Unlocking our potential: a superhot geothermal future for Aotearoa New Zealand

Deborah Kissick[1], Simon Bendall[1], Aroha Campbell[2].

[1]Traverse Environmental Ltd, P.O Box 245, Taupō, New Zealand

[2] Upflow, P.O. Box 61, Taupō, New Zealand

deborah@traverse.co.nz

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ABSTRACT

GNS Science, as part of the MBIE Endeavour Research Programme Geothermal: the Next Generation (GNG), has been considering the opportunity for superhot geothermal (> 400°C)[1] resources in New Zealand. Superhot geothermal, with potentially zero CO_2 emissions, presents an opportunity to more than double current geothermal electricity generation from 2037.

With geoscience now "looking" deeper underground and with advances in geothermal utilisation and effects management in conventional geothermal systems, Is the existing regulatory planning framework fit for purpose for superhot geothermal?

As part of exploring this question, the authors have identified a range of questions focussed on unlocking Aotearoa New Zealand's geothermal potential. While not an exhaustive analysis, these questions and challenges need to be considered to address potential barriers to a superhot geothermal-powered future as we transition to Net Zero energy.

This paper identifies a range of regulatory and broader challenges and suggests initiatives to be explored to overcome them.

1. INTRODUCTION

1.1 Geothermal: the Next Generation

The Geothermal: the Next Generation research programme (GNG) has been undertaken between 2019 and 2024. The programme has sought to advance knowledge on geological, geophysical and geochemical questions on superhot geothermal resources in the Taupō Volcanic Zone.

The programme also sought to integrate learnings about the existing regulatory and planning frameworks. Specifically, the research focussed on the regulations that apply to the development and use of geothermal resources and sought to understand the implications of this framework for managing the future use of superhot geothermal resources.

The following sections summarise the key research outcomes that provide the baseline for the issues explored in this paper.

1.2 GNG research outcomes: Regulatory Framework

As part of the GNG programme, Kissick et al. (2021) provided an overview of the planning and regulatory framework relating to existing geothermal development and the use of conventional geothermal resources in Aotearoa New Zealand. The report provides a statutory overview and details the layers of regulations for managing land and resource use that can apply to geothermal development.

This work informed further research in 2023 identifying the likely consenting requirements under the Resource Management Act 1991 (RMA) for exploratory drilling for superhot resources (Kissick et al 2023). The likely resource consent requirements for drilling a ~6km deep well at various scenario locations within the Taupō Volcanic Zone were tested. This included consideration of resources used and anticipated discharges from well site construction, well drilling and well testing.

Kissick et al (2024a) then considered the planning implications of shifting from the exploration drilling phase to the development of superhot geothermal energy resources. Using the same scenario locations in the Taupō Volcanic Zone as in Kissick et al (2023), the likely consenting requirements under the RMA for resource utilisation and reinjection, and surface development of power station facilities, were assessed.

These reports identify that the unique characteristics of each of the scenario drilling and power plant sites, alongside the classification of the geothermal system, significantly influence the nature of resource consents needed. For the scenario sites outside an identified development geothermal system, a formal plan change process to re-classify the system in the Regional Plan is required to allow a superhot production operation to be considered.

For all development scenarios, securing the right to take and use the quantities of freshwater required for drilling is anticipated to be a challenging aspect.

While the existing regulatory framework has not been designed with superhot geothermal in mind, it does not explicitly prevent superhot geothermal development, subject to the appropriate management of actual or potential adverse effects.

Drawing from each of these previous reports, Kissick et al (2024b) considers opportunities for advancing the future regulatory framework relevant to superhot geothermal in the Taupō Volcanic Zone. Potential challenges are identified that should be worked through with the key findings from the report reflected in this paper.

