GRC Transactions, Vol. 43, 2019

Competitiveness of Direct Mineral Extraction from Geothermal Brines

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Keywords

Mineral recovery, direct extraction process, lithium, brine, financial model, valuation, investment, competitiveness, battery, mining

ABSTRACT

The promise of higher lithium recovery rates and projections in lithium demand have supported the renewed interest in research and development of direct extraction technologies from brine resources. Notwithstanding the technical challenges to performance, these systems have remained constrained from market entry by the low-cost economics of conventional evaporation pond methods. This study designs a comparable basis to value direct mineral extraction of lithium from geothermal brines in comparison to investment in other current technologies compiled from recent published economic analyses. Other mineral commodities may be economically recoverable from geothermal brines, but as such flow sheets are not yet demonstrated, process costs are estimated based on commercial mining projects.

As interest in (and demand for) environmental sustainability and the social license to operate becomes a mandate in supply chain decisions, battery mineral suppliers may increasingly value these externalities, both positive and negative. In the meantime, this work touches upon potential changes in the materiality of battery minerals that may also influence the interest in domestic mineral security, and how geothermal brine mineral recovery could contribute.

1. Introduction

Mineral recovery from brine resources was a component in driving the first geothermal plant at Lardarello (Blake 1974). Currently, mineral recovery from brine resources dominates the world supply and resources of lithium (USGS 2019), dominated by the use of evaporation ponds. Other mineral commodities, such as borate, potash, salt, zinc, and copper, have known operating commercial processes for mineral recovery from solutions. While multiple processes have been proposed and tested on geothermal brines, geothermal resources have been utilized primarily for their value for power generation due to the challenges surrounding the economics of commercializing direct extraction processes of minerals that returns spent brine to the resource (e.g. Burba 2013, Cutter 2000).

With the technical advancements of battery technologies and applications, the demand for domestic mineral supplies is increasingly a focus of U.S. national security (USGS 2017b). Furthermore, technical advancements in batteries support increasing densities of minerals potentially recoverable and supplied from geothermal brines. As a result, the market environment may indeed, finally, be prepared to support commercial recovery from geothermal brines. This work endeavors to understand under what economic conditions geothermal brine projects will compete.

2. Financial Modeling

Mining companies complying with the CRIRSCO reporting standards (such as JORC and NI 43-101) are required to issue a preliminary economic assessment outlining the anticipated economic performance of a project under reasonable market assumptions at the time of issuance (CRIRSCO 2019). As these reports are made publicly available via corporate websites and are specific to a resource/project, these assumptions can be used to compile commercial project scale, operating costs, and capital expenditures. Of the 113 lithium mining projects reviewed, only 6 were sufficiently advanced to have issued a PEA since late 2017. Of these projects, 2 reference the use or exploration of a direct extraction process for lithium recovery. The annual production capacity, mine life, price forecasts, capital expenditures, operating costs per ton (in Lithium Carbonate Equivalent or Lithium Hydroxide), lithium recovery rate, initial brine lithium content, and energy consumption were compiled where available.

A study of mineral recovery from Magamax wells in the Salton Sea KGRA was used to supplement available data on the geochemistry of brines and other associated well performance such as enthalpy and flow rate (USGS 2017a, Maimoni 1982, CDC 2017, Neupane and Wendt 2017).

Before-tax cash flow was estimated from the compilation of these data for the assumption of a project with 1000 MW and an inlet brine lithium concentration of 200 ppm (i.e. the concentration initially available to the recovery process). Capital expenditures related to well development were removed for comparing the recovery process as an addition to geothermal power units with well fields completed. Four cases were investigated for a static lithium carbonate price assumption of $13,500 / metric ton LCE:

- construction of conventional evaporation ponds,
- construction of evaporation ponds with assisted evaporation and direct extraction from a concentrated solution,
- construction of a direct extraction process (commercial and pilot plants) with reinjection, and
- construction of a direct extraction process with reinjection and a proven process flow.

Although the likelihood of constructing evaporation ponds for a geothermal resource used in power generation is not feasible due to the requirements for reservoir recharge, this case provides a direct comparison of the economics of this process at the scale of recovery available from geothermal brine.

3. Value Comparison of Lithium Recovery

The following table highlights the differences in project value related to the start of revenue-generating operations: even with higher upfront capital expenditures and a higher demand for investment, direct extraction processes reduce the payback period. Direct extraction processes may well exceed the return on investment in conventional evaporation ponds after initial investments requiring pilot plants.

Table 1: Summary of financial model output for standardized cases. Capital expenditures exclude wellfield development and expansions, and does not include indirect costs or contingency. Minimum Investment is calculated as the negative free cash flow prior to debt service. Net Present Value assumes a 20-year "mine" life, 10% discount rate, and 20% tax rate.

