MINERAL EXTRACTION FROM NEW ZEALAND'S GEOTHERMAL BRINES: WHERE TO NEXT?

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ABSTRACT

New Zealand's geothermal brines offer potential for the extraction of various metals and minerals, given both the fluid compositions and volumes discharged. The realisation of commercial value from the extracted constituents could create new industries, support economic development, and potentially provide additional revenue streams for geothermal energy generation and related industries.

A 2013-2015 New Zealand Government-funded research programme ("From Waste to Wealth") sought to identify potential processing technologies and, in particular, to provide a greater understanding of the barriers and success factors likely to influence the implementation of such technologies.

This paper summarises the research to date and makes recommendations for New Zealand's future research and investment in this area.

1. INTRODUCTION

1.1 The Opportunity

In New Zealand, geothermal fluids are used as a source of heat energy, used directly and for generating electricity (Carey et al, 2015). However, the composition and high volume of geothermal fluids discharged in New Zealand also offers promise for the possible extraction of some metals and minerals.

Geothermal fluids are heated and interact with the rocks they travel through underground, becoming saturated with various minerals and metals. The minerals are already in solution, so there would be no cost associated with dissolution of ore minerals into an aqueous phase as for other mining processes.

Extraction of minerals and other materials might improve the economics of geothermal energy use by managing, co-producing and marketing selected dissolved constituents. Economic, social and environmental benefits could arise from creating new industry for New Zealand and in developing world-leading capabilities in geothermal processing technologies.

Implementation of geothermal mineral extraction would increase regional growth and development, and provide additional employment opportunities. Māori groups, as geothermal resource owners, are in a position to directly benefit from geothermal mineral recovery, supporting the development of their natural resource assets, which include electricity generation and direct uses.

1.2 The Research Programme

While the mineral and metal extraction opportunity was first identified in the 1960s (Kennedy, 1961), it still has yet to be realized. Questions remain, such as:

- What are the technical options for extraction from the geothermal fluid streams and what are potential investment opportunities?
- Could economic, social and environmental benefits arise from creating industry around some of these minerals?
- Will New Zealand develop world leading capabilities in processing technologies and in so doing further improve geothermal energy productivity, industry value and open up international opportunities?

There is a need to identify simple, cost-effective processing technologies, and to provide a greater understanding of the economic viability, market drivers and regulatory barriers for implementing such technologies.

New Zealand-based researchers undertook a small study ("From Waste to Wealth", 2013 – 2015, Figure 1) to provide a starting point for this assessment (Mroczek et al, 2015b). The purpose was to determine the commercial potential and best technical options for encouraging future investment in technologies for the extraction of saleable products from geothermal fluids.

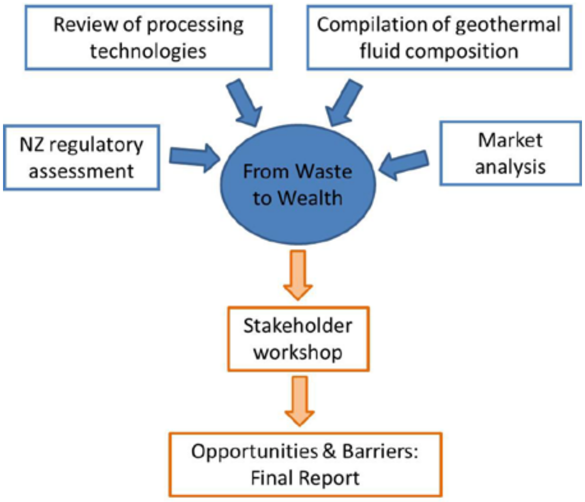

Figure 1: Diagrammatic overview of the "From Waste to Wealth" research programme components.

No studies have been undertaken that are in the public domain that cover the multidisciplinary range of topics (legal, chemical, technological, marketing) considered by this programme.

