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# Silica and Other Minerals Extraction from Geothermal Brine in New Zealand

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## ABSTRACT

Geo40 is a New Zealand technology company that was established in 2010 to develop technologies for the extraction of minerals from geothermal brine after it has been used for geothermal power production.

Silica scaling in geothermal power generation is a significant issue. Work carried out by Jacobs[1] for Geo40 has shown that silica management costs can be as high as 20% of a power plant's operating cost. Jacobs have also shown that up to 20% more power could be produced from reinjection fluids through the introduction of binary power plants, if silica levels were able to be reduced.

This paper covers the Geo40 nine-year journey in developing and commercializing a process for extracting the silica from brine that is being reinjected and turning the extracted silica into colloidal silica for sales in the specialty silica markets globally. The benefits for the geothermal power generator are little or no scaling of reinjection pipework and reinjection wells and the ability to use the reinjection fluid for further power generation or heat use without further scaling.

In April 2018, Geo40 successfully completed the construction and commissioning of a commercial demonstration plant processing 850 tonnes per day of separated geothermal water from Contact Energy's Ohaaki Geothermal Power station in New Zealand.

The processed brine from this plant has been used to restore the natural beauty of a local hot spring (ngawha) at a traditional meeting house (marae) demonstrating how the geothermal power industry and local indigenous people can work together to achieve a successful outcome.

Following this success, Geo40 is nearing completion of a much larger plant (Northern Plant) which will process geothermal brine being reinjected on the field. Geo40 has also begun work on extracting other valuable minerals from the brine and has established a pilot plant for the extraction of lithium in the form of lithium carbonate or lithium hydroxide.

This paper will take you through the patent pending process for silica and other minerals extraction, the demonstrated success of the process and restoration of the Maori hot spring and construction progress of the first full scale plant (Northern Plant) and the first lithium extraction trials.

## 1. INTRODUCTION

Geo40 Limited was founded as Environmetals Limited, in 2010 by Mike O'Sullivan, Matt Sutcliffe and Adam Peren with the vision of developing technologies for the extraction of minerals from geothermal brines.

The founders of Geo40 had observed that geothermal power generators spent considerable capital to develop geothermal fields which bring hot mineralized geothermal brine to the surface only to return this fluid back into the reservoir without extracting any of the minerals or all of the energy which it contains. It was also observed that the minerals contained within the brines did not require mining, grinding or dissolving as they were in solubilized form. Geo40 saw the opportunity to work with geothermal generators and extract the valuable minerals from the fluid prior to reinjection while improving the operating costs of the geothermal field.

In the early work carried out by Geo40 on Contact Energy's Wairakei geothermal field, Geo40 found that the silica that is present in the fluid must first be removed to gain access to the other minerals in the fluid.

Silica scaling in geothermal power generation is a significant problem and managing and controlling the scaling can account for a large percentage of operating costs. Additionally, the amount of heat that can be taken from the geothermal fluid is limited by the point at which the dissolved silica becomes saturated in the fluid.

Geo40 has successfully developed a patent pending process to extract the solubilized silica in the geothermal fluid and turn this into colloidal silica, which is used in a large range of industries such as precision investment casting, pulp and paper, refractory fibre bonding, etc.

## 2. GEO40 PROCESS

To date Geo40 has focused its development and process design on the treatment of separated geothermal water from the flash separator in a geothermal power plant. At this point, the brine is close to silica saturation or over saturated and suppressed through

[1] RZ015400-GE-RPT-001B *Cost of Mitigation of Silica Scaling*, *Study 1*

the use of pH adjustment, anti-scalents or heat. Geo40 receives the brine, optimizes the pH for its process and cools the fluid. During the cooling stage the silica forms discrete silica colloids which are aged and filtered out using a continuous ultrafiltration (UF) circuit to concentrate the silica from its incoming concentration to a 4wt% solution. Filtrate from the process is now low in silica and able to be used for further mineral extraction. Following further mineral extraction, the filtrate is used to cool the incoming hot brine, recovering the heat and making this available for further power generation from a binary plant or for a heat source.

### 2.1 Pilot Plant Trials

In 2014, the first large scale pilot plant was built on Contact Energy's Wairakei geothermal field in New Zealand. The first process trialed was based on a process developed by Dr Bill Bourcier of Lawrence Livermore National Laboratories (LLNL) at the Mammoth Geothermal Complex in California, USA.

