Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Update on Geothermal Mineral Extraction – the New Zealand journey

M. Climo[2], B. Carey[1], E. Mroczek[1]

[1]*GNS Science, 114 Karetoto Rd, SH1, Wairakei, Taupo, New Zealand*
[2]*Briger Consulting, Christchurch, New Zealand*

Corresponding author: b.carey@gns.cri.nz

Keywords: geothermal minerals, mineral extraction, solution mining, geothermal brines, silica, lithium, boron, market drivers, regulatory framework, legal framework, technologies, geothermal fluid composition, economic viability, New Zealand

ABSTRACT

The opportunity for geothermal minerals in New Zealand was first suggested in the early 1960s, with the first work on silicates and lithium undertaken by government scientists at Wairakei in the 1980s. In the 1990s, the Electricity Corporation of New Zealand and Tasman Pulp and Paper ran extensive silica extraction pilot plant trials, and Pacific Lithium began investigating the extraction of lithium at a laboratory scale.

It was recognised that more work was required to realise value from minerals in geothermal water, and in 2012 GNS Science proposed an applied research programme 'From waste to wealth: Commercial recovery of products from geothermal fluids' which sought to identify impediments to business adoption of geothermal fluid mining processes. The Ministry of Business Innovation and Employment (MBIE) funded the research. This foundation study identified effective processing methods for likely target products, and provided greater understanding of the economic viability, market drivers, and the regulatory framework influencing business in the implementation of such technologies in New Zealand.

The research and ideas generated gained the interest and support of geothermal production companies, regional councils, Māori trusts, regional development groups, and other industries. An integrated research proposal, supported by industry, was submitted into the 2016 and then 2017 New Zealand Government contestable research funding round, but both were declined funding.

Subsequently some work has been undertaken, including by GNS Science in a review of rubidium and cesium extraction methods, and by Geo40 extracting silica on a commercial demonstration scale using fluids from the Contact Energy managed Ohaaki Geothermal Field using ultrafiltration technology. Also MBIE, in conjunction with the geothermal sector, have commenced a review of the legislation influencing mining species from geothermal fluids. This work is aimed at clarifying and removing ambiguity and potential conflict in the applicable statutes.

New Zealand is underway to realise commercial value from the minerals in solution in geothermal waters. This paper provides updates, examples and experiences on the New Zealand geothermal minerals journey.

1. INTRODUCTION

In New Zealand, geothermal fluids are extensively used to generate electricity and are used directly as a source of heat energy in the industrial, commercial and residential sectors. However, despite promising fluid composition and the high volume of geothermal fluid extraction at various geothermal fields, the additional opportunity for mineral and metal extraction at the commercial scale is yet to be realised for minerals other than silica.

Figure 1 is a location map of a part of the North Island of New Zealand showing the location of the geothermal fields that are discussed in this paper in the context of mining materials from extracted geothermal fluids.

A new geothermal minerals industry offers potential economic, social and environmental benefits. Additionally, development of capabilities in processing technologies could further improve geothermal energy productivity and value, and open up international opportunities for technology transfer.

1.1 Early Geothermal Minerals Research

The opportunity for mineral and metal extraction from geothermal fluids was first identified in the 1960s by Kennedy (1961).

Pilot plant work at Wairakei in the early 1980s identified a method to produce calcium silicate from geothermal water using a lime slurry mixed with geothermal water, with the resulting solids separated from the liquid using dissolved air flotation (Rothbaum and Anderton, 1976; Shannon et al., 1982).

Lithium extraction from Wairakei separated geothermal water (SGW) by co-precipitation with aluminium hydroxide was investigated in detail by Rothbaum and Middendorf (1986), and in 1990 Rothbaum investigated the precipitation of lithium aluminium silicates from Mokai and Wairakei waters for use in ceramics. John Broome from Pacific Lithium, a company formed in 1994, worked on laboratory-scale lithium extraction from geothermal fluids using spinels, at Wairakei in the mid 1990s. Pacific Lithium went on to consider lithium extraction from seawater, and then developed an operation recycling lithium from batteries (Mroczek et al., 2015c).