1.3 GNG research outcomes: Superhot Inventory

Bromley et al (2024a) used available geoscientific and resource information, to develop an inventory of New Zealand's superhot (>374 °C, >220 bara) geothermal resources. This targets the 'deep roots' of known geothermal

[1] For pure water, supercritical conditions occur at temperatures above 374°C when pressure is more than 220 bara. This paper uses the term 'superhot' as a term encompassing supercritical geothermal fluids and geothermal fluids that are superhot but not necessarily at supercritical conditions.

systems, combined with possible 'hidden' superhot resources at depths of between 3.5 to 6 km.

The deep resources assessed are predicted to occur at potentially drillable depths of less than 6 km and at temperatures of up to 500°C. The inventory focuses on the Taupō Volcanic Zone (TVZ) and the Northland Region (Ngawha).

Bromley et al (2024a) identify, as a conservative assessment, that the superhot geothermal resources offer a potential additional electrical capacity of ~3.5 GWe or 29 TWh/yr of generated electricity for New Zealand.

In a presentation on New Zealand's geothermal potential at a workshop as part of New Zealand Geothermal Week 2024, (Bromley 2024b) identified a range of challenges in developing superhot geothermal, that need to be addressed:

- The need to more widely communicate the GNG key research findings to sector stakeholders, Māori interests, government agencies, regional councils, potential funding partners, landowners and infrastructure investors.
- Improve coordination among government and interested private sector parties in seeking to mobilise the necessary investment required for exploratory wells and associated scientific research and development.
- Demonstrating that long-term energy extraction/ sustainability is achievable through exploratory superhot geothermal wells, reservoir modelling and flow testing.
- Further develop modelling methods to improve confidence in projections of future superhot behaviour and test the hypothesis that the deeper the fluid extraction/reinjection, the smaller the near-surface effect, and hence a reduced need for a pre-cautionary approach regarding deep geothermal resource allocation.
- Consider regulatory barriers and adjust these to achieve timely development of robust superhot geothermal projects across the Taupo Volcanic Zone, Bay of Plenty, Waikato and Northland Regions.
- Encourage investment in studies to solve technical challenges such as:
    - well drilling and completion methods,
    - management of scale formation and corrosion,
    - thermal stress issues, and
    - the design of efficient and cost-effective power turbine systems, heat exchangers, and surface plant for superhot fluids.

1.4 GNG Research Outcomes: Economic and Electricity Market Modelling

The economic and market opportunity for superhot geothermal in Aotearoa New Zealand was evaluated as part of the GNG programme by Castalia Ltd, (2023).

The report identifies the significant opportunity presented by superhot geothermal to meet New Zealand's future energy demands, the Government's targets for 100% renewable electricity generation and net-zero emissions by 2050.

Informed by Bromley et al (2024a) superhot inventory assessment of ~3.5GWe potential additional electricity capacity, Castalia (2023) have estimated that between 1.3 and 2 GWe of electricity generation is likely to be economic to develop by 2050; doubling the current contribution of geothermal generation.

Castalia (2023) found that superhot development projects are economically viable, even if development costs were double those of conventional geothermal developments.

Based on these findings, Castalia (2023) identified that superhot geothermal could provide abundant, low-cost, zero emissions and reliable electricity generation, potentially generating 30,000GWh of electrical energy annually. This responds to all elements of the energy trilemma[2].

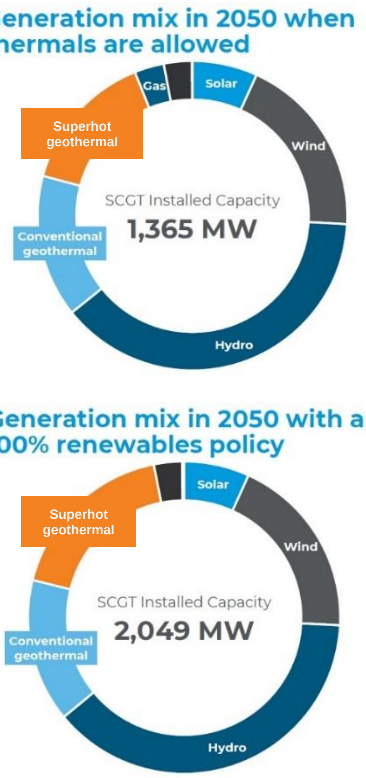

Figure 1 Electricity generation capacity mix in 2050 with and without gas fired thermal generation (Castalia 2023)

Castalia identified that a superhot geothermal development could be grid-connected as early as 2037. To achieve this timeframe, Castalia recommend that policymakers recognise the possible large potential and enable (through investment and resource consenting) exploratory wells to rapidly advance our superhot geothermal understanding.