**Photo 1: Photo of first pilot plant located at Contact Energy's Wairakei geothermal field in New Zealand**

This process was developed on the low temperature and low silica fluid leaving the Ormat binary plant. The process utilized reverse osmosis to separate the silica from the geothermal fluid and then further process this into colloidal silica. The LLNL process was developed on reinjection fluid that was 85 degrees centigrade and 300ppm of silica. The Wairakei fluid supplied to the Geo40 pilot plant was 135 degrees centigrade and 670 ppm silica.

In the pilot plant, the incoming fluid was first cooled before being sent to the reverse osmosis plant. On starting the pilot plant on these much higher silica and temperature conditions the process was unable to cope and significant damage was done to the reverse osmosis plant. Over the next four months Geo40 adapted the process to run under these conditions and filed a patent (EVM1) covering the developments.

A scoping study done on the process showed that the colloidal silica produced from this process did not have a competitive advantage from a capital cost or production cost perspective. Geo40 then set about re-engineering the process to reduce capital costs and operating costs. The reverse osmosis stage was removed and replaced with UF. The temperature of the incoming brine was further cooled to allow it to be processed through UF membranes. Chemical dosing was used to maintain the UF membrane integrity. This lowered the capital costs and pumping costs but reduced the recovery levels. A benefit of this new process was that by utilizing lower temperatures, the silica saturation point was lowered to a level that would prevent silica scaling when the fluid was re-heated for reinjection.

The scoping study showed that despite the lower recovery, the savings in operating costs and capital costs more than compensated for the loss in revenue from lower recovery. A patent application was filed for this new process (EVM2).

Further work was carried out over 2015 to refine the process and improve the colloidal silica production to make products with targeted particle sizes and distribution. The colloidal silica markets are differentiated by application and colloid size. Geo40 developed processes for producing a product range of 6nm 15wt%, 8nm 20wt%, 10nm 30wt%, 12nm 30wt% and 14nm 30wt% products. This resulted in Geo40's third patent application being filed (EVM3). The Geo40 process was finalized on this process.

Following the successful work at Wairakei a simplified pilot plant was relocated to Kawerau in New Zealand where the process was tested on the shallow field on the Norske Skog site. After four months of operation on the Norske Skog site, the pilot plant was rebuilt based on the design of a pilot plant shipped to the Kakkonda geothermal field in Japan and set-up at Mercury's Kawerau Geothermal Limited plant. At both sites the process worked extremely well. Product made in the pilot plant was sent to potential customers in New Zealand and Japan for testing. The results of this testing showed that the quality and performance of Geo40 geothermally produced colloidal silica was on par with industrially produced products.

**Photo 2: Simplified pilot plant on Norske Skog site at Kawerau in New Zealand**

**Photo 3: Newly designed pilot plant located at Mercury's Kawerau Geothermal Limited site at Kawerau, New Zealand**

In 2017, Geo40 formed part of a New Energy and Industrial Technology Development Organization (NEDO) sponsored consortium in Japan with Geothermal Energy Research and Development Company Limited (GERD), Japan Gas Corporation and University of Kitakyushu to test Geo40's process at Tohoku Sustainable & Renewable Energy Co geothermal plant at Kakkonda, Japan. Over a three-year period, a Geo40 pilot plant operated on G-site and 6-site at Kakkonda. The pilot plant performed well and colloidal silica product from the pilot plant was tested in Japan and confirmed to be of similar quality to leading industrially-produced product. During the trial, lithium extraction work was carried out on the UF filtrate by University of Kitakyushu. In this work over 95% of the lithium was extracted.

GERD also carried out simulated reinjection scaling tests on the UF filtrate using a packed column test. This test work is reported in a separate WGC2020 paper titled: *Application results of Silica Extraction Technology at Kakkonda Geothermal Area and Evaluation of extending the life of the reinjection well* presented by Masatake Sato, Kaichiro Kasai and Kazumi Osato from GERD.