2. CORE STUDIES

The "From Waste to Wealth" programme was composed of four studies (Figure 1) to answer four underlying questions:

1. Chemical fluid composition: what have we got?
2. Legal rights: what permissions are needed?
3. Technology review: how do we do it?
4. Market drivers: who wants what we have?

This section overviews the aims of each study and the key findings. The four publically available reports are Mroczek et al, 2015c; Mroczek et al, 2015b; Barton, 2015; and Hill, 2015.

2.1 Chemical composition of geothermal fluids

The aim of this study (Mroczek et al, 2015c) was to determine the quantities of minerals and metals that are potentially available for extraction from New Zealand's geothermal fluids.

The chemical composition for each of New Zealand's developed, high-temperature geothermal systems (Figure 2, red dots) was updated and summarised using data from wells in the Taupō Volcanic Zone (TVZ) and Ngawha (Figure 2).

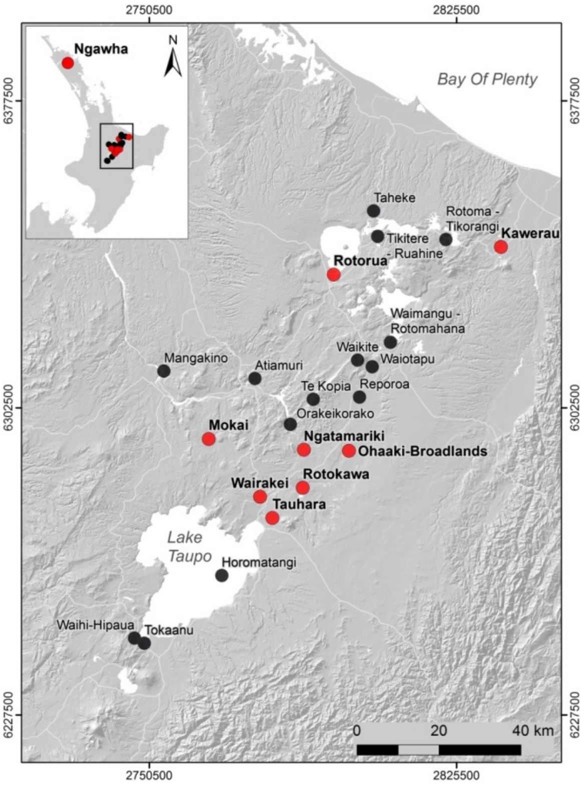

Figure 2: Geothermal areas in the Taupo Volcanic Zone and Ngawha discussed in the text. ● Fields with compositional data in bold.

The data used came from published historical data, as well as that released for the study by geothermal field operators. The "typical" reservoir water composition was characterised. Most information was available on the major chemical constituents: Na, K, Ca, Cl, B, SiO_2, SO_4 and HCO_3, but also minor components of Li, Rb, Cs and Mg. These data is available because these constituents are used to monitor the effects of geothermal production. Limited information was available for trace elements and precious metals (Au, Ag and Cu) as they are of low concentration in surface discharges and are rarely analysed

Observations include that the TVZ eastern fields (Mokai, Wairakei and Tauhara) are characterised by high chloride and lithium. Chloride, sodium, silica and potassium (generally in that decreasing order) were the most common components of the geothermal brine. The remaining components are low in comparison to these four. A notable difference to this trend is at Ngawha, where boron replaces silica as the third highest component dissolved in the fluid. Ngawha's composition is low in silica (as the reservoir temperatures are low ~ 230°C) but the boron is 25x higher than any of the TVZ fields.

It is not only concentration of the constituent but also the total mass discharged that may determine extraction economics. To reflect this, both the concentration and consented geothermal fluid were used to calculate the species mass flux for each field. Wairakei had the highest mass discharge of Cl, Li, Rb, Ca, K and Na, while Kawerau had the highest silica flux. Of the minor elements, rubidium at Wairakei and cesium at Mokai have not inconsiderable annual discharges (~143 and ~89 t/y respectively).

