Evaluating geothermal-derived mineral production for sodium-ion batteries for utility scale energy storage in New Zealand

Karan Titus[1], Mathieu Ricketts[1], Jannik Haas[1], David Dempsey[1], Rebecca Peer[1], Rosalind Archer[2]

[1]Sustianable Energy Research Group (SERG), University of Canterbury, 20 Kirkwood Avenue, Upper Riccarton, Christchurch, 8041, New Zealand

[2]Griffith University, Gold Coast Campus, Parklands Drive Southport, Qld 4222, Australia

karan.titus@canterbury.ac.nz

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ABSTRACT

Deriving minerals such as lithium from geothermal brine has garnered notable interest in recent years. Lithium is a critical component in batteries, and therefore increasingly valuable to the energy transition. Traditional deposits of lithium are locked to a handful of geographic locations. Thus, the production of lithium from geothermal brines can enable wider supply while generating additional revenues for geothermal operations.

Sodium-ion batteries are an emerging counterpart to lithium-ion batteries, quickly approaching technological parity with lithium-ion batteries for utility scale storage. Given that the relative abundance of sodium in the Earth's crust is three orders of magnitude larger than lithium, sodium-ion batteries can greatly improve scalability variable renewable energy technologies. This relative abundance is also reflected in the dissolved mineral concentrations of geothermal water, warranting further investigation.

Here, we estimate the potential sodium-ion demand to supply utility scale battery storage for New Zealand by 2040. Further, we calculate the production potential of sodium-ions from New Zealand's geothermal brines. A major advantage of geothermal-derived sodium-ions is the access to onsite energy from the geothermal plant. Due to the nature of metallic sodium, CO_2 and ammonia are needed to facilitate the extraction. The former can be sourced directly from the geothermal fluid while the latter can be derived through a parasitic load.

New Zealand's utility scale battery demand is expected to grow up to 700 MWe by 2040. Assuming standard cycles of 4-hours per day and current energy densities of ~140 kWh/kg, this could require 528 kt of sodium. Our results show that Wairakei alone could supply this and provide enough electricity to facilitate all stages of cathode production.

1. INTRODUCTION & BACKGROUND

Today, geothermal energy supplies 17% of New Zealand's electricity demand in the form of valuable base load generation (MBIE, 2023). This contribution is second only to hydroelectric. Together, the two form the backbone of New Zealand's high renewable electricity penetration (~90%; MBIE, 2023; MBIE, 2024).

Although geothermal's current role in the energy system is well understood, most new renewable energy developments in the future are expected to be from solar-photovoltaics (PV) and onshore wind (MBIE, 2024). These variable renewable energy (VRE) technologies are generally at odds with baseload generators.

At maximum production, VREs can cause very low or even negative electricity prices in the market, forcing geothermal plants to curtail production (Ricks et al., 2022). Conversely, geothermal typically cannot ramp up to meet troughs in VRE generation the same way fossil-fired thermal plants can (Ricks et al., 2022).

For these reasons, Titus et al. (2024) suggested that geothermal's role in New Zealand's future energy system be reimagined away from solely providing baseload generation. Geothermal is unique among renewable energies as it can theoretically support all three of (i) green hydrogen production, (ii) net atmospheric carbon removal and (iii) direct lithium (Li) extraction (DLE; Titus et al., 2024). These products and services are valuable to the energy transition and present an opportunity for deep decarbonisation.

DLE, in particular, has synergies with VRE technologies, as Li is a major component in lithium-ion batteries (LIBs). LIBs are important for utility scale daily energy storage to balance out generation shortfalls from VREs. Schönfisch et al. (2024) estimate that global energy storage demand could grow from 27 GWe in 2021 to 3900 GWe by 2050. Even when just accounting for New Zealand, Transpower (2020) estimates demand for utility scale storage at 400 MWe and 700 MWe by 2035 and 2040, respectively.

In such scenarios, LIBs become critically important to grid stability and energy security (Schönfisch et al., 2024; Song et al., 2017). Unfortunately, due to the high resource potential of Li in global south nations, LIBs are often subject to scrutiny when considering the dangers of green- or eco-colonialism (Dorn, 2022; Jerez et al., 2021). Balancing decarbonisation efforts with social impacts is crucial for a just energy transition (Wang & Lo, 2021). Thus, exhausting all other opportunities to acquire Li, including through geothermal-based DLE, is reasonable to consider.