**Photo 4: Geo40 pilot plant at G-site at Kakkonda, Japan.**

### 2.2 Commercial Demonstration Plant

Following successful pilot plant trials at Wairakei and Kawerau geothermal fields in New Zealand and Kakkonda geothermal field in Japan, Geo40 signed an agreement with Contact Energy in New Zealand for a staged commercialization of the technology at Contact Energy's Ohaaki geothermal field. The agreement was a three-way agreement with Contact Energy, Geo40 and with the local indigenous (Maori) landowners, Ngati Tahu Tribal Lands Trust.

The agreement requires Geo40 to first carry out pilot plant trials to show the process works on the Ohaaki separated geothermal water (SGW), build a commercial demonstration plant and once proven, build a larger commercial plant that will process the SGW going down a single reinjection well. After six-months of operation and proof that there was no deleterious effects on the reinjection well, Geo40 will be allowed to proceed with the treatment of the majority of the SGW on the Ohaaki field.

Under this agreement, and on the success of pilot plant trials, Geo40 was required to build a commercial demonstration plant at the Ohaaki field. The feed to the plant was SGW from the Ohaaki geothermal power plant steam separator, SP2. The SGW being supplied to the plant was the same fluid that was being piped to an historic Maori hot spring (ngawha) situated on the banks of the Waikato River and adjacent to the local Ohaaki marae (meeting house). Back in the 1980s, when the Ohaaki geothermal field was developed, hot water flowing to the historic ngawha dried up. Under an agreement with Ngati Tahu and the New Zealand government, the hot water flow to the ngawha was restored using SGW. However, this fluid was saturated in silica (720ppm) and when sent to the ngawha it turned milky white from the silica. The outflow from the ngawha flowed into the local Waikato river where this also turned white. The ngawha had originally flowed with crystal clear geothermal water due to the silica being filtered through the ground before reaching the surface.

Under the agreement, the Geo40 commercial demonstration plant is required to process the fluid that feeds the ngawha and remove the silica to return the historic ngawha back to its pristine historical state. The plant is required to run 24/7 demonstrating to Contact Energy that the process works reliably and can remove the silica to demonstrate that there should be no issues with putting the processed fluid down a reinjection well.

Construction of the commercial demonstration began in October 2017 and was completed in April 2018. The plant was fully commissioned in June 2018. Since this period the plant has been running continuously. Over 500 metric tonnes of colloidal silica has been sold to companies in New Zealand, Australia, Japan, USA and Mexico.