2. REGULATORY ISSUES AND CHALLENGES FOR REALISING OUR SUPERHOT POTENTIAL

As explored in Kissick et al (2024a & b), a range of regulatory considerations present potential barriers to superhot

[2] Energy trilemma described globally as energy equity, environmental sustainability and energy security.

geothermal resource exploration and use. These are outlined in the sections below.

2.1 Issue 1 - Interconnectivity

Environmental regulation for conventional geothermal resource use has historically taken a precautionary approach to the preservation of hydrothermal system features. This was in part due to observed effects from early geothermal development (including loss of surface features and subsidence) and uncertainty about whether these effects were permanent or reversible.

Since 1980, a substantial body of knowledge about interconnections and reservoir hydrology has been acquired. Reinjection has been adopted as the preferred approach for pressure management of reservoirs, and development has occurred, significantly increasing resource/reservoir simulation capability.

Further, monitoring and modelling of observed effects from developed geothermal systems has demonstrated that some reversibility of past adverse effects is possible (Kissick et al 2024b).

An adaptive approach to effect mitigation and the use of expert peer review panels has also been adopted within the effects management framework provided by the RMA.

Where uncertainty regarding boundaries and system interconnections remains, this has seen the use of intermediately located 'sentinel' wells to test hypotheses regarding potential interference effects. A 'sentinel' well is monitored for pressure and temperature changes that might originate from a developed system such that any changes reach the sentinel well before they reach an adjacent system. If a sentinel well shows an adverse effect, the operator can adjust the injection and production strategy accordingly to avoid or remedy the adverse effect.

An example of this adaptive approach is the use of sentinel monitoring wells between the Ngā Tamariki development geothermal system and the Orakei-Korako protected system (Jackson et al 2020).

With better knowledge, improved technology and adaptive management practices, a less precautionary regulatory approach may enable further sustainable use of geothermal and superhot geothermal resources.

For superhot systems, our understanding of the connections between deep, superhot resources and shallower conventional geothermal resources, geothermal surface features, groundwater and the wider environment continues to evolve. Modelling is suggesting that with deeper production, potential effects on the surface from the utilisation of superhot geothermal energy (~5km deep) are diminished relative to conventional production from 2km depth (Bromley 2024a). Ongoing research will assist us with better understanding of connectivity and real data from superhot wells will usefully validate and improve the reliability of the modelling.

2.2 Issue 2 – System Boundaries

Direct Current (DC) resistivity data developed in the 1960's by the Department of Scientific and Industrial Research (DSIR) provides an initial guide to the lateral extent and location of shallow geothermal resources. However, this data is limited to a depth range to the ground surface of less than 500m. The interpreted data forms the basis for the current boundaries of geothermal systems defined in regional planning documents in both the Waikato and Bay of Plenty Regions.

The approach taken in the Bay of Plenty and Waikato regions is to delineate a limited number of geothermal systems for development or protection. Outside this, geothermal systems default to a research classification with limited activities able to be undertaken within these systems with energy production essentially excluded.

Over the past 25 years there have been a number of published examples of improved geophysical delineation of New Zealand's geothermal resources, both vertically and horizontally, using MT resistivity survey data and 3D inversion modelling (e.g. Bertrand et al 2015).

Relying on 'old' information and technology to define where geothermal energy can and cannot be utilised presents barriers to the future further use of our geothermal resources in the rapid transition to net zero. This is particularly so when seeking to improve the understanding of and planning for superhot geothermal resource use.

Regional planning frameworks require that changes to the extent or classification of a geothermal system necessitate a formal plan change following the process set out in Schedule 1 of the RMA. This is a time and cost intensive process to progress at the individual system scale.