Table 1: Na^+ and Li concentrations from select samples of geothermal brines (from Sharma et al., 2023).

Sampled brines	Metal concentration (mg/L)	
	Na^+	Li
Salton Sea (USA)	53 000	194
Brawley (USA)	47 600	219
Wairakei (New Zealand)	1250	13.2
Salak (Indonesia)	5000	17
Cerro Prieto (Mexico)	8300	27
Hvergerdi (Iceland)	212	0.3
Mote Amiata (Italy)	1977	21.9

However, concentrations of Li in geothermal brines are generally low (Warren, 2021; Geo40, 2024), especially in New Zealand (Table 1). Despite this, DLE from brines with

concentrations on the order of 10 mg/L is undertaken in the Taupō Volcanic Zone (TVZ).

Although yet to reach techno-economic parity with LIBs, innovation in sodium-ion batteries (SIBs) is rapidly progressing (Hirsh et al., 2020; Nurohmah et al., 2022). Sodium (Na^+) is three orders of magnitude more abundant than Li in the Earth's crust (Taylor & McLennan, 2001). If strategically deployed in conjunction with LIBs, SIBs can help effectuate a more just energy transition.

This relative abundance is also reflected in geothermal brines (Table 1). Only 1% of 2000 sampled geothermal brines in the Western United States contained concentrations of Li >20 mg/L (Warren, 2021). Meanwhile, Na^+ is typically the second or third most common chemical species in New Zealand's geothermal waters (Mroczek et al., 2015). The combination of available brine, CO_2 and electricity at geothermal power plants presents an opportunity to produce sodium-ion cathode precursors in a single location. If realized, this could provide an additional role for geothermal in the energy transition.

Here, we estimate the quantity of Na^+ required for SIB cathodes needed to supply all of New Zealand's utility-scale storage demand by 2035 and 2040. We outline the chemical processes, brine and energy required to meet achieve this. Unlike LIB cathodes, it is theoretically possible (from a raw materials perspective) for New Zealand to domestically manufacture SIB cathodes to meet its utility scale demand.

1.1 Comparing lithium- and sodium-ion batteries for the energy transition

Aligning the global energy transition with 2°C mitigation pathways will require a concerted substitution of fossil fuels with variable renewable energy (VRE) technologies over the next 25 years (IPCC, 2023). This makes daily energy storage a critically important infrastructure for all countries going forward (Schönfisch et al., 2024). Even when just considering utility scale storage, the global demand for Li, the primary cathode component in modern batteries, is expected to grow over a hundred-fold by 2050 (IEA, 2024; Schönfisch et al., 2024).

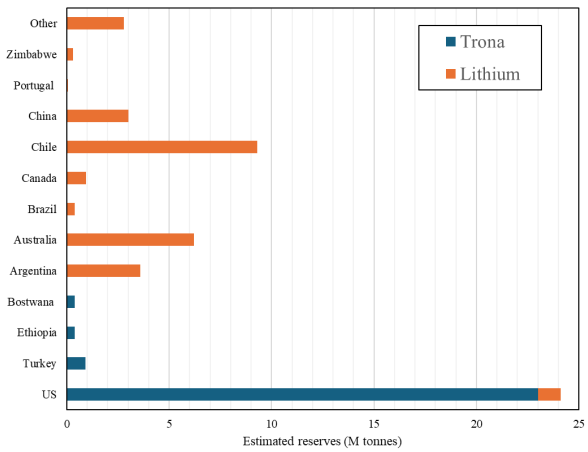

Figure 1: Reserves of trona (Hirsh et al., 2020) and lithium (USGS, 2025) in millions of tonnes. Note that the values for lithium only include mining reserves.

Approximately 70% of Li is currently mined from hard rock deposits (Huang et al., 2021). The countries with the largest of these are Chile, Australia and Argentina (Fig. 1; USGS, 2025). Together, these countries have almost twice the hard rock reserves of the rest of the world combined.