**Photo 5: Ohaaki geothermal field, New Zealand**

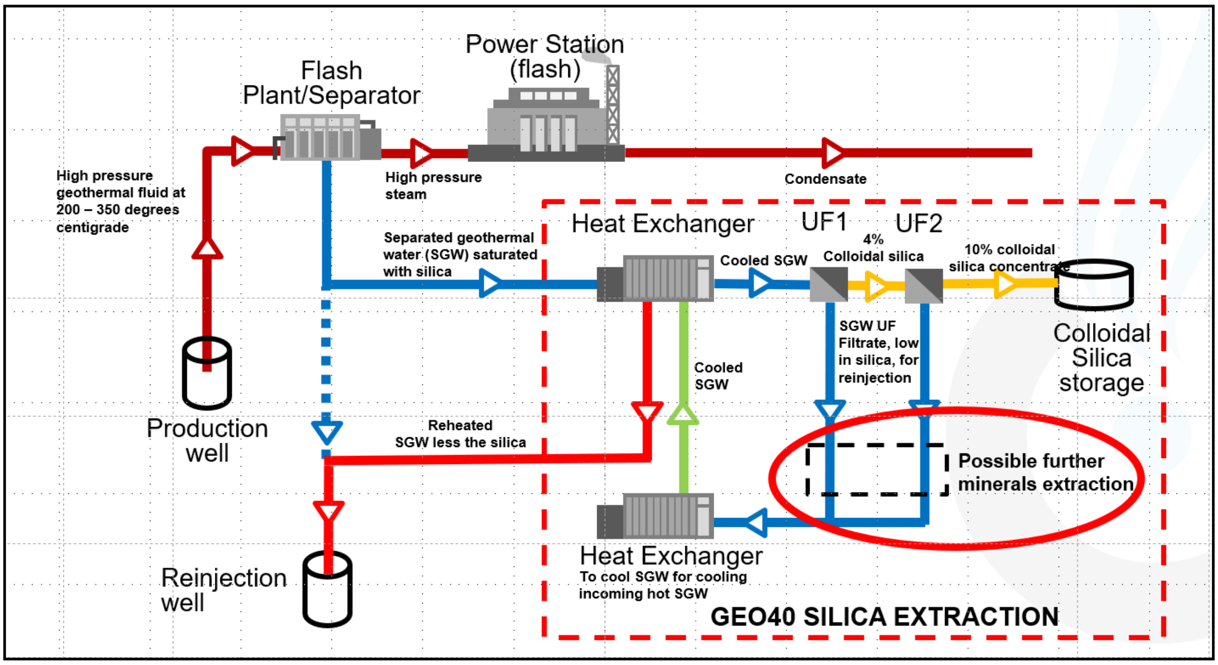


**Figure 1: Schematic of the Geo40 process where the processed fluid is reinjected**

**Photo 6: Commercial demonstration plant at Ohaaki, New Zealand**

The following are the key operating conditions for the plant:

- Incoming SGW flowrate - 9.8 kg/s
- Incoming SGW temperature - 140°C
- Incoming SGW silica content - 720ppm
- Exiting SGW flowrate - 9.7 kg/s
- Exiting SGW temperature - 132°C
- Exiting SGW silica content - 250ppm
- Plant availability - >98%
- Colloidal silica produced - 450 tonnes per annum at 30wt% product

The process operates in two distinct phases. The first is a continuous process where the incoming SGW is cooled to 35°C to 45°C to nucleate the silica colloids. This is then filtered in a multi-stage UF system which removes approximately 70% of the silica to produce a 4wt% colloidal silica concentrate. The UF filtrate is used to cool the incoming SGW, thereby returning the heat back to the UF filtrate.

In the commercial demonstration plant, the re-heated UF filtrate is sent to the ngawha at 132°C. As the UF filtrate now has a silica level of 250ppm silica, the silica remains solubilized and the filtrate is crystal clear in appearance. This has successfully returned the ngawha back to its original pristine natural beauty.

The next stage of the Geo40 process is a batch process where the 4wt% concentrate of largely 4nm – 6nm colloids is further concentrated to 10wt% in a second UF circuit. The 10wt% concentrate is then further processed in renewable geothermal energy heated reactors to grow the colloids to specific sizes and size distributions.

In the commercial demonstration plant Geo40 is producing two 10nm products for customers, the first with a narrow particle size distribution and the second with a wider distribution. Geo40 is also producing a 14nm product.

After the colloids have been grown to specific particle sizes and surface area, the 10wt% product is concentrated in a final UF circuit to 30wt% and packaged into IBCs or bulk flexi-tanks for sale and distribution internationally.

**Photo 7: Aerial shot of before the Geo40 process**

**Photo 8: After of the Geo40 process showing silica terraces**

**Photo 9: Outflow into the Waikato river before Geo40 process**

**Photo 10: Clear outflow after the Geo40 process**

Geo40 also placed coupons in the inflow to the commercial demonstration plant and on the exit. These were removed after six-months of operation of the Geo40 process.

