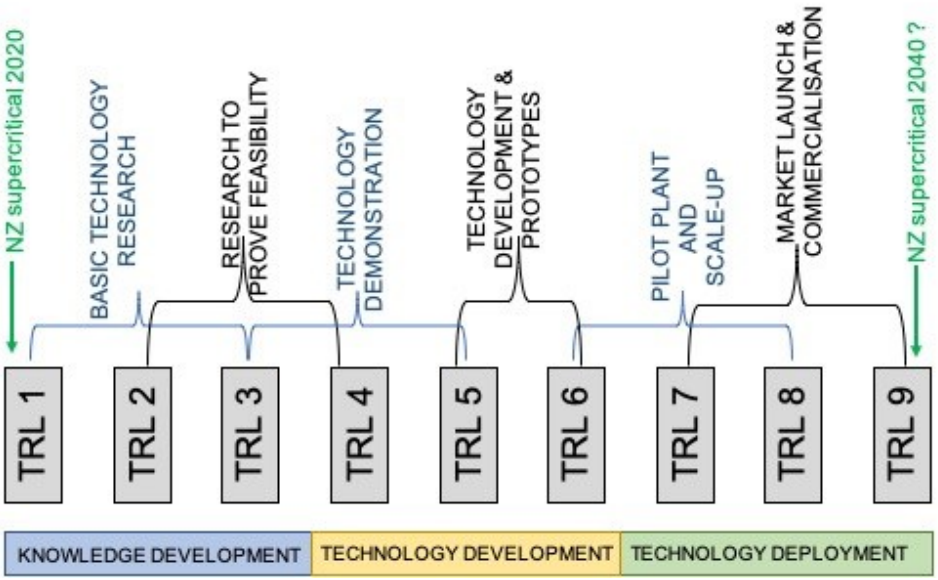

Figure 4: Technology readiness levels (redrawn from EARTO, 2014; Climo et al, 2020b)

The Strategy development process aims to:

1. identify strategic issues, opportunities and barriers – including planning frameworks, environment and sustainability considerations, competitor analysis/advantages, information gaps, etc;
2. build on the most current scientific understanding of NZ's supercritical resources, and account for international experiences;
3. engage with potential players across NZ and global industry, researchers, business, Māori, and Government; and
4. prioritise actions that leverage strengths to maximise opportunities and reduce barriers to uptake.

Today, there are more questions than answers as to what the supercritical future for New Zealand might look like, and a collaborative, consultative processes is essential to develop the most promising pathway for supercritical technology delivery for New Zealand.

3.1 Structured for Success

The following information outlines the current vision and plans for the Strategy (at December 2020). This is expected to change and evolve as the Strategy develops and stakeholders are engaged and consulted. Much of the approach, strategy structure and consultation design being applied here builds on the successes and lessons learned through the development of a Geoheat Strategy for New Zealand (Climo et al, 2016; Climo et al, 2017).

Themes

Scientific, technological, regulatory, market and societal solutions must work together to de-risk and accelerate New Zealand's supercritical development. Climo at al., (2020b) poses a detailed list of questions being considered. The Strategy will be built around stakeholders who need to be involved, identifying questions to be answered, confirming issues to be resolved, overcoming potential barriers to development, and organising and targeting actions for maximum impact and strategic effect.

Preliminary thinking and discussion has highlighted five high-level themes, that may become or inform workstreams in the Action Plan(s). Consultation and strategy development will also be structured around these five themes, acknowledging that flexibility needs to be retained should the consultation process identify new or refined themes.

Currently proposed themes are:

1. Science
2. Engineering
3. Regulatory
4. Investment
5. CO_2 management

Partnering Organisations

Our long-term vision is for the Strategy to be owned by the geothermal industry as a whole, not any single company nor organisation.

Supercritical strategy and action plan development will use a consultative approach. During its funded term, GNG will lead and support development of the Strategy and the implementation of actions where they align with the scope of the GNG programme. Through discussion with New Zealand Geothermal Association (NZGA), support will come from the involvement of a number of NZGA members operating out of their own individual work capacities. The Strategy, once developed, will be presented to the NZGA board in draft for discussion and possible ratification.

A Strategy Steering Group will be established to bring oversight and guidance. The balance of the steering group will be selected on relevant skills. This small and agile group will provide advice, oversight and direction for Strategy development, action group activity and strategy progress. A member of the NZGA Board will be on the Steering Group to keep the NZGA Board appraised of the strategy development work.

Action Plans & Action Groups

The Strategy will be designed to be enduring, whilst the accompanying short-duration Action Plans will be responsive, flexibly adapting to the prevailing circumstances while seeking to take the most progressive next steps to move towards the Strategy's goals. The intention is to produce a targeted action plan under the Strategy every two to three years, to ensure that activity is regularly reviewed and remains effective.

Action Groups will support supercritical strategic implementation. They will meet regularly, gather interested/key parties into their workstreams, and develop and implement tactical plans. The appointment of a dedicated strategy coordinator will be explored if funding can be secured; this is seen an important method of supercharging progress and action, as was achieved in the Geoheat Strategy (Climo, et al., 2017).