Bolivia also holds large reserves of Li, though instead dissolved within continental brines (Dorn, 2022; USGS, 2025). Bolivia, Argentina and Chile are often referred to as the 'lithium-triangle' (Jerez et al., 2021). Since so much of the world's Li supply is concentrated in a single geographical region, the sheer volume of demand from the global energy transition places pressure on local water resources and indigenous communities (Jerez et al., 2021).

Without socio-environmental safeguards, the energy transition could further propagate the trauma of a region historically vulnerable to resource conquest (Dorn, 2022; Jerez et al., 2021; Wang & Lo, 2021), albeit this time under a 'green' veneer. Australia is not wholly without these challenges either. For example, the country faces considerable Li revenue inequity despite >50% of mines falling within indigenous people's lands (Burton et al., 2024).

Developing sodium-ion (SIBs) is a pathway to lower the strain on these communities while making strategic progress towards the energy transition. Although less efficient than LIBs, they can be effectively utilized for stationary applications (i.e. utility scale storage; Hirsh et al., 2020; Hwang et al., 2017; Nurohmah et al., 2022; Slater et al., 2013; Yabuuchi et al., 2014). Sodium-based compounds are already used in a multitude of industries. The best known, sodium-chloride (NaCl, table salt), is precipitated out of sea water and continental brines through solar evaporation (Song et al., 2017). However, in the case of SIBs, the precursor to the sodium-iron-phosphate ($NaFePO_4$) cathode is usually sodium carbonate (Na_2CO_3), also known as soda-ash (Hwang et al., 2017; Slater et al., 2013; Yabuuchi et al., 2014).

Soda ash is either mined from a naturally occurring ore known as trona or manufactured using the Solvay process through a combination of brine, ammonia (NH_3) and CO_2 (Hirsh et al., 2020; Nurohmah et al., 2022). Like hard-rock lithium, trona is geographically locked to specific regions around the world (Fig. 1; Hirsh et al., 2020). The Solvay process however can be used anywhere provided there is access to the aforementioned reactants. Since trona is not found in New Zealand (Kostick, 2000) the Solvay process must be used instead.

We suggest geothermal brines are advantaged over both continental brines and sea water because electricity from the geothermal plant is already available at site. Further, geothermal CO_2 could theoretically be used in place of limestone-calcination CO_2 as part of the Solvay process. In place of recycled ammonia (NH_3), the sale of ammonium-chloride (NH_4Cl) for fertilisers is a plausible way to recuperate costs. The NH_3 can be generated at geothermal sites via green hydrogen (H_2) electrolysis followed by Haber-Bosch synthesis (Bicer et al., 2017). Harnessing Na^+ this way would follow historical Li and silica extraction efforts from geothermal fields.

1.2 Geothermal mineral extraction

Lithium (Li) extraction from geothermal powerplants has garnered notable interest in recent years as an additional avenue to increase global supply (Warren, 2021). For the geothermal plant operator, this presents a secondary revenue stream to compliment power production (Titus et al., 2024). Li can be directly extracted from geothermal brine using (i)

sorbents, (ii) solvents, (iii) membranes, and (iv) electrodialysis (Warren, 2021).

A handful of geothermal fields, such as the Salton Sea (US) and Upper Rhine Valley (Germany), have Li concentrations on the order of hundreds of grams per litter (Warren, 2021). Although such high concentrations are a rare occurrence, it is still possible to commercially extract Li from fluids with concentrations as low as 10 mg/L (Geo40, 2024).

Silica (SiO_2) is another mineral of important note. SiO_2 is extracted from geothermal brines to (i) reduce scaling risks, (ii) pretreatment for Li extraction efforts and (iii) be used for raw construction materials (Spitzmüller et al., 2021). Approximately 450 tonnes of SiO_2 are produced each year from Ohaaki (Lea & O'Sullivan, 2020). Precipitation is the method of choice for SiO_2 extraction due to its relatively high concentration in geothermal waters (Table 2).

Despite its synergies with enabling SIB technologies, geothermal Na^+ has yet to garner the same levels of commercial interest as Li and SiO_2. In 2015, Mroczek et al. identified the composition of various chemical species in New Zealand's geothermal waters. They found chloride (Cl^-) and Na^+ are usually the two most common dissolved components across all fields, save for Kawerau, Rotokawa and Ngatamariki where high levels of SiO_2 are observed, and Ngawha with unusual levels of boron. The concentration of Na^+ across all fields tends to be far greater than that of Li (Table 2).