Case	Capital Expenditures (million USD)	Minimum Investment (million USD)	NPV (million USD)
Conventional Ponds	424.8	434.6	1,985.6
Ponds with Hyper-Evaporation and Direct Extraction	798.4	470.8	3,169.6
Direct Extraction Process with Pilot	1,058.5	561.7	3,421.6
Direct Extraction Process post-Pilot	1,045.4	43.9	3,729.5

4. Additional Mineral Commodity Steams

Implementation of a multi-stage process flow requires an understanding of the relative economics of each of the operations. This analysis does not aim to assess current economics of any prior flow sheets proposed for geothermal systems (e.g. Maimoni 1982). No publicly available data was found at the time of writing to assess operating costs, capital costs, and recovery rates of any such systems recently tested.

The addition of commodities to a mineral recovery operation requires transparency into the balance between the added operating costs and capital expenditures and the long-term revenue stream. In the case of adding KCl to a conventional lithium evaporation pond in Argentina, the estimated net present value of the combined operations were less than the value of the lithium operations alone (Lithium International 2018).

5. Materiality of Battery Minerals

Currently, the market for lithium-ion batteries uses lithium carbonate as the primary form of lithium, requiring producers to convert extracted lithium into carbonate for sale. Moving forward, the trajectory is to use higher quantities of lithium hydroxide in battery chemistries such as NMC811 that require less cobalt. Beyond the near term, the International Energy Agency estimates that solid lithium metal anodes will become commercial within the next decade (2018). However, given the 3-year construction timeline for a commercial plant and 4-5 year resource development, by the time new battery chemistries are commercially available, their ability to be cost-competitive in the global market is not a material contribution to supplying demand until late 2020s at the earliest.

Recent sensitivity analyses by BNEF demonstrate that Li-ion battery costs are not highly sensitive to lithium prices; a doubling of today's lithium price would affect the price of an NMC 811 battery pack by approximately 5.6%, in comparison to an 18.8% increase in price should the cost of nickel double. Such analyses suggest lithium demand on a per-battery basis is relatively inelastic; projections of lithium demand modeled by demand of battery packs should approximate market demand regardless of lithium carbonate (or lithium hydroxide) price volatility without significant technology disruptions.

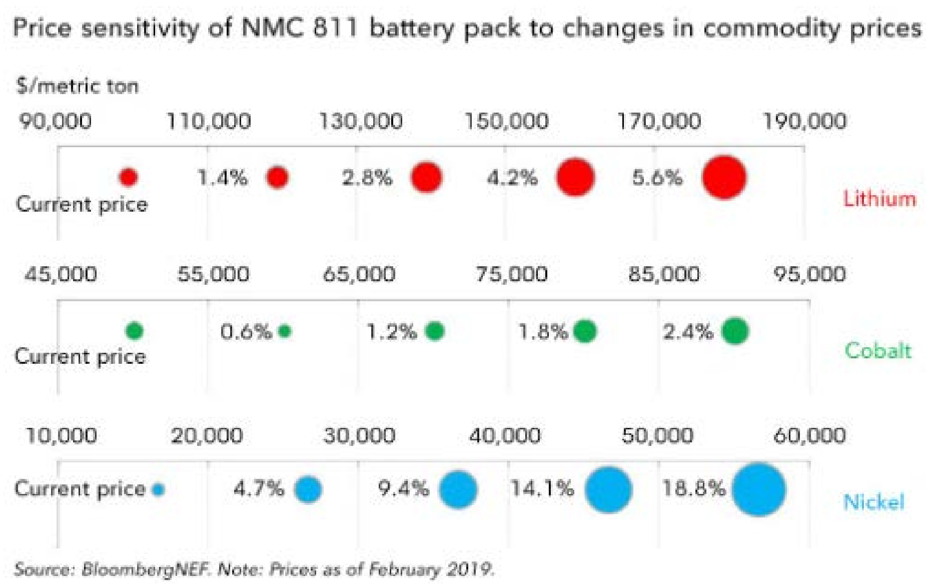

Figure 2: Sensitivity analysis of lithium, cobalt, and nickel price increases within the NMC 811 battery pack (Goldie-Scott, 2019).

6. Conclusions

Many arguments have ensued as to why direct extraction processes for mineral recovery have not been commercialized if such flow sheets have been postulated for decades. With the availability of economic data from commercial conventional brine mineral recovery via evaporation ponds, this work constructs a direct comparison to quantify where the investment value proposition of direct extraction processes on geothermal brines could succeed. The higher upfront capital costs of direct extraction processes require careful attention to competitive operating costs at scale, particularly if multiple commodities are harvested. The challenge to the geothermal industry is thus not whether direct extraction processes can be deployed economically, but how quickly these solutions will be integrated into conventional low-cost-leading processes to further advance market placement on the supply curve. Ongoing work from this analysis is to place geothermal resources within the global commodity supply curves.

As interest in (and demand for) environmental sustainability and the social license to operate becomes a mandate in supply chain decisions, battery mineral suppliers may increasingly value these externalities, both positive and negative. In the meantime, this work touches upon potential materiality of battery minerals that may influence the interest in domestic mineral security to match future demand.

Acknowledgement

Great appreciation is given to the industry partners offering to review and advance this work.

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