THE CASE FOR SECONDARY LITHIUM MINERAL PROJECTS

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ABSTRACT

In this paper secondary lithium mineral deposits are considered to be those hosting predominantly non-spodumene minerals. These include lithium bearing micas, sedimentary deposits such as clays and jadarite. In general, these resources have a lower grade of lithium and the amount of ore that needs to be processed is significantly more than for a corresponding spodumene producer. A common perception is that this will result in a higher operating cost as a result of higher energy and reagent costs and therefore, as long as there are additional spodumene resources, there is little chance of a secondary lithium mineral resource being developed.

This paper discusses the challenges facing the companies producing lithium from brines as well as from spodumene. The question is asked if the new spodumene concentrates should be regarded as identical to the Talison SC6.0 concentrate, which currently is the industry standard. A comparison of the cash cost to produce lithium carbonate is made between four spodumene concentrate supply cases with significant variation in outcomes. Using the same basis, a comparison is then also made with the proposed production of lithium carbonate from a Zinnwaldite concentrate from European Metals Holding's Cinovec project. While the attractive economics of this project are in part attributable to project specific factors, such as its by-product credits and geographic location, they support the case for consideration of secondary lithium mineral projects for development to supply lithium to fill the growing demand for lithium chemicals.

Keywords: Lithium recovery, lithium extraction, spodumene, zinnwaldite, lepidolite, hectorite, clays, lithium micas, mica, operating cost, project development

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INTRODUCTION

The demand for lithium is unprecedented in 2017 and the current annual growth shows no signs of abating in the foreseeable future with the critical mass being close to being achieved in the solar Photovoltaic Cell (PV) market and its close association with lithium batteries for storage. It is projected that the global battery consumption will increase 5x over the next 10 years, placing pressure on the lithium ore miners, converters and battery manufacturers to supply the market.

It is reflective to consider that the Greenbushes Mine (now owned by Talison Pty Ltd) only commenced mining of lithium minerals in 1983 and commissioned a 30,000tpa lithium mineral concentrator two years later in 1984-1985. Production capacity was increased to 750,000 tpa after completion of the new concentrator plant in 2013. (Golden Dragon Capital, 2017). Talison is reported to currently supply approximately 40% of worlds lithium, and has recently announced its intentions to double the current production rate.

In addition, there are a number of new spodumene projects either being constructed or awaiting financial approval that could see a significant number of new suppliers of spodumene concentrate joining the market.

There has also been increasing interest in secondary lithium mineral deposits and a handful of these projects are currently in the feasibility stage of evaluation. One of these projects is the Cinovec project which is discussed in more detail in this paper to answer the question as to whether there is a place for such projects in the future supply of lithium.

WHAT ARE SECONDARY LITHIUM MINERALS?

Historically the source of lithium from mineral origins has been dominated by spodumene, supplied almost exclusively from the Talison mine located in Greenbushes, Western Australia. In this paper all non-spodumene lithium minerals are defined as secondary lithium minerals. These include the hectorite and polylithionite clays, the zinnwaldite and lepidolite lithium micas and jadarite.

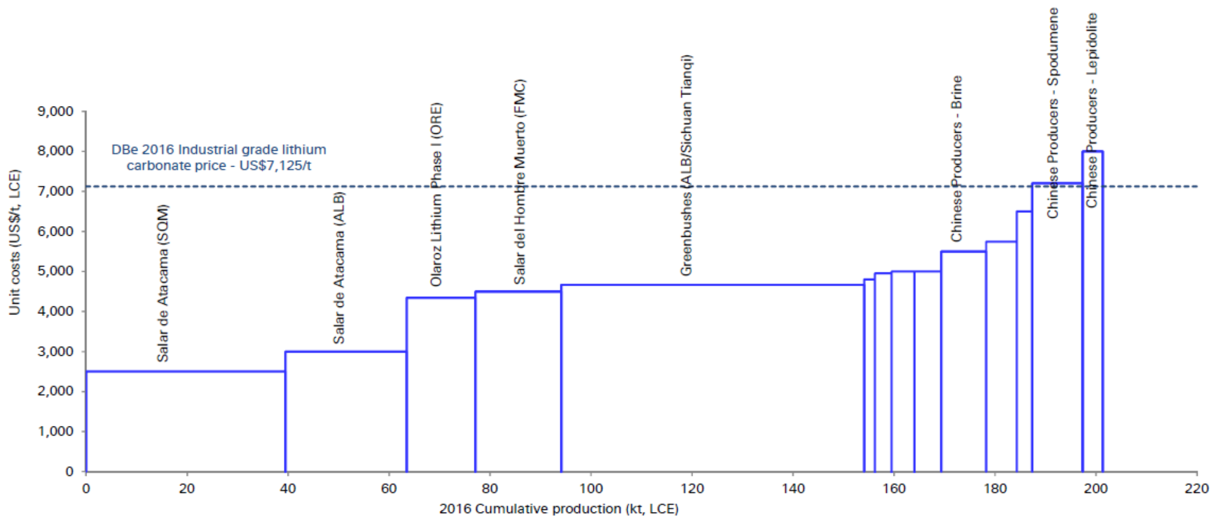
There are some 127 known lithium containing minerals of which 9 are deemed to be of commercial interest and are listed in Table 1. The lithium minerals have vastly different compositions, with spodumene and petalite being comprised of lithium, silicon, oxygen and aluminium, whereas the secondary minerals contain additional elements, such as boron, potassium, sodium, iron and fluoride. This results in the concentration of lithium in the secondary minerals being lower than in spodumene.