Table 2: Select ion concentrations from sampled geothermal brines in New Zealand (from Mroczek et al., 2015).

Sampled brines	Ion concentration (mg/kg)			
	Na^+	Li	SiO_2	Cl^-
Wairakei	905	9.5	459	1479
Kawerau	518	4.1	624	672
Rotokawa	324	4.0	594	560
Ngatamariki	588	7.3	614	948
Ohaaki	499	6.3	451	621
Mokai	869	14.5	532	1757
Tauhara	763	9.4	501	1368
Ngawha	835	9.7	361	1151
Rotorua	459	2.4	280	454

This is the first study to propose harnessing Na^+ from New Zealand's geothermal waters for SIB cathode production. Rather than simple precipitation or electrodialysis, Na^+ necessitates the Solvay process. We propose a version of this process that takes advantage of geothermal CO_2 in the following section.

2. METHODS

New Zealand's utility scale storage is expected to grow to 400 MWe by 2035 and 700 MWe by 2040 (Transpower, 2020). In this work, we estimate the Na^+ resource, relevant cathode precursor mass, and energy required to fulfil this demand with SIBs. Assuming one cycle per day, for a period of four hours, the electricity storage required each day would be 1600 and 2800 MWh, respectively.

SIBs are still considered emerging technologies (Hirsh et al., 2020). Therefore, we draw on values from literature and reasonable assumptions based on LIBs to inform our work. Gravimetric energy density is one of the most important parameters when implementing battery technologies. For current technologies, the gravimetric energy density of SIBs tend to be lower than LIBs (Freitas et al., 2024; Hirsh et al., 2020). Thus, we select a value of 140 Wh/kg (cell weight).

A multitude of composite designs could constitute an SIB cathode (Du et al., 2024). In recent years, developments into LIBs have considered Li synthesis with iron phosphates ($FePO_4$), bypassing certain rare elements like nickel and cobalt (Lu & Zhu, 2024; Yao et al., 2025).

A similar composite, $NaFePO_4$, is possible for SIBs (Hirsh et al., 2020; Nurohmah et al., 2022). This composite is therefore the cathode of choice in this study. We note in Section 4 that both Fe and PO_4 can be sourced domestically in New Zealand (Christie et al., 2024). While we do not consider SIB anodes within the scope of this work, they are usually comprised of a hard carbon (Nurohmah et al., 2022).

The cathode in LIBs comprises approximately 20% of the total cell weight (PEM & VDMA, 2023). We assume this proportion is true for SIBs as well. When combining this value with the molar mass distribution in $NaFePO_4$, approximately 0.0264 kg of Na^+ is needed per kg of battery cell. We use a Na^+ concentration of 1.25 kg per tonne of brine, representative of Wairakei geothermal field (Sharma et al., 2023).

2.1 Solvay process and solid-state synthesis

We consider the application of the Solvay process to produce sodium-ion cathode precursors to supply New Zealand's near-term utility scale storage demand. Additionally, we calculate the electricity load to facilitate solid-state synthesis of the final cathode. In the past, the Solvay process has been commercially applied to rejected brines at desalination plants (Quang et al., 2019).

First, a source of ammonia (NH_3) and CO_2 is needed. NH_3 can be sourced via green H_2 electrolysis and Haber-Bosch synthesis (Bicer et al., 2017). In the conventional Solvay process, CO_2 is obtained using limestone ($CaCO_3$) calcination at over 1000 °C (Quang et al., 2019). This is shown in reaction 0. The second product of this reaction, quicklime (CaO), is used again later (reaction 1a).

$$CaCO_3 \rightarrow CaO + CO_2 \quad (0)$$

Once both CO_2 and NH_3 are obtained, they are bubbled into brine (a mixture of NaCl and H_2O). The products of this reaction (reaction 1) are baking soda ($NaHCO_3$) and ammonium chloride (NH_4Cl).