4. ENGAGEMENT & COMMUNICATION

The GNG team is committed to establishing an engaged stakeholder community that actively supports future supercritical geothermal development in New Zealand. Success means the supercritical stakeholders are on board, embracing this future and championing it in their area of expertise.

4.1 Supercritical Stakeholders

Engagement and consultation with a wide range of stakeholders is critically important (Figure 5, Climo et al., 2020a).

Potential investors are key to realising the potential of supercritical resource development. Such investors might include (i) those with existing knowledge of geothermal energy developments, such as New Zealand and international geothermal companies, New Zealand government and ahu whenua trusts with geothermal assets; and (ii) new entrants to geothermal projects, such as private investors, Māori trusts and investment entities. For these groups, a supercritical strategy should work to ensure potential investors have confidence in the business cases for future New Zealand supercritical energy developments.

There is also a group of stakeholders expected to have an involvement in supercritical resource regulation. This involvement may stem from a statutory regulatory function, an interest in sustainable environmental outcomes and resource management, or as a future potential applicant for resource consent or other regulatory approval. This group could include local government (particularly Waikato, Bay of Plenty and Northland Regional Councils), central government (e.g. MBIE, MFE, EPA, Climate Change Commission and EECA), and Māori entities and groups, electricity generators and/or industrial heat suppliers/users.

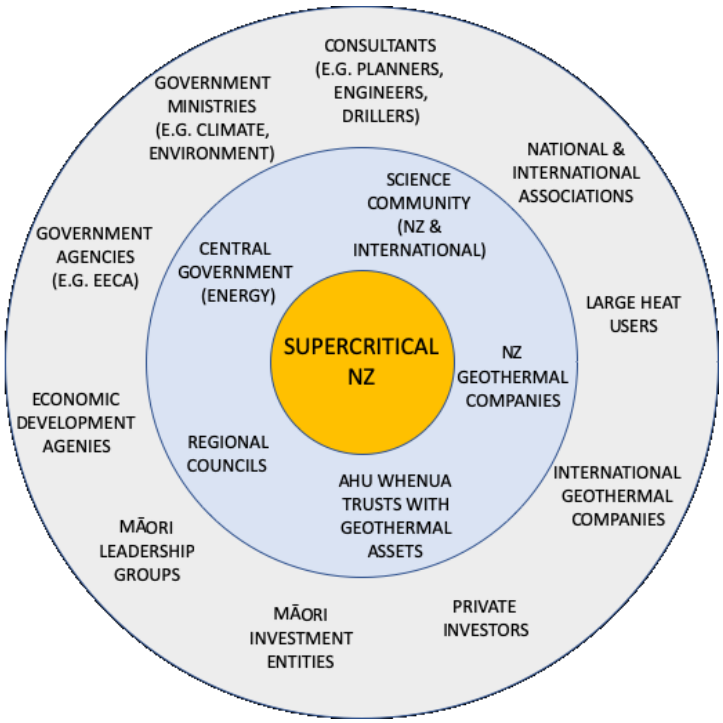

Figure 5: Key stakeholder groups with a potential interest in realising the potential of supercritical resources for New Zealand. Greater engagement activity will occur with groups within the central (blue) circle.

Additionally, developing and fostering enhanced understanding and awareness in the wider New Zealand public can support social license for ongoing supercritical research and acceptance of science outcomes (short-medium term), and de-risk industry drilling and development programmes (longer term).

A supercritical strategy should also ensure that decision making is underpinned by high quality science. Some nations are progressing deep drilling and supercritical projects and there is much value in collaboration and learning from each other (Reinsch et al, 2017). International experience will be drawn on and where possible translated to New Zealand's circumstances. Connections established with the International Partnership for Geothermal Technology (IPGT), IEA Geothermal and other international programmes in, but not limited to, Italy, Iceland, Japan, Switzerland and the USA, offer significant collaborative opportunity to assist New Zealand's supercritical development effort.

5. CONCLUSIONS

Supercritical geothermal is potentially a very large energy source for New Zealand. For existing geothermal users, a supercritical reality might mean extending the energy resource that they currently draw on, and new prospects might also be identified beyond the boundaries of what New Zealand currently identifies as a geothermal "system". With higher temperatures, more effective energy conversion might transpire, and with emissions management, supercritical geothermal energy use can be a significant contributor to New Zealand's 2050 "carbon zero" agenda.

Supercritical is the next generation of geothermal development. While supercritical geothermal energy is an, as yet, unknown resource, it may provide a vast indigenous energy source. A supercritical strategy (2020-2050) is being developed to support progression towards deployment of supercritical energy technologies. The next steps (in 2021) will be focussed on stakeholder consultation to develop the Strategy document and the first action plan (for 2021-2023).

Visit www.geothermalnextgeneration.com to follow the Strategy development progress and/or to join in the discussion and get involved.

ACKNOWLEDGEMENTS

Ehara taku toa i te toa takitahi engari he toa takitini - It is not my strength alone, but the strength of many that contribute to my success

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