There are very few studies that have been published on trace elements, such as the metals gold, silver and copper. Their concentration in geothermal waters are very low (measurable in µg/kg; ppb) and have generally been measured on samples collected downhole. The downhole concentration does not necessarily represent the concentration of these elements in fluids at the surface, which is often lower due to deposition on walls or surface piping.

2.2 Extraction Technologies

The study (Mroczek et al, 2015a) summarised publically available information on mineral and metal extraction work undertaken in New Zealand. Material was also added from relevant overseas studies. The study focussed on options for extraction of silica, lithium, boron and rubidium and cesium from New Zealand separated geothermal water.

A number of technologies have been trialled at a pilot scale, but many only at an experimental and laboratory scale. Generally there were three main types of processes; absorption, concentration and precipitation. Often these are used in series. Specific techniques that have been used include filtration, electrocoagulation, electrodialysis and ion-exchange resins.

Silica is the most important mineral to extract, as this mineral limits energy extraction efficiency, and hence is the species that has the most research and development to date. Silica techniques reviewed included precipitation as metal silicates (primarily as calcium silicate); precipitation by cationic flocculants; removal by dissolved air flotation; deposition onto seed particles; and ultrafiltration. Given the level of previous trials and testing on silica in New Zealand (including international pilot scale studies), the barrier to extraction of silica is perceived not to be technical. Silica extraction from separated geothermal water could:

- open up opportunities for additional energy extraction
- offset costs associated with other silica control techniques currently in use
- be a prerequisite to the extraction of other species from the separated geothermal water (SGW)

Lithium has received the second most focus, after silica. Despite its potential being recognised in New Zealand in the late 1950s (Kennedy, 1961), it is the recent increasing demand that has revived interest for possible extraction from geothemal fluids. Lithium techniques reviewed included co-precipitation with aluminium hydroxide; manganese oxide (spinels) and cation exchange resins; electrodialysis; and evaporation. Few laboratory trials have been undertaken, with none being pilot tested. The low concentration in New Zealand SGW (10-30 mg/L) compared to highly saline brines found elsewhere (200-5000 mg/L) could be an impediment to economic extraction. However, with geothermal heat available, concentration by evaporation might assist with reducing costs and increasing secondary extraction viability.

Internationally boron extraction has focused on environmental remediation, not economic recovery. There have been no New Zealand published field trials or pilot tests of boron extraction from SGW. Boron techniques reviewed included precipitation/absorption (e.g. clays, electrocoagulation, chelating resins); and concentration (e.g. ion exchange; reverse osmosis, solvent extraction). There are limitations in the applicability of these techniques to geothermal waters, for example some reagent based extraction processes suitable for high boron concentrations (> 0.3%) are only efficient at less than 30°C. Technology development is required. In New Zealand geothermal fluids, boron is present at low concentrations (40 mg/L), except at Ngawha (1000 mg/L), so enrichment technologies may also be required.

Cesium and rubidium are minor but valuable components in SGW. No studies have been published on extraction of these constituents from New Zealand SGW. Successive extraction processes to remove silica, lithium and boron will leave the residual water concentrations of these two constituents essentially intact. However, the small market for these metals and adequate world supply means that any process would need to be highly efficient and cheap. Methods for removing these metals include solvent extraction and ion-exchange.

Technologies for extracting precious metals, such as gold, silver and copper, from geothermal fluids have not yet been developed. Their very low concentration in SGW means that extraction is likely to be economically marginal.

2.3 Market Opportunities

This study (Hill, 2015) undertook a market analysis for potential products from the species present in geothermal fluids. The focus was on silica and lithium, with some information also provided for boron, cesium, rubidium, sodium, potassium, magnesium, and gold. Opportunities identified include dispersed silica for automotive tires, battery grade lithium salts and borate fertilisers.

In principal each of these compounds/elements has opportunity for high value product. However, the market opportunity is highly dependent on the detailed nature of the downstream product. Some niche products, such as colloidal silica, could command a significant premium over other potential extract forms of silica. Similarly some forms of organo-lithium command a significantly higher price than battery grade lithium salts. However, the amount of processing required to manufacture a suitable quality product will need careful consideration with respect to relative margin.