$$NaCl + H_2O + CO_2 + NH_3 \rightarrow NaHCO_3 + NH_4Cl \quad (1)$$

$NaHCO_3$ is dispatched for thermal decomposition into the final cathode precursor, whereas NH_4Cl is used for the regeneration of NH_3. To regenerate NH_3, the CaO from reaction 0 is now combined with water to form $Ca(OH)_2$:

$$CaO + H_2O \rightarrow Ca(OH)_2 \quad (1a)$$

Then, NH_4Cl and $Ca(OH)_2$ react together to form NH_3 and other products. This creates a closed loop of NH_3 after the initial amount is synthesized:

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$$2NH_4Cl + Ca(OH)_2 \rightarrow 2NH_3 + 2H_2O + CaCl_2 \quad (1b)$$

Acquiring CO_2 from limestone calcination requires a major energy load (Ewis et al., 2024). Further, the limestone itself must be sourced. In the past, fossil fuel CO_2 from oil and gas wells and desalination plants have been considered as potential ingredients to produce sodium bicarbonate through the Solvay process (Ewis et al., 2024; Villardi et al., 2022).

Here, we propose the use of geothermal CO_2 that is captured during power production. The energy load to do so could be as high as 0.34 kWh/kgCO_2 based on results from the Icelandic Carbfix project (Gunnarsson et al., 2018). High concentrations of other non-condensable gasses in the geothermal fluid may require further separation measures. If geothermal CO_2 is used instead of limestone CO_2 in reaction 1, the need to calcify limestone is eliminated. However, this would also prevent the regeneration of NH_3.

A constant production of NH_3 would then be required. Further, ammonium chloride (NH_4Cl) is used as an agricultural fertilizer (Stefan-Kharicha et al., 2018), meaning it can theoretically be sold to offset some of the costs of NH_3 production. Thus, if opting for geothermal CO_2 in the Solvay process, reactions 0, 1a and 1b are voided. The total load for green hydrogen electrolysis and Haber-Bosch synthesis is 11 kWh/kgNH_3 (Sousa et al., 2022).

The final sodium-based cathode precursor is soda ash (Na_2CO_3), which is derived through the thermal decomposition of $NaHCO_3$. This decomposition takes place at around 200 °C (Hartman et al., 2013). We use the specific heat capacity of $NaHCO_3$ (1.196 J/gK; Haynes, 2018) to approximate the activation energy for the reaction (reaction 2). The byproducts are CO_2 and H_2O, which can be injected into the geothermal system. Note that twice the moles in reaction 1 are needed to facilitate reaction 2 since two moles of $NaHCO_3$ are needed to thermally decompose into Na_2CO_3 (Nurohmah et al., 2022).

$$2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O \quad (2)$$

The final step is solid-state synthesis of the cathode (reaction 3). Several different iron and phosphate precursors may be available to react with the Na_2CO_3 in a given market. For this study, we show one example of solid-state synthesis of sodium-iron-phosphate ($NaFePO_4$) using a combination of Na_2CO_3, iron oxide (Fe_2O_3) and monoammonium phosphate ($2NH_4H_2PO_4$). These two reactants that have previously been considered for cathode production (Du et al., 2024; Nurohmah et al., 2022), but they cannot be sourced from the geothermal water itself.

Commencing solid-state synthesis could require temperatures of up to 550-700 °C (Akhtar et al., 2023; Han et al., 2024). This can be enabled via an electric furnace powered by geothermal energy. Once more, to approximate the activation energy needed for reaction 3, we use the specific heat capacity of Na_2CO_3 (1.04 J/gK; Haynes, 2018).

$$Na_2CO_3 + Fe_2O_3 + 2NH_4H_2PO_4 \quad (3)$$

$$\rightarrow$$

$$2NaFePO_4 + 2NH_3 + CO_2 + 3H_2O + \frac{1}{2}O_2$$

With these particular set of reactants, the $NaFePO_4$ cathode is produced alongside NH_3 and CO_2. The first co-product may not be produced if a different phosphate precursor is available (such as phosphoric acid; Zhang et al., 2019). The latter will always be produced if Na_2CO_3 is the sodium-based precursor, and can be recycled or injected into the geothermal field. Since some amount of brine itself is a reactant in reaction 1, all instances of H_2O produced in subsequent steps can be reinjected into the geothermal system, thereby avoiding any consent issues. The stoichiometric balance of most relevant reactants is given in Table 3.