As a result of the plan change requirement, system boundaries remain as they were originally identified in early Regional Plans and do not reflect the current improved information on the extent of geothermal resources that the scientific community has developed.

Zuquim (2024) outlines the geothermal inventory review of all systems in the Bay of Plenty region, incorporating findings from recent modelling that is publicly available. This type of information can be used by Councils to initiate their own, region-wide plan change processes including revision of system boundaries.

2.3 Issue 3 – Significant Geothermal Features (SGFs)

Significant geothermal features such as geysers, hot springs, mud pools and steam heated ground exist in many geothermal systems. These features are highly valued for cultural, historical, environmental and other reasons. There are examples of features being lost as a result of geothermal development.

The presence of these features is used by regional councils, alongside existing development and system temperatures, to determine the classification of geothermal systems.

Generally, the protection of outstanding and significant geothermal features is a policy directive of the relevant planning documents.

The National Policy Statement for Indigenous Biodiversity 2023 (NPSIB) includes requirements for the identification and protection of Significant Natural Areas (SNA) which are areas identified for their significant indigenous flora and/or fauna. The NPSIB includes a specific requirement to identify SNAs with geothermal features. Until the work to identify SNAs is completed, it is not clear whether there are geothermal features that are not currently protected as a result of system classification.

2.4 Issue 4 – Consent duration

Section 123 of the RMA limits the maximum duration of resource consents to 35 years (excluding land use or subdivision consents and some coastal permits.) This limitation on consent duration applies to all consents for the take, use and discharge of natural resources including freshwater and geothermal fluid.

While Castalia (2023) found that superhot development remains an economic prospect even with increased development costs, there is significant investment required through the exploration and development phases given the drilling depths, the technology challenges and the more than doubling of the capacity of the geothermal plant that is anticipated.

The maximum term currently allowable under the RMA may not align well with the nature of superhot development with the intensity of capital investment necessary.

Adaptive management approaches within the term of consents granted for geothermal resource utilisation have been shown to be effective for management of conventional geothermal systems and so effects management should not be seen as an issue that might otherwise support the status quo of 35 year maximum consent terms.

2.5 Issue 5 – National Direction/Pan-regional challenges

Under the existing RMA framework, there are a series of documents which make up the planning and regulatory framework (Figure 2).

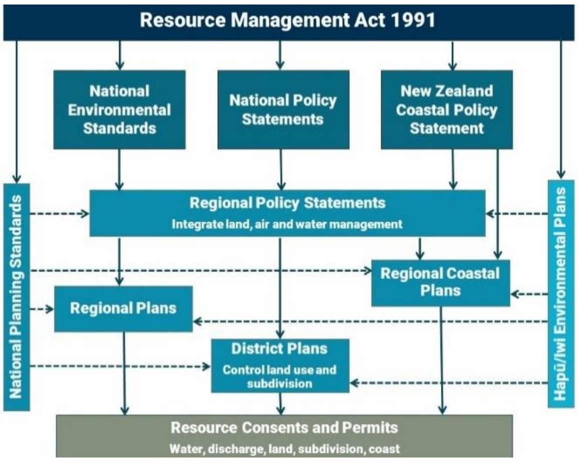

Figure 2: RMA framework hierarchy (Source: Kissick et al 2021)

National Policy Statements (NPS) and National Environmental Standards (NES) provide national direction and consistency. Regional Policy Statements (RPS) and Regional Plans (RP) provide direction at a regional level including on the take, use and discharge of natural resources, giving effect to national direction. District Plans (DP) are focused on land use at a district-specific level.

Currently, there is an NPS that provides specific policy guidance on renewable electricity generation (NPSREG) and recognises the vital role of renewables in addressing the effects of climate change and powering New Zealand. A 2023 review of this NPS (MBIE 2023) proposed supportive policy direction for solar and wind generation, overlooking the significance of the ongoing and future role of geothermal, including superhot, in achieving NZ's renewable energy targets.