The aim is to identify the correct customer/price level within the supply chain for the specific/niche finished product to return higher margins. Markets are dynamic, and economic feasibility of mineral extraction is highly dependent on international mineral prices. The physical nature of the product is very important (e.g. purity, morphology). Also geographic market considerations will dictate the applicability of a New Zealand based supply chain.

2.4. Legal Rights

This study (Barton, 2015) undertook a legal analysis of rights to minerals in geothermal fluids. Rights to dissolved minerals and other materials in geothermal fluids are not dealt with explicitly in New Zealand law, so the legal position must be determined by the application of general legislation and the general principles of law. The analysis assumed that a geothermal minerals operation is likely to be ancillary or incidental to a geothermal energy facility.

In New Zealand, the sole right to tap and use geothermal energy, falling short of explicitly conferring ownership, is vested in the Government. Geothermal resources are treated as water, and their use is managed regionally under the Resource Management Act 1991 (RMA).

The legal analysis concluded that:

- the use of the term "water" in the RMA includes material dissolved or entrained in geothermal water,
- management of water under the RMA includes the granting of rights to such material as part of water more generally,
- a regional council has jurisdiction over the materials in geothermal water, and has obligations to manage them under the RMA, and
- the RMA provides a number of justifications for regional council to look favourably on a geothermal minerals operation.

This conclusion is reinforced by reference to other legislation. Subject to the specific terms on which it was granted, an RMA water permit gives its holder the rights, otherwise vested in the Crown, to take and use water in terms that include the matter and material dissolved or entrained in water. This means that the use of the minerals and other dissolved materials could be included in the RMA permit. Once it comes into the pipe system of the permit holder company, the water (and its dissolved materials) is the property of the company.

Even with close legal analysis it is not possible to determine definitively whether the Crown Minerals Act 1991 (CMA) also applies to a geothermal minerals operation. (It is not uncommon for an operation to be obliged to comply with multiple Acts.) The CMA uses general words to define "mining" as "to take, win, or extract, by whatever means" a mineral in its natural state in land. This could include geothermal minerals operations. It provides no exception for geothermal minerals, and it provides no exception for a taking of minerals incidental or ancillary to another operation. A court could decide that it should take an integrated view of a geothermal project and not consider a mineral extraction component in isolation. On the other hand, it is also arguable that the purpose and context indicate that the CMA does not intend to catch an ancillary or incidental operation, particularly where it involves lawful extraction of geothermal water bearing minerals dissolved in solution and where the operation cannot be described as taking minerals in their natural state.

If a geothermal minerals operation is "mining" under the CMA, then the consequences are that the company must obtain a mining permit and must comply with other obligations under the Act, as well as complying with the RMA. The CMA's requirements are notably different in obligations to supply information that will in due course be made public.

The options for geothermal mineral operations are either to live with this commercial risk, go to court to test the uncertainty, or promote reform of the law. As a matter of policy, the uncertainty about the CMA should be removed by law reform in order to reduce risk and provide better levels of regulatory and commercial certainty.

2.5 Integration & Validation

Active end user engagement is vital to develop a geothermal minerals industry in New Zealand. Recognizing this, the research programme culminated with a stakeholder workshop to integrate and validate the work to date. Over sixty participants attended, with representatives including power companies, regional and local government, independent contractors, universities, crown institutes, Maori Trusts and businesses, engineering companies and central government representatives.

The presentation of the core reports was followed by wide ranging discussion facilitated by expert panel members. Feedback, ideas and questions were collated from the participants to guide future R&D directions and investment decisions. This paper summarises and brings together the opportunities and barriers for a New Zealand geothermal minerals industry into a final report.

3. FUTURE WORK THEMES

This section outlines the identified gaps, questions and recommendations for future work, arising from integration of the core studies and the feedback gained through the stakeholder workshop. These have been summarised into seven themes. This matrix for future studies builds on the initial four topics, and adds depth in economics, integration and business structure. To deliver value future work will be multi-disciplinary, combining and integrating expertise in scientific, engineering, legal, business, economic and social research.