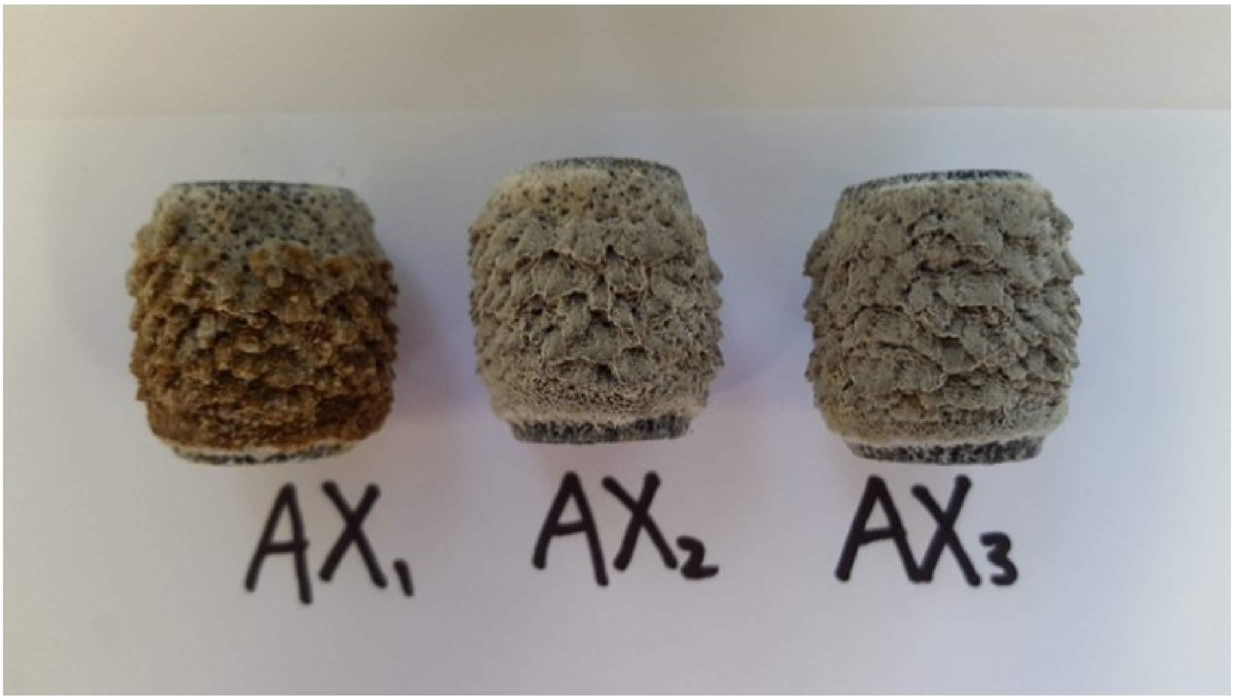


**Photo 11: Inlet scaling coupons after 6 months**

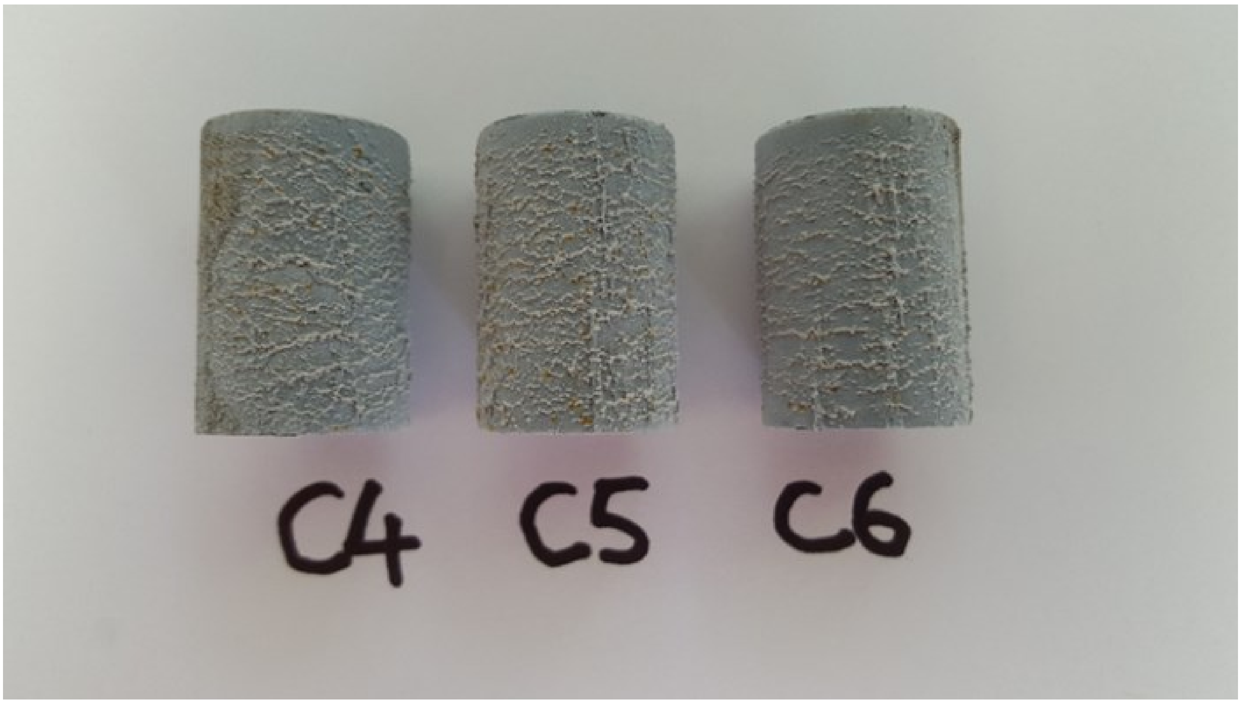


**Photo 12: Outlet scaling coupons after 6 months**

The coupons and the restored clarity of the ngawha, dramatically show the effect of using the Geo40 process to extract the silica from SGW.