In the mid-1990s, innovative pilot plants were constructed by the Electricity Corporation of New Zealand (ECNZ) at the Wairakei Geothermal Power Station, under the direction of the Station Chemist Lew Bacon, seeking to prove processes that might improve the operational, environmental and economic performance of the facility (Brown and Bacon, 2009). Of the several pilot plants installed, two focussed on silica in the geothermal water. Over the same time, Harper et al. (1995) described work undertaken for Tasman Pulp

and Paper Co. Ltd for extraction of precipitated silica from Kawarau geothermal fluid.

With regard to the ECNZ silica studies the work looked at:

- fluid flow dynamic effects on silica scaling; and
- production of controlled particle size silica sols to evaluate the potential for generating commercial grade silica products.

The controlled particle size silica work was very successful and the ultra-filtration methods employed produced sols of specific particle sizes (Brown and Bacon, 2000). This work remained unused until the ultrafiltration technology was picked up by Geo40, some 20 years later (described in Section 3 of this paper).

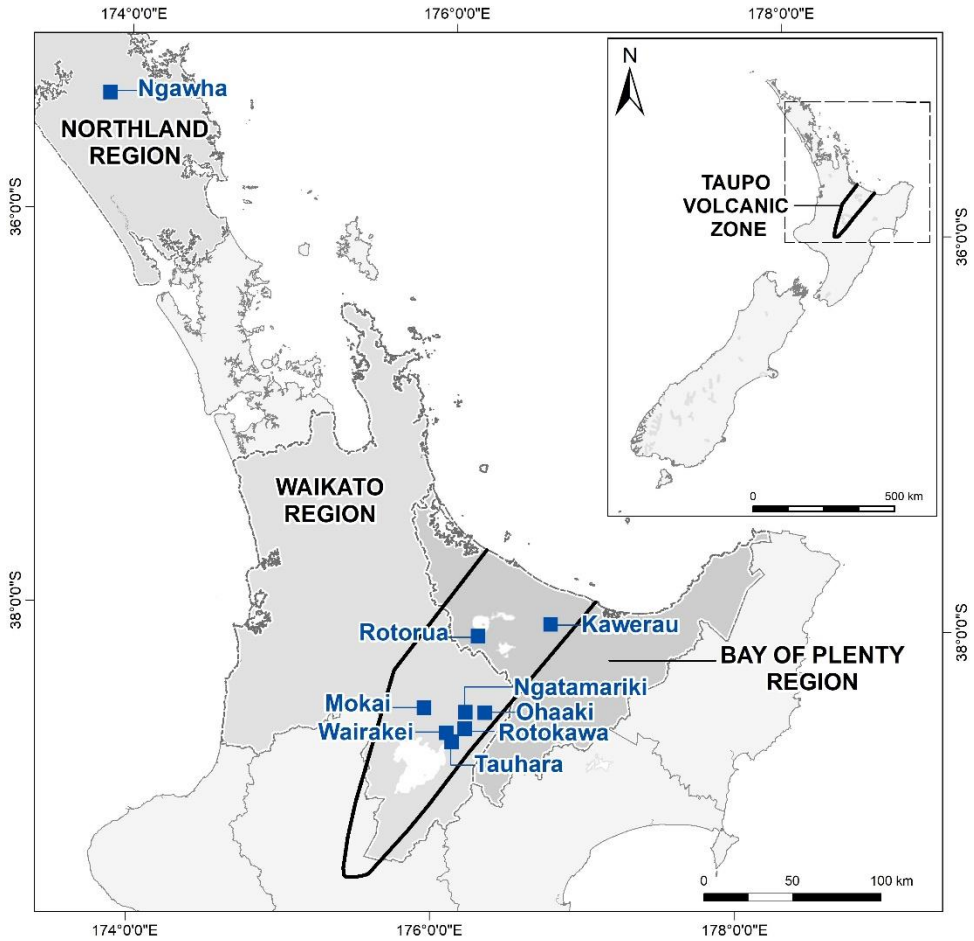

Figure 1 : Part of the North Island of New Zealand showing the geothermal fields and the Regional Council areas discussed in the paper.