The Government has indicated a proposed NPS for Infrastructure will be introduced before the end of 2024 and passed into law mid-2025. The detail of this proposed NPS is not available at the time of writing, however it is understood that the NPS will incorporate policy direction relating to renewable energy which could include geothermal. It is not yet clear how this will interact with the NPSREG or other national direction.

Transpower's (2023) data assumes total electricity demand growth of 60% and a maximum installed conventional geothermal capacity of 1.7 GWe (levelling off after 2035). However, the potential for superhot power plants to come online from 2037 (Castalia Ltd, 2023), indicates that reliance on future wind and solar would reduce. Subsequently, the total share of geothermal generation would rise from 18% to around 34%, almost matching that of hydro-power generation (35%) by 2050 (Bromley et al, 2024c). (Figure 3).

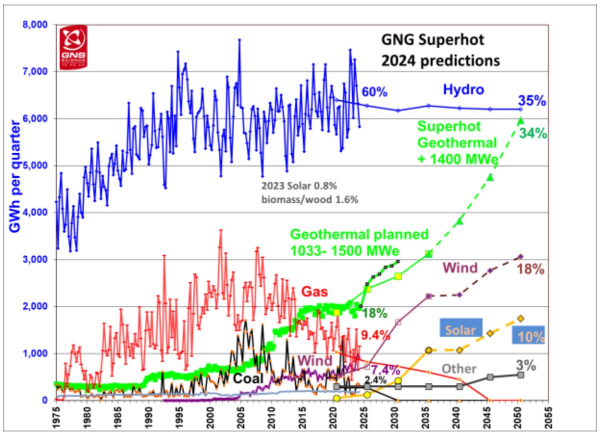

Figure 3 Modified Transpower projections using economic superhot geothermal instead of some wind and solar after 2037. (Source: Bromley et al 2024c)

An existing NES relating specifically to electricity transmission activities exists and provides Transpower, as the national electricity grid operator, with a streamlined process for undertaking necessary works on the national network.

These national-level policy documents, alongside other topic-specific national direction, provide a precedent for developing direction of this nature. Geothermal energy, despite its potential contributions, has been given limited attention in existing national policy direction.

3. REGULATORY-ADJACENT ISSUES AND CHALLENGES FOR REALISING OUR SUPERHOT POTENTIAL

A number of regulatory-adjacent issues have arisen through the GNG research. These are outlined in the sections below.

3.1 Issue 6 – Māori cultural values

Taute et al (2019) describe the cultural indicators and benefits for tangata whenua from geothermal resources. Geothermal resources are identified as among the most sought-after resources for Māori, along-side coastal and freshwater resources. This is due to these resources providing access to warmth, cooking and healing capabilities (referenced in Taute et al 2019 from Kawharu, 2000).

Geothermal (waiwhatu) sites and resources also hold cultural and spiritual significance for Māori. They are considered as meeting places between the physical and spiritual worlds, and ancestral stories and legends often connect these areas to creation and history.

The kaitiaki role of Māori is recognised in the RMA. The relationship of Māori and their culture and traditions with ancestral lands, water, sites, waahi tapu and other taonga are recognised as a matter of national importance in Section 6 of the RMA.

The current approach, directed through the RMA, focuses on recognising the relationships of tangata whenua, in large part through iwi authorities, as a representative group for the wider iwi.

However, in order to identify the range of values associated with a particular geothermal system or resource, broader engagement than solely with iwi authorities, including with tangata whenua in their capacity as kaitiaki (guardians) of the land and resources is fundamental. This can be overlooked with the current RMA focus on engagement at the iwi authority level.

3.2 Issue 7 – Freshwater access and availability

Freshwater is a finite resource with its management and availability for use a key resource management issue nationwide. The volumes of freshwater required to open hole drill a single ~6km deep exploratory well, with no water returning to the surface, could be upwards of 4,000 litres/minute (6,000 m^3 per day). This water requirement is anticipated to be needed for at least 4.5 months (140 days) in drilling each ~6km deep geothermal exploratory well (Figure 4). Given the volumes required, availability of freshwater is an important element to resolve to enable drilling to proceed.