Table 1: Common Lithium Containing Minerals and their Properties

Mineral		Chemical Composition	Measured Li_2O%
Spodumene	Australia	$Li_2OAl_2O_3(SiO_2)_4$	8.0
Petalite	Zimbabwe	$Li_2OAl_2O_3(SiO_2)_8$	4. 5
Zinnwaldite	Czech Republic	$KLiFeAl(AlSi_3)O(F,OH)$	2.19 - 3.72
Lepidolite	Zimbabwe	$K(Li,Al)_3(Si,Al)_4O_{10}(F,OH)_2$	7.7
Hectorite	Mexico,USA	$Na_{0.3}(Mg,Li)_3Si_4O_{10}(OH)_2$	1.17
Jadarite	Serbia	$LiNaSiB_3O_7(OH)$	7.3
Amblygonite	Canada	$LiAlPO_4(F,OH)$	10.1
Eucryptite	Zimbabwe	$Li_2OAl_2O_3(SiO_2)_2$	11.8
Zabuyelite	China	Li_2CO_3	40.4

WHAT ARE THE SUPPLY OPTIONS FOR LITHIUM?

Figure 1 shows a well know global cost curve which compares the operating costs between the current producers of lithium chemicals from brine and hard rock. This version of the comparison was published by the Deutsche Bank in May 2016 and shows the costs have increased in over the last years. SQM is generally thought to be the lowest cost producer at a cost of around $2,600/ t LCE and Albemarle marginally higher at around $ 3,000/ t LCE.



Source: Deutsche Bank

Figure 1: Global Cost Curve for Lithium Carbonate Supply

Brines

Olaroz Phase 1 is shown with a cost of production of around $4,300/t LCE. Orocobre recently published figures based on production of 12,000 t lithium carbonate which would suggest that the actual cost is closer to $3,600/ t lithium carbonate.

While SQM and Albemarle have both continued to produce at the lowest cost from the Atacama, newcomers have costs considerably higher and the commonly held belief that hard rock would never be able to compete with brine producers, is clearly no longer true.

There appear to be a growing list of challenges for the current and potential new producers of lithium from brine. These include:

1. Most brines were formed as a result of volcanic activity and are therefore located close to volcanos and are on fault lines prone to earthquakes.

2. The grade of the lithium in the Atacama brine in the South continues to fall and is thought to now be around 1,400 ppm.

3. Albemarle has recently negotiated a new license with Fosco with a royalty of up to 40% on sales, which is a significant shift in government expectations.

4. The higher pump rate, although small compared with the current SQM pump rate, is raising real concerns that it is not sustainable in the Atacama.

5. The Chilean Government is reported to be preventing any new projects that require evaporation of water.

6. New projects have more challenging chemistry compared with the brine from the South end of the Atacama.

7. Potential sovereign risk and Government restrictions in some South America countries.

8. Adverse weather conditions affecting production.

As a consequence of the challenges listed above, it is not surprising that a number of observers have stated the bulk of additional lithium production will need to be sourced from hard rock resources.

Hard Rock

The predominant source currently is spodumene will a little petalite, and lepidolite reported to being supplied in China, Brazil and Europe. Further the bulk of the spodumene historically has been supplied by Talison's Greenbushes mine in Western Australia. In the following section different spodumene concentrates are compared to better understand the challenges that spodumene concentrate producers face.

ARE ALL SPODUMENE CONCENTRATES THE SAME?

The simple answer is that they are not. There are significant differences between the ores types, the ore texture and variability within the ore body. That means a concentrate will vary over time even if mined from the same ore body.