2.0 REVIEW OF THE GEOTHERMAL MINERALS OPPORTUNITY

In 2012, GNS Science developed the research proposal titled *'From waste to wealth: Commercial recovery of products from geothermal fluids'* (Mroczek et al., 2015a). The proposal was accepted in 2013 and research was funded for $400,000 over two years (2014 / 2015). The study assessed opportunities for investment, identified processing technologies for mineral extraction from geothermal fluids, developed an understanding of some market drivers for geothermal derived minerals, and assessed the regulatory framework as it might influence the implementation of solution mining from geothermal fluids in New Zealand.

Near the conclusion of the studies, in July 2015, the GNS Science-led research team held an open stakeholder workshop that summarised the outputs from the work and sought to identify the next steps that would coherently take this work forward (Climo et al., 2016). The research and ideas generated were of real interest, gaining support from geothermal production companies, regional councils, Māori trusts, regional development groups, central government agencies, and other industries.

The four, 'From Waste to Wealth', study streams are summarised below. Each theme was formally reported, with the reports referenced in the sections that follow.

2.1 Chemical Composition of Geothermal Fluids

This study (Mroczek et al., 2015b) quantified the minerals and metals in New Zealand's geothermal fluids potentially available for extraction. Publicly available data, along with additional data released by geothermal field operators, on chemical composition of geothermal waters was summarised for geothermal fields in the Taupo Volcanic Zone (TVZ) and Ngawha. The "typical" reservoir water composition for each of the developed, high-temperature geothermal systems is shown in

The most common components of New Zealand's geothermal water were chloride, sodium, silica and potassium (generally in that order of decreasing concentration). The southern TVZ fields (Mokai, Wairakei and Tauhara) showed higher chloride and lithium compared to the eastern fields (Kawerau, Ohaaki and Rotokawa). Ngawha, in the North of the North Island, has a composition low in silica, but with boron as the second highest dissolved species (25x higher concentration than any of the TVZ fields).

Data on precious metal trace elements, such as gold, silver and copper, was scarce and their concentration in geothermal waters are very low (measurable in µg/kg; ppb).