Freshwater in New Zealand is currently allocated on a first-in, first-served basis. Where there is insufficient water for all demands, this allocation approach does not guarantee that water is allocated to the uses with the greatest environmental, social, cultural or economic value.

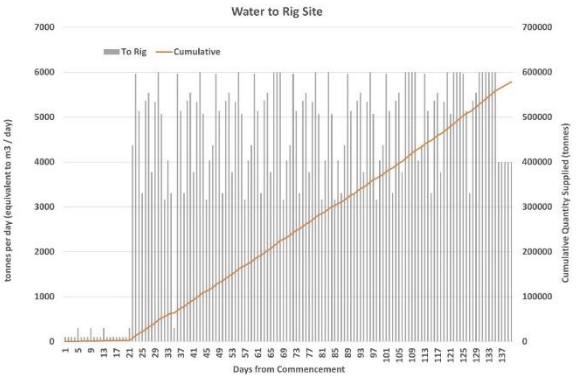

Figure 4 Indicative graph of anticipated water use for a 6km exploratory well drilling (Kissick et al 2023)

Unless a developer already holds consents, or there is sufficient available allocation within the freshwater resource, a superhot development may require water allocation from a range of existing consent holders (including, for example, transfer of water permits under section 136 of the RMA) and from a number of freshwater sources.

3.3 Issue 8 – Investment risk

To date, there has not been a superhot well drilled in New Zealand. As a result, we have no local data to rely on regarding superhot potential to inform investment decisions.

Proving a superhot resource to development stage will require a number of exploratory wells to be drilled. Given the depth and technical complexity of drilling for superhot resources, the level of investment in exploration will be greater than that required for conventional systems, with some estimating costs of $50 million for a single well and $200 million for a three well programme. This presents an investment challenge and potential barrier to superhot exploration.

4. POTENTIAL SOLUTIONS

While the authors have identified a range of challenges to realising superhot geothermal development, the following potential solutions are presented as conversation starters. Solutions will need to be developed with a wide range of stakeholders both domestically and internationally, including mana whenua, Government, researchers, policy makers, electricity generators and other users of geothermal energy.

4.1 Global initiatives

While Aotearoa New Zealand has yet to drill to superhot depths, several countries are actively undertaking research into the deep, high-temperature roots of geothermal systems which potentially host superhot geothermal fluids (Bromley & Carey 2023).

Continued global collaboration and knowledge sharing to work through the challenges associated with resource identification and delineation, technology development, investment and the development of appropriate regulatory regimes is to be encouraged.

4.2 National initiatives

At a national level, policy makers have a significant role in recognising the contribution of geothermal to future energy and carbon goals. In the resource management context, policy direction at the national level flows through to regional policies and rules. Without this, a local approach can result in an inconsistent or ad-hoc responses to a nationally significant issue.

4.2.1 Recognition

In recent years, geothermal energy has not been recognised in central government policy making as a potentially significant contributor to New Zealand's carbon-zero future.

As an example, in 2023 the government consulted on a proposed review of the National Policy Statement for Renewable Electricity Generation (NPS-REG). Geothermal energy did not feature in proposed revisions, which instead focused on wind and solar.

Research outcomes from the GNG programme have shown that the geothermal potential could be very large. Matching this potential to policy making will be an important change to recognise the resource significance to Aotearoa New Zealand and to put in place appropriate supportive policy settings.

4.2.2 Investment

There is significant advantage for Aotearoa New Zealand from the increased understanding of superhot geothermal resources that can only come from exploratory drilling. Yet the costs are high, and the returns uncertain in the short term.

Central government financial support for exploratory drilling will greatly assist in advancing the realisation of superhot geothermal powered futured. This is the approach that was previously used by the Government for the majority of large-scale geothermal exploration in New Zealand.

4.2.3 Public Awareness

Past geothermal energy developments have resulted in adverse effects through subsidence and loss of surface features. However, modern management and practices have significantly reduced the risk of adverse effects.