Concentrate Composition

Although a 6% Li_2O spodumene concentrate contains roughly 85% spodumene it also contains a number of other minerals such as mica as shown in Table 2. In the case of spodumene this mica is generally muscovite but it could also contain biotite or lepidolite. Small quantities of these lithium micas (lepidolite) do not change the fact that the predominant mineral is spodumene.

Table 2: Comparison between Typical Spodumene Concentrates

Minerals Present	Spodumene A	Spodumene B
Spodumene	77.2	77
Quartz	11.3	2
Albite	3.8	5
K-feldspar	3.1	1
Muscovite (Mica)	0.8	8
Phosphates	0.2	1
Iron Minerals	3.6	
Amphibolite		6

Ore Texture

The ore texture is a key element in developing the beneficiation flowsheet for a given resource. (MinAssist, 2017). This is specifically pertinent for DSO (Direct Shipped Ores) sourced from the Pilbara, which in reality is neither a concentrate nor a particularly high grade ore.
The texture of an ore includes:

- grain size distribution,
- grindability of the ore,
- degree of liberation of the target mineral,
- phase specific surface area of the target mineral,
- the amount of fines generated, and
- the number of coarse composite particles.

For example, an ore such as that studied in the preliminary studies for Tawana, with a lower grade of 0.9 – 1.4 % Li_2O, requires only minimal crushing and dense media separation to produce a 6.7% Li_2O concentrate. The Talison ore with a high lithium feed grade of around 2.65% Li_2O, requires a more complex processing plant to produce 6% Li_2O.

Lithia Content

The industry standard for chemical grade spodumene concentrate is Talison SC6.0, which has a Li_2O (Lithia) content of 6%. Most of the Spodumene-to-chemical conversion plants were designed or modified to accept the Talison SC6.0 feed.

If the grade is lower than 6% Li_2O then more mass needs to be processed in order to produce the same amount of the lithium chemical. In reality the mass flow through a chemical plant is fixed and a decrease in the concentrate grade would result in less lithium chemical being produced and less revenue being earned.

Non-Spodumene Content (Impurities)

The pure spodumene mineral, with the chemical composition $Li_2OAl_2O_3(SiO_2)_4$, contains 8.03 wt% Li_2O. This implies that the SC6.0 is 75% pure spodumene and that the balance of the concentrate is made up of gangue minerals such as quartz, mica, feldspar and amblygonite. Two potential issues with higher impurity levels are (i) that the impurities will produce a lower melting temperature eutectic mixture in the calciner and (ii) that these impurities can be leached from the concentrate making the purification of the leach solution more difficult.

The main issue for converters is the behaviour of the ore in the calciner. In the calciner α-spodumene is converted to β-spodumene at around 1,080°C and there are typically a number of impurities that will melt below the calcination temperature, as shown in the Table 3.

Table 3: Melting Point of Some Minerals Found in Spodumene Concentrates

Mineral	Melting Temperature [°C]
Amphibole	800
Micas	700-1,000
Albite	1,100
K-Feldspar	1,250
Spodumene	1,420
Quartz	1,670

Spodumene Conversion Temperature [1,080 °C]

The minerals present in the concentrate that melt at lower temperatures (above the red line) will likely melt and contribute to clinker formation. If the amount of the low temperature melting minerals is small, then the amount of clinker formed will be around 2%, which is not a problem. If the amount of these minerals present is higher, then the amount of clinker formed is higher and the extraction of lithium from clinker, even after grinding, is likely to be lower than 75%.

Iron content is normally a critical impurity and Kings Mountain plant used to add chlorine gas to the calciner to convert the iron to iron chloride which was volatized to prevent the formation of excess clinker and glassing. Some of the current producers also face the challenge of increasing iron content.

Size Distribution

The spodumene concentrate is produced differently in every plant and depends on the ore texture as discussed above.

If the concentrate is produced using only HMS (Heavy Media Separation), the particle size is relatively coarse i.e. in the region 3 mm to 0.5 mm, while if the concentrate is recovered by flotation, then the particle size will be considerably finer, in the region of 0.6 mm to 0.075mm.

The particle size of the feed affects the performance of the calciner in two ways namely, (i) dusting and (ii) the rate of heating up the ore.

The finer the feed particle size is, the more will be blown out (elutriated) from the calciner. In general, the dust blown out of the calciner is not converted to β-spodumene and there may be limits as to how much of the dust can be recovered and successfully returned to the calciner. Dust may have to be dumped or the calciner gas firing rate decreased, to reduce the gas velocity in the calciner, which will impact on the conversion of the ore and capacity of the calciner.