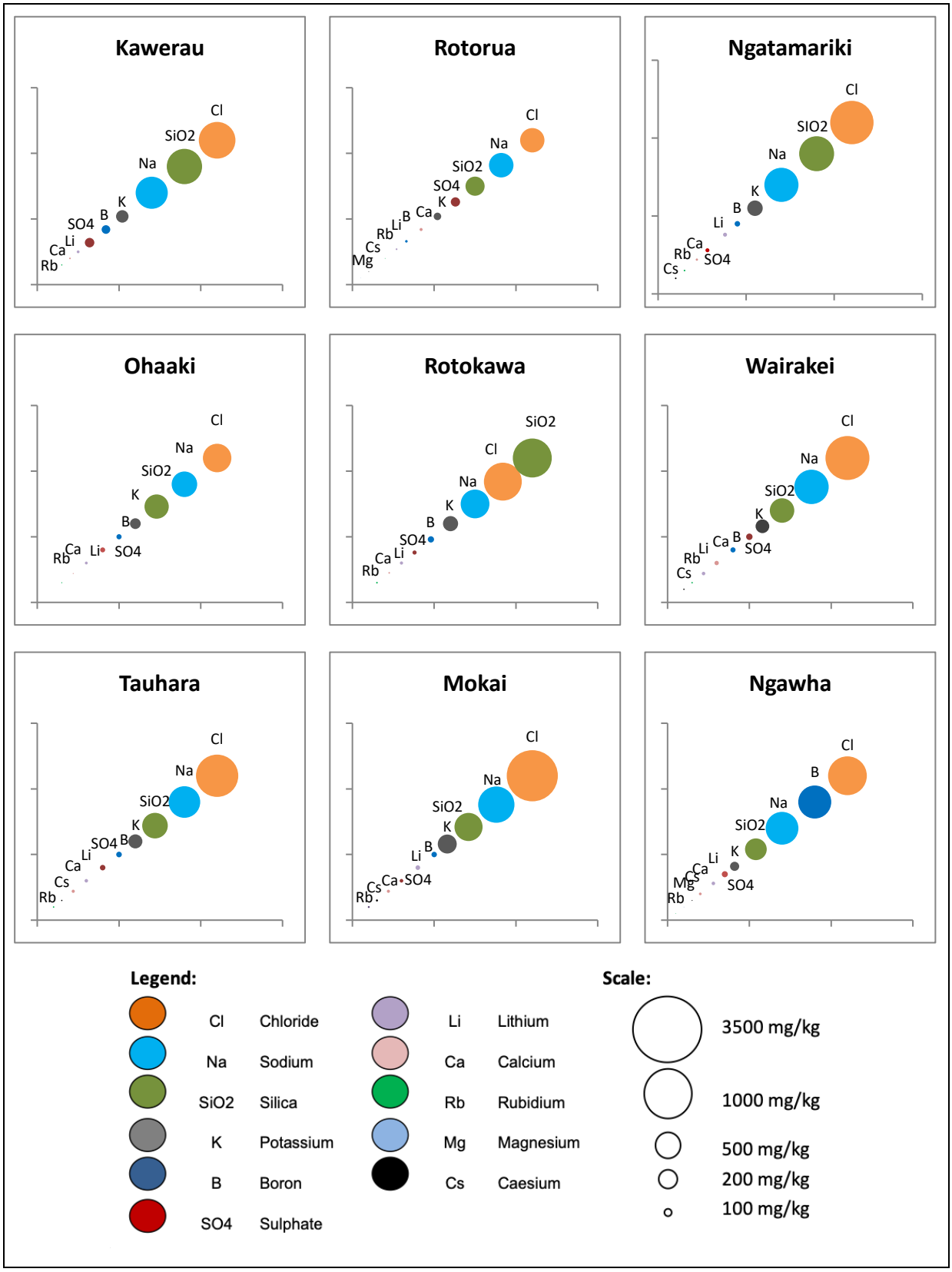

Figure 2: Concentration of species in geothermal water in areas in the Taupo Volcanic Zone and Ngawha (from Mroczek et al., 2015b).

The mass produced or consented to be taken at each geothermal field was then used to produce an annual species flux (Figure 3). Kawerau had the highest silica flux (~55,000 tonnes per year), while Wairakei had the highest mass discharges of chloride, lithium, rubidium, calcium, potassium and sodium. Of the minor elements, rubidium at Wairakei and cesium at Mokai have species fluxes of about 100 tonnes per year respectively.