The key to successfully developing a geothermal minerals industry in New Zealand is economic viability. Figure 3 illustrates the connections between the technology, economics, market drivers and business risk that directly influence economic viability. In turn, the legal frameworks, technologies, and ultimately the chemical composition of the geothermal fluid in a given location, influence these factors.

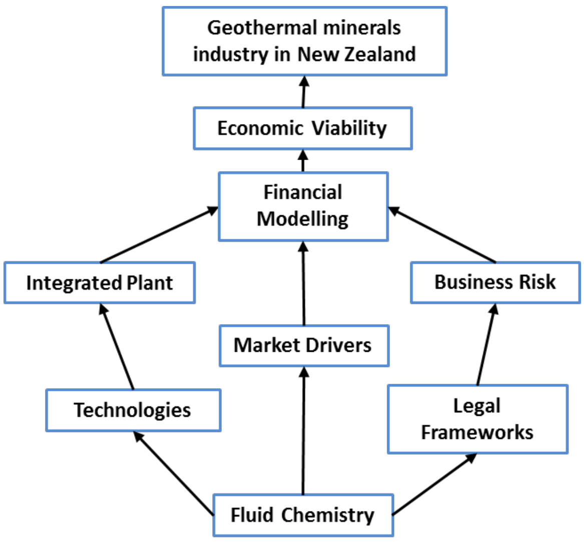

Figure 3: Interdependence and connections between the success factors for developing a geothermal minerals industry in New Zealand.

3.1 Fluid Composition

The compositional and flux data for New Zealand's geothermal fields is the underpinning information required to guide the development of geothermal mineral extraction processes and markets (Figure 3). The next step is to fill the identified data gaps, gather more data, undertake international comparisons, and to clarify sustainability.

Positive feedback on the initial study included questions around the robustness of the data and the usefulness of additional comparative analysis.

Suggested work areas include:

- update data for geothermal fields where the public data is over 10 years old
- calculate mass flux using actual flows and part-flows
- investigate the change in species composition and chemistry with time
- investigate mineral resource sustainability especially given that demineralized waters are reinjected
- look for single wells with unusually high concentrations of selected constituents
- include other constituents, such as arsenic, mercury, antimony and carbon dioxide
- investigate concentration changes with depth
- undertake a study to measure trace elements concentrations in surface discharges from wells (not down-hole)
- compare New Zealand data with major geothermal fields internationally and with seawater

3.2 Technologies

Laboratory, pilot and full-scale demonstration of technologies for geothermal mineral extraction in New Zealand are required. The next step is to develop, test, adapt and/or validate extraction technologies under New Zealand conditions.

The stakeholder workshop was rich with suggestions, such as:

- pilot scale testing of lithium extraction technologies
- test, adapt and/or develop new technologies for extraction specifically from geothermal fluids, for example boron, cesium, rubidium
- blue sky research into new technologies for downhole gold and precious metal extraction
- examine methods for purifying geothermal off-gases (e.g. CO_2)
- investigate biological opportunities, such as micro-nutrients and bioremediation
- examine the opportunities for using novel methods (often untested at large scale) such as nano-materials and biotechnologies
- determine the techno-economics to make the choice clearer

3.3 Integrated Plant Design

Geothermal mineral/metal recovery is most likely to be feasible either by, or in partnership with, geothermal energy production, for both practical and economic reasons. Geothermal plants are already RMA permitted and are experienced in processing, handling and disposing of geothermal fluids.

A cluster of processes, individually uneconomic on their own, may be the catalyst to move the technology from technically possible to be adopted. Also, the implicit assumption is that none of these extraction processes would be viable without ready access to SGW and easy integration into an energy production process. It is assumed that the cost for stand-alone production and disposal of fluid for the express purpose of minerals extraction is unlikely to be economically viable in the next few decades, but a stand-alone operation can be analysed. Whether integration could be achieved with existing infrastructure is a crucial point of discussion and assessment.