Following six-months of demonstrated consistent performance, Geo40 and Contact Energy have agreed for Geo40 to move to building a much larger plant processing around 80kg/s of SGW from the power station, which is being reinjected down a single reinjection well. The plant is located on the northern reinjection well site on the Ohaaki field.

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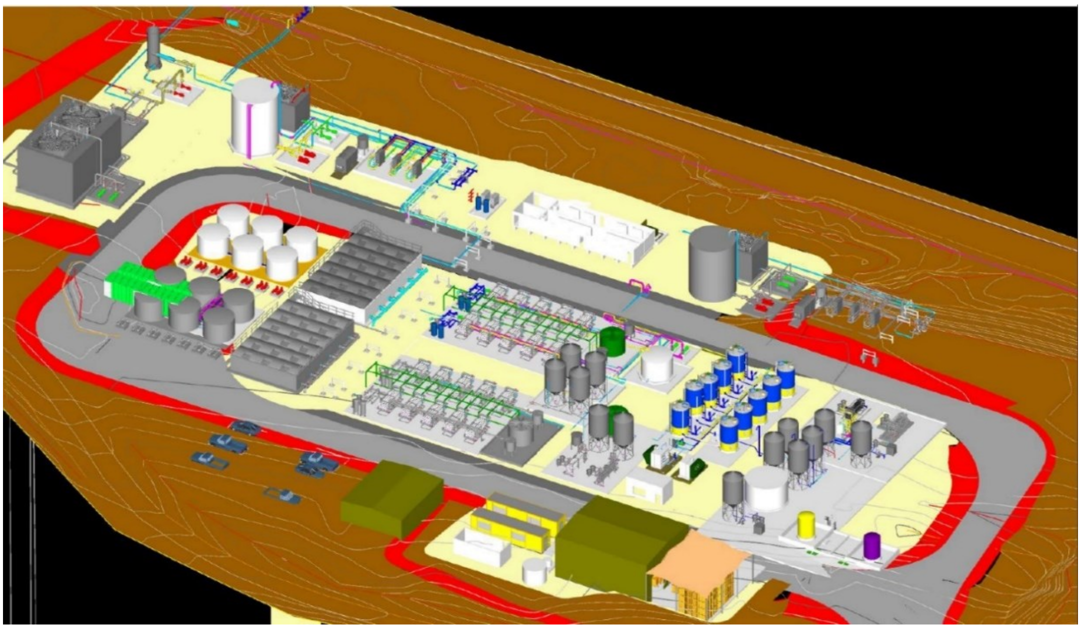

**Figure 2: 3-D rendered drawing of the Northern Plant**

### 2.3 Northern Plant

At the time of submitting this paper, Geo40 has completed the complete design and estimated capex for the Northern Plant. Funding for the plant has been secured and earthworks are planned to start in August/September 2019, with completion expected to be in July/August 2020.

The Northern Plant is expected to produce around 4,700 tonnes per annum of 30wt% colloidal silica which will be exported to customers in Australia, parts of Asia and to North America.

For the six months after completion of the Northern Plant, Contact Energy and Geo40 will monitor the performance of the reinjection well, specifically the flowrate, pumping pressure and corrosion levels.

## 3.OTHER MINERALS EXTRACTION

As the world moves to control motor vehicle $CO_2$ emissions by replacing them with electric vehicles (EV), the demand for lithium and other key battery minerals is expected to increase significantly. Geothermal fluid contains a range of valuable minerals including lithium. The focus to date on lithium extraction from geothermal fluids has been on fluids with high levels of salinity and lithium. Much of this work has been focused on geothermal fluid around the Salton Sea in California, USA. A key issue for lithium and other mineral extraction from geothermal fluid is the presence of silica which scales-up extraction equipment and ion exchange resins.