Table 3: Stoichiometric balance for most relevant reactants for reactions 1, 2 & 3 (molar mass values from Haynes, 2018).

	Molar Mass (g/mol)	Moles (mol)	Mass (kg) per kg Na^+
Na^+	22.99	43.5	1.00
Na_2CO_3	105.99	21.7	2.31
$NaHCO_3$	84.01	43.5	3.65
NaCl	58.44	43.5	2.54
CO_2	44.01	43.5	1.91
NH_3	17.03	43.5	0.74
H_2O	18.02	43.5	0.78

3. RESULTS AND DISCUSSION

We calculate that up to 700 MWe of SIB capacity could require 528 tonnes of Na^+ ions (Table 4), assuming 4 hours per cycle, 1 cycle per day and a gravimetric energy density of 140 Wh/kg. If the batteries last around a standard 6000 cycles (Yuan et al., 2015), this would only need to be replenished every ~16 years. Wairakei alone could supply this.

With Na^+ concentrations of 1.25 kg/tonne-brine, Wairakei could meet this potential demand by diverting only ~422 kt of brine. Wairakei's consented daily take is 245 kt (Mroczek et al., 2015), meaning this could theoretically be accomplished within two days. In practice, only a small amount of brine would be diverted at a time to facilitate a constant stream of production.

For context, the concentration of Li at Wairakei is ~0.01 kg/tonne-brine (Mroczek et al., 2015; Sharma et al., 2023). If instead New Zealand's utility scale demand was met with $LiFePO_4$ batteries (190 Wh/kg; Lu & Zhu, 2024), it would require 53 days' worth of Wairakei's full consented take. This is after accounting for the lower relative weight of Li to Na^+, only requiring one third of the mass per kg-cell (PEM & VDMA, 2023). Thus, the abundance of Na^+ in New Zealand's geothermal waters can enable domestic scalability of energy storage solutions.

Even the other precursor components from a $NaFePO_4$ cathode could potentially be sourced domestically in New Zealand. As recently as 2016, Fe has been mined on the order of millions of tonnes from North Island ironsands (Christie et al., 2024). A GNS consultancy report suggested revisiting a sizeable resource potential of phosphates (1.6 Mt at 18% P_2O_5) in the Clarendon site (South Otago) for domestic production (Christie et al., 2024).

Note that domestic fertilizer production may compete for phosphate deposits. If such is the case, recycling iron phosphates ($FePO_4$) directly may constitute a suitable route while bolstering the sustainability profile of SIBs (Wang et al., 2022).

Table 4: Results for resource estimation and energy load required for 400 MW and 700 MWe utility scale battery capacity by 2035 and 2040.

Year	2035	2040
Utility scale demand (MW)	400	700
Daily load demand (MWh)	1600	2800
Battery energy density (Wh/kg)	140	140
Mass of batteries (tonnes)	11 429	20 000
Mass of Na^+ (tonnes)	302	528
Brine Na^+ Concentration (kg/tonne)	1.25	1.25
Brine diverted (tonnes)	241 371	422 400
NaCl required (tonnes)	767	1342
H_2O required (tonnes)	236	413
CO_2 required (tonnes)	577	1010
NH_3 required (tonnes)	223	391
H_2 required (tonnes)	40	69
Energy for CO_2 capture (MWh)	196	343
Energy for Haber-Bosh process (MWh)	2456	4298
Mass of baking soda (tonnes)	1103	1929
Mass of soda ash (tonnes)	695	1217
Energy for thermal decomposition (MWh)	68	119
Energy for solid state synthesis (MWh)	140	245
Total energy load (MWh)	2860	5005

Overall, the energy load for reactions 1, 2 and 3 are not significant compared to the power produced by a Wairakei size power plant. Producing 528 kt of Na^+, thermally decomposing $NaHCO_3$ and synthesising the $NaFePO_4$ cathode would only require ~5 GWh. This is only ~120% of Wairakei's daily electricity generation (MBIE, 2023). As a result, the energy return on energy invested for the SIB cathode would be recuperated by 35 cycles. In practice, this will take longer when considering full cell and pack manufacturing and transport.