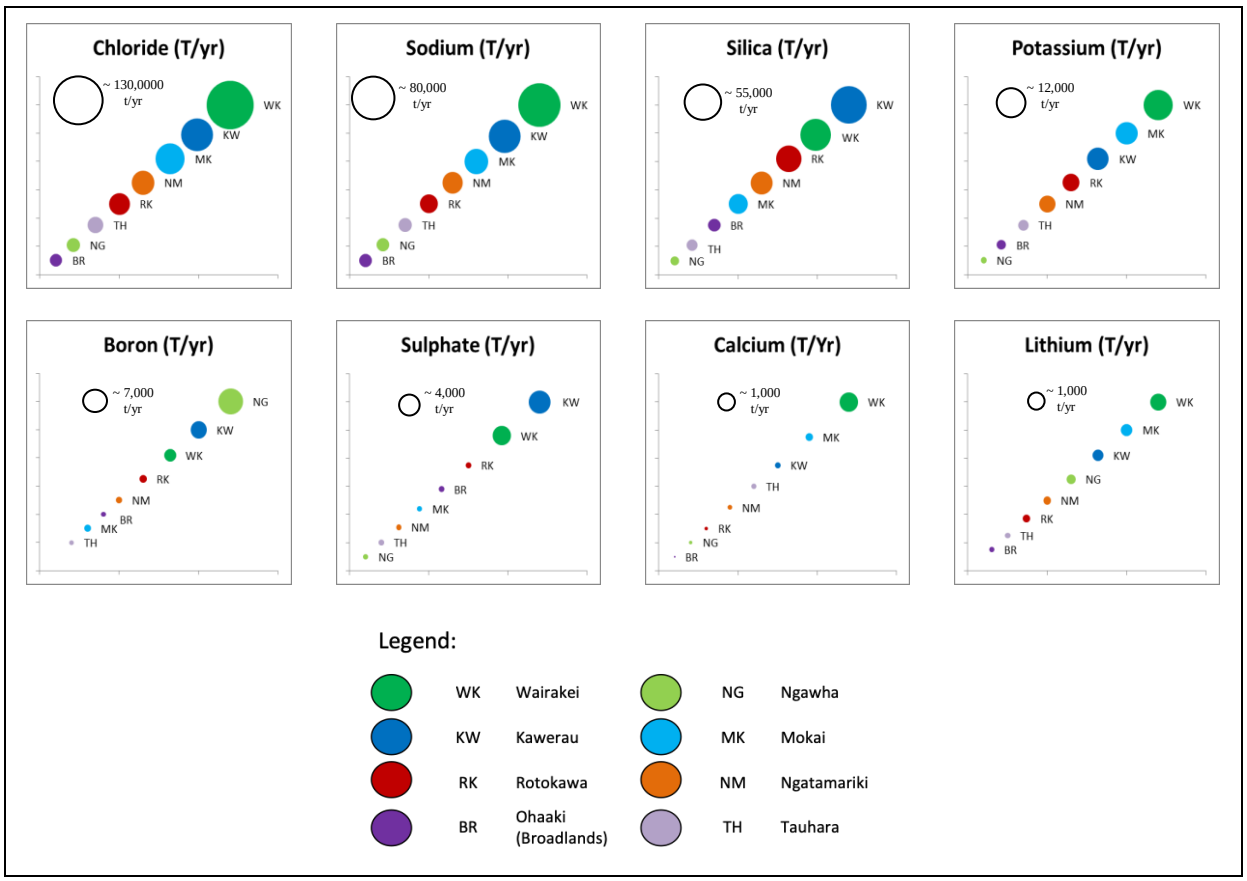

Figure 3: Chemical species fluxes by field (selected species; from Mroczek et al., 2015b).

2.2 Extraction Technologies

This study (Mroczek et al., 2015c) summarised previous geothermal mineral extraction undertaken in New Zealand, and relevant international studies, with a focus on silica, lithium, boron, rubidium and cesium from separated geothermal waters. New Zealand has trialled a number of techniques at an experimental and laboratory scale, but only a few at a pilot scale. Processes used include absorption, concentration, precipitation, ion-exchange resins, filtration, ultra-filtration, electrocoagulation, and electrodialysis.

Most of the research and development work has been undertaken on silica, as deposition of this mineral limits the amount of energy able to be extracted. Operationally at the large geothermal energy production facilities, silica deposition is managed by controlling the temperature of the geothermal water, so it remains close to the amorphous silica saturation, or by acid dosing. A low pH inhibits deposition, providing time for the silica saturated SGW to move through the surface plant, down the injection wells and out into the reservoir before the onset of deposition.

Extraction 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 ultra-filtration. Silica extraction from SGW will almost certainly be a prerequisite to the extraction of other species of interest. It will also create an opportunity for additional energy extraction, and allow a cost offset associated with the silica control techniques that are currently in use in geothermal energy production operations.

The second focus species was lithium, with recent increasing demand for automotive batteries for electric cars reviving interest for possible extraction from geothermal fluids. 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. John Broome from Pacific Lithium worked on laboratory scale lithium extraction from geothermal fluids using spinels, at Wairakei for a period in the mid 1990s (Mroczek et al., 2015c). The low lithium concentration in New Zealand SGW compared to highly saline Salton Sea geothermal brines or saline lakes in the Andes is an impediment to adoption of lithium extraction technology, and Pacific Lithium went on to consider lithium extraction from sea water. However, geothermal lithium solutions might be able to be cheaply concentrated using geothermal heat if it is available.

For boron there have been no published field trials or pilot tests in New Zealand, though potential techniques reviewed included precipitation/absorption (e.g., clays, electrocoagulation, chelating resins); and concentration (e.g., ion exchange; reverse osmosis, solvent extraction).

There are no studies published on the extraction of the minor components (such as cesium and rubidium) nor precious metals (such as gold, silver and copper) from geothermal fluids. Low concentrations in SGW means extraction would likely be uneconomic, especially where current adequate world supply means that any geothermal process would need to be highly efficient and cheaper than incumbent production methods.