The second impact is the time it takes to heat up the ore. The larger the particle size, the longer it takes to heat up and conversely, small particles heat up much faster. If the calciner has been designed for smaller particles, then changing to a coarser feed will require more heat input which will result in higher temperatures in the calciner leading to clinker formation.

In summary, each spodumene concentrate is different and changing concentrate source and supplier may have an impact on the existing facility, such as reduced production and operational issues that would require modifications to the plant.

THE CASH COST OF PRODUCING LITHIUM CARBONATE FROM SPODUMENE

In Table 4 the costs of producing lithium carbonate based on concentrate sourced from different sources are compared. It needs to be stressed that there is limited transparency in the lithium market and most of the data used in the cost model has been obtained from a combination of information published in the public domain and from people in the lithium industry.

Four cases have been considered based on supply of spodumene from Australia.

CASE 1: Galaxy Concentrate is transported to a conversion plant in China located on the Eastern side of China. Furthermore, the spodumene concentrate is supplied through a third party that charges a fee and VAT is payable on ore imported into China.

CASE 2: In this case Tianqi and Albemarle source the concentrate from their Talison mine and send it to China for conversion, such as the toll treating currently being done by Albemarle. No profit has been allowed for the toll treating in this case.

CASE 3: Similar case to CASE 2 except that the concentrate is sourced from the Pilbara, Western Australia and the beneficiation cost of the ore is higher due to the low ore grade which is offset by the tantalum credits.

CASE 4: In this case a combination of existing tailings or mined ore with a grade around 1.5% Li_2O is shipped to China. It is assumed that the ore can be beneficiated to 5 – 6% Li_2O and that the overall lithium recovery would be 70%.

Table 4: Comparison Four Spodumene Concentrate Supply options on the Estimated Total Cost of LCE Production

		Chinese Converter using Galaxy Con	Tianqi/ Albemarle using Talison Con	Chinese Converter using Pilbara Con	Chinese converter using Pilbara DSO
Cost SPOD FOB	USD/t SPOD	$905	$200	$171	$120
Transport to Asia	USD/t SPOD	$50	$50	$36	$36
Inland transport	USD/t SPOD	$40	$40	$40	$40
Li Grade	wt% Li_2O	6	6	6	1.5
VAT 17% CIF	USD/t SPOD	$162.35	$42.50	$35.19	$26.52
Mitsubishi margin 15%	USD/t SPOD	$143.25	$0	$0	$0
Total cost	USD/t SPOD	$1,301	$333	$282	$223
Lithium content	kg Li_2O/ t SPOD	60	60	60	15
Lithium recovery in LCP	%	88	88	88	70
Lithium recovered in LCP	kg Li_2O/ t SPOD	52.8	52.8	52.8	10.5
	kg Li_2CO_3/t SPOD	130.24	130.24	130.24	25.9
Conversion cost	USD/t Li_2CO_3	$3,000	$3,000	$3,000	$3,000
	USD/ t SPOD	$391	$391	$391	$78
TOTAL cost	USD/ t SPOD	$1,691	$723	$673	$300
	USD/t Li_2CO_3	$12,986	$5,553	$5,167	$11,592

Assumptions:

1. Galaxy, Mount Cattlin mine, Western Australia spodumene cost is US$905/t (FOB Esperance) for 6% Li_2O delivered in Q1 2017. (Commsec Online Trading Website, 2017).

2. Transportation for concentrates from the South-West of Western Australia is assumed from Bunbury or Esperance ports to a port in China. The additional transport cost is for truck or barge cost to the Chinese converter plant.

3. Transportation from the Pilbara based on Pilbara Minerals ASX announcement (Pilgangoora DFS Confirms World-Class Australain Lithium Project, 2016).

4. VAT is an import tax on the spodumene entering China. There is also a cost if lithium chemicals are sold internationally. It is assumed in this model that consumption by Chinese converted chemicals is within China.

5. It is assumed that Mitsubishi, purchasing agent, would charge a fee for the procurement of the spodumene. Nominally this has been set at 15%.

6. The Talison concentrate price is based on the Namaska value of USD 200/ t FOB Greenbushes, Western Australia (How to Profit from the Booming Lithium Markets, 2016).

7. The conversion cost for the spodumene using the sulphation route is based on Orocobre Ltd ASX announcement (Investor Update, 2016).

8. The sales price for DSO (direct shipped ore) is not known. A value of $150/t was stated in a local West Australian newspaper but thought to be too high. The model above tends to support the view that a price around $120/t is plausible.