### 3.1 Lithium Extraction

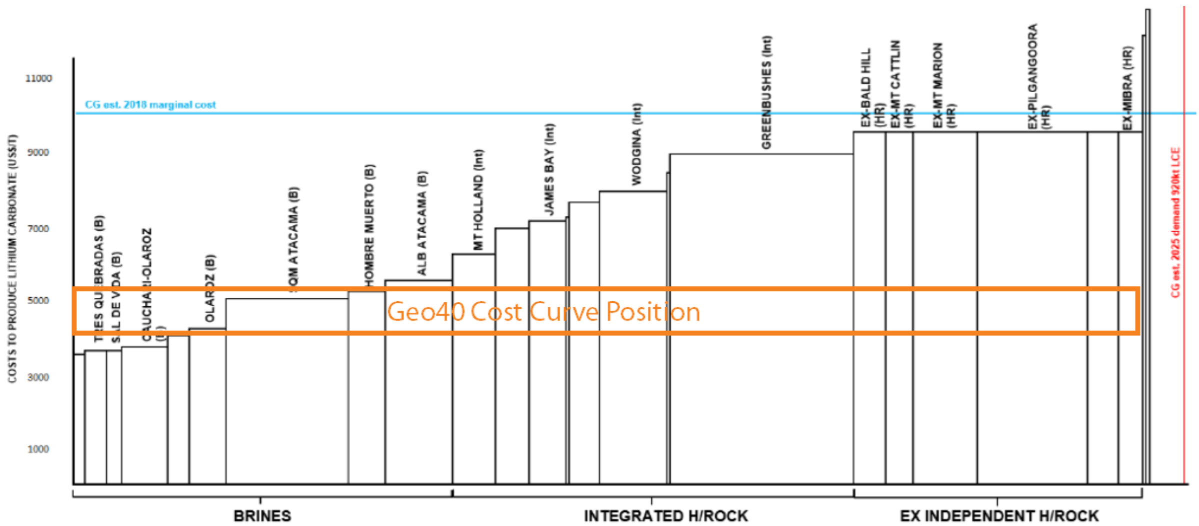


**Figure 3: Relative lithium extraction costs**

SGW processed through the Geo40 process reduces the silica to levels where the silica remains in solution, allowing the SGW to be further processed for the extraction of other minerals. In Geo40 pilot plant trials carried out at the Kakkonda field in Japan, lithium extraction trials were carried out by the University of Kitakyushu on the UF filtrate. The geothermal fluid at Kakkonda does not contain very high levels of lithium. In the processed UF filtrate the level of lithium was 3ppm. In these trials, packed columns containing a pelletized specific lithium absorbent were exposed to the silica depleted UF filtrate from the Geo40 process.

In these initial trials over 95% of the lithium was successfully extracted from the UF filtrate. Following this early success, Geo40 has continued this work on bench scale in the USA using UF filtrate sent to the USA from the commercial demonstration plant at Ohaaki in New Zealand. This fluid has a much higher level of lithium, being 10ppm.

In the test work carried out on bench scale in USA, the focus was on measuring all the key parameters that effect the economics of extracting the lithium. Following this work a scoping study was completed. The scoping study concluded that lithium could be extracted from the processed SGW at an estimated cost that is similar to the extraction costs from lithium salar brines.

This work was repeated in New Zealand using fresh processed SGW from the commercial demonstration plant. The results of this work confirmed the original USA findings. In late 2019, Geo40 is planning on installing a pilot plant at Ohaaki to extract lithium.

## CONCLUSION

Over the last nine years, Geo40 has worked on a process to extract minerals from geothermal brines that have been separated from steam (SGW) which is being used to generate electricity. Early in the research and development it was found that silica in the SGW needed to be removed to access the other minerals. Managing silica scaling in the production of geothermal power is a significant cost for the global industry. Geo40 has worked to develop a process for extracting the geothermal silica from the SGW and further process this into colloidal silica which is used as a specialty product in a range of industries. Geo40 has shown that its colloidal silica products compete favorably against industrially produced equivalents. Geo40 has also shown that the silica depleted SGW can then be further processed to extract other minerals, such as lithium.

Geo40 is in the final stages of commercializing its technology with the construction of a full-scale processing plant at Contact Energy’s Ohaaki geothermal field in New Zealand. Processed SGW from the full-scale plant will be reinjected down an existing reinjection well, demonstrating the benefits of silica removal in a geothermal power generation plant.