2.3 Market Opportunities

A market analysis (Hill, 2015) for potential products focussed on silica and lithium, with some information also provided for boron, cesium, rubidium, sodium, potassium, magnesium and gold.

Key opportunities identified included dispersed silica for automotive tires, battery grade lithium salts and borate fertilisers. However, while these elements/constituents have opportunity for high value products, the true market opportunity was seen to be very dependent on the detailed requirements of the downstream product manufacturing. The physical nature of the product was important (e.g., purity, morphology). Also, niche products were suggested to command a significant premium (e.g., colloidal silica, some forms of organo-lithium), but the processing required to manufacture a suitable quality product requires consideration with respect to cost margins relative to techniques currently used.

Geographic market considerations will dictate the applicability of a New Zealand-based supply chain, requiring identification of correct customer/price level within the supply chain for the specific finished product (possibly niche) to return higher margins.

Further supply chain studies were recommended as part of future study to identify where a specific material might penetrate the supply chain.

2.4 Legal Rights

A legal analysis (Barton, 2015) examined the rights to minerals that might be extracted from geothermal fluids, including principally New Zealand's Resource Management Act (RMA) (1991), and the Crown Minerals Act (CMA) (1991). Rights to dissolved minerals and other materials in geothermal fluids are not dealt with explicitly in New Zealand law, so the legal position was determined by the application of general legislation and the general principles of law.

The key finding from the RMA was that the use of the term "water" (which includes geothermal resources) includes material dissolved or entrained in geothermal water. Thus, the RMA grants rights to dissolved minerals along with the "water" and mineral extraction would be managed regionally under the RMA, and could be included in an RMA permit. Once the fluid containing the dissolved materials comes into the piping systems of the permit holder, the water and the dissolved materials are the property of the company.

However, the CMA was not as clear. It was not possible to determine definitively whether the CMA also applies to a geothermal minerals operation. "Mining" is defined as "to take, win, or extract, by whatever means" a mineral in its natural state in land, and the CMA provides no exception for geothermal minerals, including in ancillary to another operation (e.g., geothermal energy production). If a geothermal minerals operation is "mining" under the CMA, then the company would have to obtain a mining permit and comply with other obligations under the CMA, as well as complying with the RMA.

Clarity was needed to be brought to the law on solution mining of geothermal minerals. Certainty in this legal position would remove a potential impediment to commercial investment.

2.5 Recommendations

Following the four core studies, the research team sought feedback through a stakeholder workshop and moved to recommend the next steps - to examine risk profiles, explore alternative business models and deliver commercial proof (Climo et al., 2016; Climo et al., 2015).

Suggested work areas included:

1. defining roles of government, investors, industry and others;
2. investigating mechanisms to bridge the commercialisation funding gap between pilot scale demonstration and full-scale commercial facilities;
3. examining how business decisions influenced the discontinuation of previous pilot scale plants;
4. determining why international extraction projects failed or were discontinued;
5. promoting reform of the law to get clarity on the CMA to improve the level of regulatory certainty;
6. assessing options for mitigating against commodity supply and demand cycle impacts;
7. investigating appropriate business models for use by a geothermal minerals company; and
8. developing robust financial models to determine the economic big-picture for a geothermal minerals industry in New Zealand.

A new funding proposal to continue this study, supported by industry, was submitted into the 2016 and then a revised proposal into the 2017 New Zealand Government contestable research funding round, but was declined.

3. WORK IN PROGRESS

The hypothesis underlying future studies was that a New Zealand-based geothermal minerals industry is only possible if technological and commercial barriers to implementation are addressed in an integrated way – combining engineering, scientific, business and legal expertise.

Future work was grouped into four key workstreams, seeking to:

1. quantify the economics of silica extraction technologies when integrated into a geothermal energy facility;
2. develop new methods and novel approaches for extraction of minerals and gases from geothermal fluids;
3. quantify the sustainability of geothermal mineral extraction; and
4. determine business risks, resolve legal uncertainty, and strengthen the position of geothermal minerals products in the market.

Some of these proposed workstreams have been continued by others in the New Zealand geothermal community, through smaller, ongoing projects examining silica extraction technologies and some methods testing.