The next step is to examine process design options for integration with existing plant facilities, and to determine the economics of integration. Suggested work areas include:

- calculate and compare the economics of a stand-alone operation versus integration with an existing plant
- examine the synergies possible through access to heat, electricity and extraction
- examine options for retrofitting extraction methods and existing plant
- model alternatives for process integration
- calculate the cost benefit position for silica extraction assisting power generation
- determine the learnings/outcomes from previous pilot scale trials in New Zealand and overseas

3.4 Market Drivers

Geothermal minerals and compounds could have market suitability, based on a matrix of considerations:

1. the physical nature of the product including compound, purity, morphology, consistency of supply and product support;
2. the price and value chain including identifying the entry point and customer/ price level to the supply chain; and
3. the geographic market considerations where New Zealand can be competitive in the supply chain.

The next step is deeper/wider market analysis to provide greater detail to inform these considerations. Suggested work areas include:

- determine the strategic advantage and value proposition of extracting minerals from New Zealand's geothermal fluids
- identify complementary existing markets and supply chains in New Zealand
- investigate market segments where niche products could be viable
- identify correct customer/ price level within the supply chain for the finished product(s)
- calculate the economics of conventional versus geothermal production
- examine the opportunities that might arise from geopolitical influences, supply and demand commodity cycles, environmental issues/ reputation and disruptive technologies

3.5 Legal Frameworks

Clear legislative and legal frameworks are essential to de-risk a geothermal minerals operation in New Zealand. There is particular uncertainty in the application of the Crown Minerals Act, and little information about Maori perspectives on this opportunity. The next step is to clarify the position of the governing Acts and their implementation.

Suggested work areas include:

- clarify the Crown's stance with regards to the Crown Minerals Act as it relates to geothermal mineral extraction
- investigate the Crown Minerals Act regards applicability for mining geothermal minerals versus ancillary extraction by a energy company
- determine whether existing RMA consents authorise the use of geothermal minerals and the position of Regional Councils
- examine the legal position of previous trial plants in New Zealand for mineral extraction from geothermal fluids

- examine the kaitiaki obligations for geothermal mineral extraction and Maori perspectives
- examine examples of international legal positions

3.6 Managing Business Risk

The path to market must be de-risked for a geothermal minerals industry to be realised in New Zealand. There is opportunity to look for value, other than for energy, from geothermal resources, but a mind-set shift is expected to be needed on risk. Assuming that a geothermal minerals operation will occur alongside a geothermal energy development, this means connecting two different business risk mind-sets; one being that of a risk-averse utilities company and the other being that of a mining and commodity–based company with an appetite for developing and deploying new technology. The balance of risk and reward is different for each type of company and its investors.

The next step is to examine risk profiles, explore alternative business models and deliver commercial proof. Suggested work areas include:

- define the role of government, investors, industry and others
- survey boards, senior management and government to determine their risk appetite for geothermal mineral operations
- determine opportunities for bridging the commercialisation funding gap to go beyond desktop and pilot scale demonstration to full-scale commercial facilities
- examine how business decisions influenced the discontinuation of previous pilot scale plants
- determine why international extraction projects failed or were discontinued.
- assess options for mitigating against commodity supply and demand cycle impacts
- investigate appropriate business models for use in a geothermal minerals operation

3.7 Financial Modelling

A holistic and integrated approach is needed to determine the economic big-picture for a geothermal minerals industry in New Zealand. Robust financial models are needed to integrate the technology economics data and product pricing (Figure 4). Prioritisation will be necessary, as financial modelling will not be practical for all potential products, with many being a long way from market-ready. However, it will be beneficial to establish a financial modelling framework that can be applied to a range of minerals/products in future.