A breakdown of the major energy loads (CO_2 capture, NH_3 production, thermal decomposition and solid-state synthesis) is given in Fig. 2. Most of the energy load (86%) comes from H_2 electrolysis and Haber-Bosch synthesis to produce NH_3. To put this in perspective, if NH_3 could be purchased from a third party by the geothermal operator the total energy load of the Solvay process would only be 1.3 kWh/kgNa^+. If Haber-Bosch synthesis is required, the energy load grows to 9.5 kWh/kgNa^+. As NH_3 is not regenerated in reaction 1b if geothermal CO_2 is used for the Solvay process, a geothermal operator could instead opt for the classic Solvay process if limestone ($CaCO_3$) is readily available.

New Zealand does have high quality $CaCO_3$ deposits in South Waikato (Christie et al., 2024), specifically to manufacture quicklime (CaO). A geothermal power plant that intends to generally produce green H_2 may find the limited added use-case for NH_3 production less of an opportunity cost. NH_3 is itself a valuable energy carrier (Chang et al., 2021), meaning Haber-Bosch synthesis may already be a worthwhile operation for a geothermal plant. The geothermal operator could already be required to capture CO_2, incentivising temporary use.

In the version of the Solvay process we proposed, NH_3 eventually transitions into ammonium chloride (NH_4Cl), a material which is used for fertilisers (Stefan-Kharicha et al., 2018). In the classic Solvay process, calcium chloride ($CaCl_2$) is instead the final carrier of the chloride (Cl). High grade $CaCl_2$ is used in food production (Vrana, 2000). In theory, both NH_4Cl and $CaCl_2$ could be sold as additional revenues. Thus, there are multiple interesting trade-offs to applying the Solvay process at geothermal plants that will require site specific consideration.

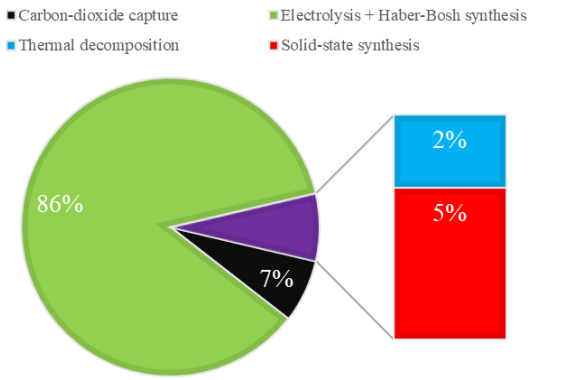

Figure 2: Energy load breakdown of $NaFePO_4$ cathode production using geothermal CO_2 and green NH_3 for the Solvay process.

Due to the different procedures for extracting Li, SiO_2 and Na^+ it is possible that all three are operations are conducted together at a single geothermal plant. At the same time, the presence of many different chemical species in the brine could increase extraction difficulty. Finally, removing NaCl from geothermal water can improve the solubility of CO_2 in the diverted brine stream (Duan & Sun, 2006), making it potentially easier to reinject CO_2 used in the Solvay process.

4. CONCLUSION

We show that a single geothermal plant the size of Wairakei could produce enough sodium-ion cathode precursors to support 2800 MWh of a daily energy storage through sodium-iron-phosphate batteries. This translates to 528 kt of sodium produced over a 16-year period, enough to meet New Zealand's 2040 utility scale demand.

CO_2 and ammonia are needed to extract sodium from brine. Both can be sourced from the geothermal power plant by capturing NCGs and hydrogen production, respectively. The latter represents the largest energy load of our proposed procedure at ~4.3 GWh. However, this value is only a little over a single day's worth of Wairakei's generation. Available electricity, CO_2 and the means to make ammonia are the key synergies between geothermal brine and sodium-ion batteries.

This represents a unique role for geothermal to bolster the uptake of variable renewable energy technologies. In theory, New Zealand can substitute its reliance on lithium for utility scale storage needs with domestically produced sodium-ion cathodes. This would alleviate the scarcity component of the cathode, shifting focus towards acquiring hard carbons for the anode.

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