3.1 Engineering Studies / Design for Retrofitting Mineral Extraction Processes

In 2017, GNS Science developed a readiness position for geothermal minerals, moving from basic research through to commercial development, shown in Figure 4 (GNS Science, 2017).

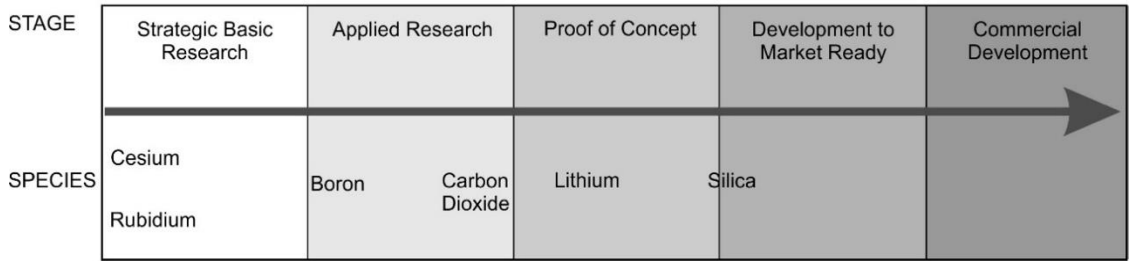

Figure 4 : Geothermal minerals species commercialisation readiness pipeline.

Silica is the closest to market ready; the extraction techniques are well understood, to the point that the next step for silica extraction would be engineering studies to determine how a silica minerals plant would be integrated into a large geothermal energy production facility in an operational satisfactory manner. The operation of the silica plant must not impede or negatively impact the primary business of geothermal energy production.

Additionally, researchers are Victoria University of Wellington and staff of Geo40 have also continued with more pilot plant silica extraction work. Borrmann and co-workers from Victoria University of Wellington have continued studies on the formation of calcium silicate from geothermal waters (Borrmann et al., 2018) through laboratory experiments and field trials at a pilot plant at the Wairakei Geothermal Field, commissioned in September 2017.

A containerised ultra-filtration silica sol pilot plant, developed by Geo40 (previously Environmetals), was installed in the Wairakei Geothermal Field (Feb. 2014 – Sept. 2015) and at two sites in the Kawerau Geothermal Field (Oct. 2015 – July 2017). The conditions the pilot plant was operated under are shown in Table 1. The Geo40 pilot plant work led to a commercial demonstration plant being installed and commissioned in the Ohaaki Geothermal Field in April 2018. Commercial production of silica from the plant for use in consumer product manufacture commenced in August 2018 (Geo40, 2018). A bid prepared to the New Zealand Government's Regional Development Provincial Growth Fund seeking $15 million in loan support for enlarging commercial production sevenfold was granted in July 2019. The funds will be used to support an initial public share offering within 12 months (NZ Herald, 2019), with $5 million of the government loan converting to shares at that time.

Table 1 : Geo40 ultrafiltration silica pilot plant inlet water conditions

Field	Geothermal Water Temperature Degrees C	Silica Concentration ppm
Wairakei	126	550
Kawerau (2 sites):		
Surface SGW Discharge	85-95	700
100 MWe Power Station SGW	140	950

3.2 New Methods for Mineral Extraction

Little has been undertaken in this workstream, other than through a small study by GNS Science using student support to review extraction methods of rubidium and cesium (Christopher and Mroczek, 2017).

3.3 Sustainability of Geothermal Mineral Extraction

No work has been undertaken on this workstream, the key thrust of which was around understanding the minerals transport through the geothermal production and injection operations, seeking to determine if the rock water interactions underground would limit the

availability of certain minerals over time to the point that this might constrain minerals supply to a mineral extraction business.

3.4 Legislative Review

A legislative review initiated by MBIE is underway, seeking the removal of ambiguity in the governing laws, particularly around the Crown Minerals Act.

SUMMARY

New Zealand is on a journey to realise commercial value from geothermal materials that were once considered nuisance or waste materials, seeking to open up new opportunities for holistically using geothermal fluids, increasing geothermal energy production and making geothermal industries even more sustainable.