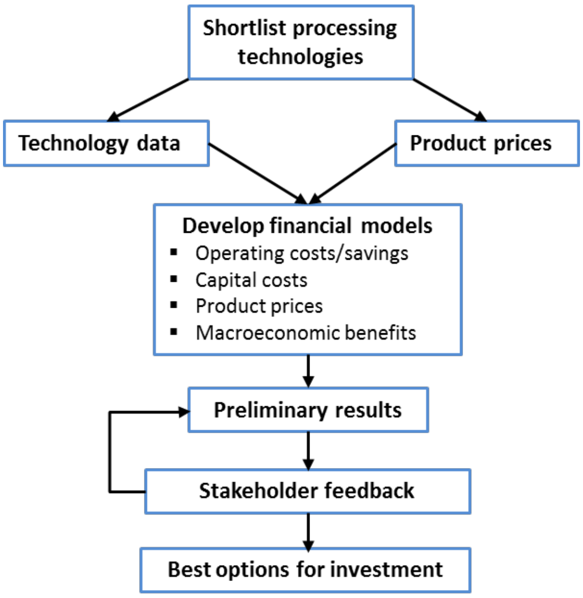

Figure 4: Financial modelling integrates technology and market economics, and includes review to ensure industry buy-in.

The next step is to develop/adapt financial models to suit a geothermal minerals operation. Financial models would incorporate data such as:

- market pricing
- capital and operating costs
- process yields
- macroeconomic benefits

The development of a new geothermal minerals industry is reliant on geothermal industry and others making investment decisions based on these results. A key aspect of this work will be the robustness of the financial modelling. This will rely on the outcomes of other activities, such as the integrated plant design, de-risking and market analysis. Industry "buy-in" to the approach and assumptions will be essential.

4. CONCLUSION

The development of a geothermal minerals industry is a very real possibility for New Zealand, leveraging our geothermal resource assets and experience. The market-readiness varies by product, with silica the most advanced, followed by lithium, and then a numbers of other species and compounds.

The outputs and delivery of the "From Waste to Wealth" research programme offers a solid starting point to identify potential processing technologies, and to provide a greater understanding of the barriers and success factors likely to influence the implementation of such technologies. The programme generated significant interest and support from stakeholders.

This research provides a springboard to pursue future funding in partnership with stakeholders, with a diverse forward programme of work that is robust, informed and inter-connected.

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REFERENCES

Barton, B. 2015. *Legal rights to minerals in geothermal fluids.* Centre of Environmental, Resources and Energy Law, University of Waikato. ISBN 978-0-473-31289-3 (softcover); ISBN 978-0-473-31290-9 (PDF). Also available as GNS Science Miscellaneous Series 75, ISSN 1177 (print); ISSN 1172-2886 (online).

Carey, B.; Dunstall, M.; McClintock, S.; White, B.; Bignall, G.; Luketina, K.; Robson, B.; Zarrouk, S.; Seward, A., 2015. *2015 New Zealand Country Update.* World Geothermal Congress Proceedings, Melbourne, Australia, Melbourne, Australia, 19-25 April, 2015, 18p.

Hill, A. 2015. *Market drivers for commercial recovery of products from geothermal fluids.* Hill Technology and Management. 67p. Also available as GNS Science Miscellaneous Series 81; ISBN 978-0-478-19996-3 (print), 978-0-478-19997-0 (online).

Kennedy, A.M. 1961. *The recovery of lithium and other minerals from geothermal water at Wairakei.* In: proc. of the UN Conf. on New Sources of Energy, Rome. Paper G/36, p502.

Mroczek, E.; Carey, B.; Climo, M.; Li, Y. 2015a. *Technology review of mineral extraction from separated geothermal water*, GNS Science Report 2015/25. 32 p.

Mroczek, E., Climo., M., Carey, B. 2015b. *Waste to Wealth: mineral extraction from geothermal brines.* Proceedings: World Geothermal Congress, Melbourne, Australia, 19-25 April, 2015. 7p.

Mroczek, E.; Climo, M.; Evans, D. 2015c. *The composition of high temperature geothermal fluids in New Zealand producing geothermal fields.* GNS Science Report 2014/68. 25 p.