Superhot geothermal energy is a new technology for Aotearoa New Zealand and this presents new challenges.

Efforts to inform the public about the potential benefits of superhot resources, as well as how these resources can be sustainably utilised, are needed. This will ensure that stakeholders can engage in an informed manner in future policy-making and consenting processes.

4.2.4 Regulatory response

National direction and pan-regional spatial strategies

There are already examples of national direction for specific resource management issues, such as electricity transmission and renewable electricity generation. Superhot geothermal resources have unique characteristics, are pan-regional and potentially offer significant national benefit. National direction to provide a targeted and bespoke regulatory framework, such as through an NES, may be warranted. This could help to streamline and de-risk superhot exploratory and development projects.

Legislation introduced under the previous NZ government presented the concept of regional spatial strategies including opportunities to develop cross-regional spatial strategies. This approach, either as an alternative or complementary to national direction, could apply to the management of geothermal resources, particularly in the TVZ, resulting in a consistent management framework.

Resource Consent durations

Consideration of the maximum consent duration allowable under the RMA for developments accessing superhot geothermal resources may be warranted. Extension of this duration would acknowledge the high level of investment required, the national-good component to low-cost, zero emissions and reliable electricity generation, and the long-term nature of the activity once established. In addition, expert peer review panels, adaptive management approaches and improved modelling and understanding mean that effects management can be effective without necessarily requiring reconsideration of an entire consent.

Longer consent terms could be achieved, either through longer initial consent terms or through the ability to more efficiently renew expiring consents.

The authors acknowledge that longer consent terms may not always be appropriate and a high threshold for approval would likely need to be established for a longer term consent to be granted. However, a longer consent term could reduce uncertainty for high investment and longer-term superhot geothermal projects.

This change would be needed at the legislative level, given that this is where the current 35-year restriction on some resource consents is imposed.

Engagement with mana whenua

While engagement at iwi authority level may be appropriate for a range of resource management matters, understanding the intricate values and relationships of mana whenua to geothermal systems means that, in some cases, engagement may be better focussed with hapū and whānau.

Providing for different levels of engagement rather than the current focus of the RMA on iwi authorities, depending on the circumstance and resources involved, needs to be enabled through the RMA and any future replacement resource management legislation.

This will enable mana whenua, as kaitiaki to specifically engage on resources of value to them rather than relying on the broader iwi authority to represent their views.

4.3 Regional solutions

Revising the current approach to geothermal system boundary delineation in regulatory planning documents could benefit the development of superhot resources. Some superhot resources are located outside of currently identified development geothermal systems.

Boundary delineation of protected systems is a tool used for the identification of these geothermal systems and to protect their important values and surface features. However, the same boundary approach may not be strictly necessary for other systems.

The resource consent application process to utilise geothermal resources for development requires robust assessment and analysis. This includes assessment of the extent and capacity of the system and the actual and potential effects on the environment. Management of these activities through the imposition of, now outdated, two-dimensional field/system boundaries, places additional limitations on realising the future potential of these resources, particularly in the case of superhot resources.

An option could be to remove existing system boundaries from Regional Plans, except for the boundaries of protected systems. This would remove the requirement to undertake a formal change to the planning regime if exploratory investigations prove the resource potential. The resource consent process would continue to require the necessary technical assessments to evaluate and manage the actual and potential effects on the environment from undertaking the proposal including the protection of Significant Geothermal Features.

5. CONCLUSIONS

Superhot geothermal energy has the potential to provide abundant, low-cost, zero emissions and reliable electricity generation, and could more than double current geothermal electricity generation from 2037. If this potential is realised, geothermal energy as a whole has a major role to play in Aotearoa New Zealand's energy future.

To unlock this potential, there are a range of challenges to overcome. In the view of the authors, there are practical and achievable initiatives that can be explored to overcome these challenges. Through international, national and local collaboration and action, a superhot geothermal future can be realised for Aotearoa New Zealand.

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