More work could usefully be undertaken, as much of the work proposed by GNS Science in 2016 / 2017 remains on hold. No matter how well the silica extraction technology works, it needs to be shown that integration at a large scale in energy production facilities is technically and economically feasible. The reservoir minerals sustainability assessment work could be started and the legal / regulatory clarification work could usefully be completed to assist in releasing value from geothermal minerals for further benefit for New Zealand.

ACKNOWLEDGEMENTS

This 2014-15 review was funded by the New Zealand Ministry of Business, Innovation and Employment under contract C05X1307. Subsequently, this paper was supported by GNS Science through the core funded NGF 13 Direct Use programme.

The authors would like to acknowledge the contribution of participants in the July 2015 stakeholder workshop, and those who supported the research studies with data and expertise

REFERENCES

Barton, B. 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). (2015)

Borrmann, T., Schweig, M., Cairns, M.J., Johnston, J.H., Gray, A.K. Removing silica from geothermal water - year one of pilot plant operation with a focus on carbonate and silica analysis. New Zealand Geothermal Workshop. http://www.geothermal-energy.org/pdf/IGAstandard/NZGW/2018/023.pdf (2018)

Brown, K.L. and Bacon, L.G. Manufacture of silica sols from separated geothermal water. In: Proceedings World Geothermal Congress 2000, Kyushu-Tohoku, Japan. (2000).

Brown, K., Bacon, L., Pilot plant experiments at Wairakei Power Station. *Geothermics* 38 (2009) 64–71. (2009)

Christopher, T.D. Mroczek, E.K. A review of rubidium and cesium extraction methods from geothermal and radioactive sourced materials, GNS Science Report 2017/02. 30 p. (2017)

Climo, M., Mroczek, E., Carey, B. Mineral Extraction from Geothermal Brines in New Zealand: 2016 Update, *GNS Science Report* 2016/28. 26 p. (2016)

Climo, M., Mroczek, E., Carey, B., Hill, A., Barton, B. Mineral extractions from New Zealand's Geothermal brines: Where to next? *Proceedings*, 37th New Zealand Geothermal Workshop, 18-20 November, Wairakei, Taupo, New Zealand. (2015)

CMA (Crown Minerals Act), http://www.legislation.govt.nz (1991)

Geo40. Silica extraction starts at Ohaaki. http://geothermalresourcescouncil.blogspot.com/2018/08/new-zealand-geothermal.html (2018)

GNS Science. Economic Mineral Extraction - Waste to Wealth 2. Proposal 51654 to the 2017 Endeavour Funding Round. (2017)

Harper, R.T.; Thain, I.A.; Johnston, J.H. 1995 An Integrated Approach to Realize Greater Value from High Temperature Geothermal Resources: A New Zealand Example. Proceeding 1995 World Geothermal Congress; https://pangea.stanford.edu/ERE/db/IGAstandard/record_detail.php?id=4900

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

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

Mroczek, E., Climo, M., Li, Y., Evans, D., Carey, B., Gao, W. From Waste to Wealth: Mineral Extraction from Geothermal Brines. *Proceedings* World Geothermal Congress, Melbourne, Australia, 19-25 April 2015. (2015a)

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

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

NZ Herald. A company going public within a year is getting a $15 million Provincial Growth Fund loan. Press Article 8 July 2019. Retrieved https://www.nzherald.co.nz/business/news/article.cfm?c_id=3&objectid=12247627 (2019)

Rothbaum, H.P., Anderton, B.H. 1976 Removal of silica and arsenic from geothermal discharge waters by precipitation of useful calcium silicates. Proceedings of the Second United Nations Symposium on the Development and Use of Geothermal Resources, San Francisco, 1417-1425 (1976).

Rothbaum, H.P., Middendorf, K. 1986 Lithium extraction from Wairakei geothermal waters. NZ Journal of Technology, 2(4): 231-235. (1986)

RMA (Resource Management Act), http://www.legislation.govt.nz/act/public/1991/0069/latest/DLM230265.html (1991)

Shannon, W.T., Owers, W.R., Rothbaum, H.P. Pilot scale solids/liquid separation in hot geothermal discharge waters using dissolved air flotation. Geothermics Volume 11, Issue 1, 1982, Pages 43-58. (1982)