9. There is no profit added for the supply of the concentrate nor for the sale of the lithium carbonate product.

10. Spodumene concentrate production costs include tantalum by-product credits and deduction of royalties.

The takeaways are:

- The growing lithium industry will become increasingly reliant on minerals containing lithium for the supply of lithium chemicals.
- The days of lithium carbonate at US$ 6,000/ t LCE are gone and even prices above US$8,000/ t LCE could be possible in the longer term.
- In the short to medium term selling prices will be high in China until they find cheaper sources of supply.

SECONDARY LITHIUM MINERAL PROJECTS

There are only a handful of secondary lithium projects that are currently known to be actively progressed beyond Scoping Study level. These are:

Project	Company	Minerals
Sonoro	Bacanora Minerals	Hectorite clay
Nevada Lithium Project	Lithium America	Hectorite clay
Cinovec	European Metals Holdings	Zinnwaldite
Jadar	Rio Tinto	Jadarite

In this paper the Cinovec project will be discussed in detail and an overview provided of the clays projects in Nevada, USA and Sonora, Mexico.

WHAT IS ZINNWALDITE?

The mineral got its name from the locality Zinnwald, Erzgebirge, Saksen (nowadays known as Cínovec in the Czech Republic). Zinnwaldite is a phyllosilicate with properties similar to that of biotite, while it resembles lepidolite in its chemical aspects with high Si/Al ratio, high Li content and replacement of OH by F.

Zinnwaldite can be considered to be part of a solid solution series of the ferrous lithium micas. The main criteria being:

- If the Li occupies fewer than 0.25 octahedral sites the mineral is termed a siderophyllites;
- If the Li occupies between 0.25 and 0.75 sites the mineral is termed a protolithionites;
- If the Li occupies between 0.75 and 1.25 sites are defined as zinnwaldites; and
- If the Li occupies more than 1.25 sites are considered lepidolites.

The series is characterized by the progressive replacement by Li^{+I} by Fe^{+2}, with an average replacement ratio of 2.0 Li^{+1} for 1.5 Fe^{+2}. Siderophyllites and protolithionites can contain significant amounts of

Fe^{+3}, zinnwaldites have some Fe^{+2}, while Fe^{+2} is low in all the lepidolites.

Zinnwaldites are commonly found in pegmatites rich in rare elements, especially lithium, where they are associated with other lithium bearing minerals such as lepidolite and spodumene.

The iron content of the zinnwaldite results in the para-magnetic behavior of the ore which is the reason that Cinovec ore can be magnetically separated so effectively.

Figure 2 shows the mica books which characterize this mineral.

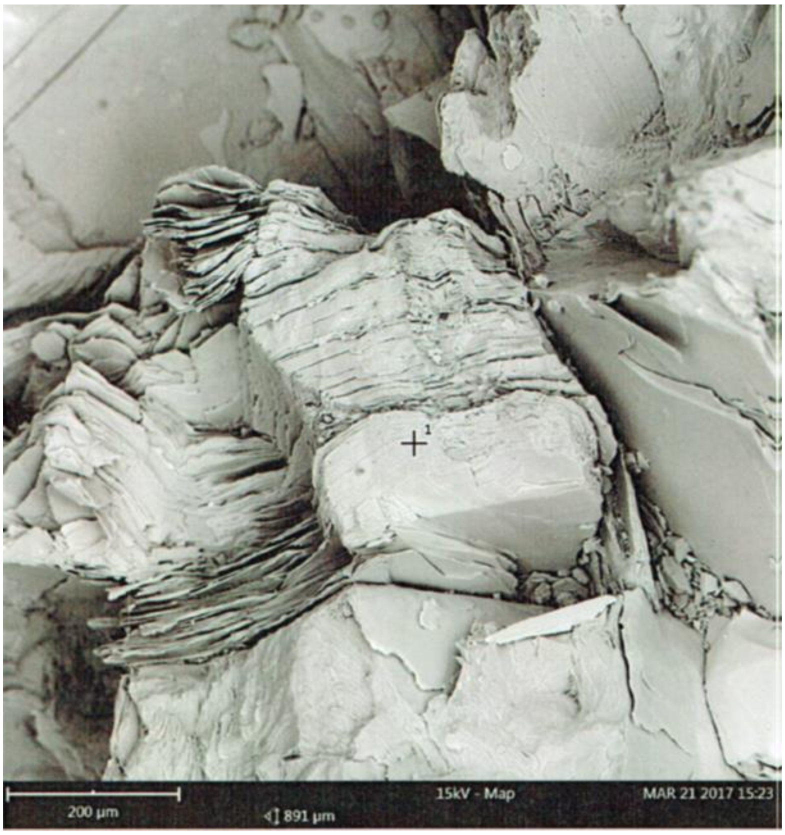
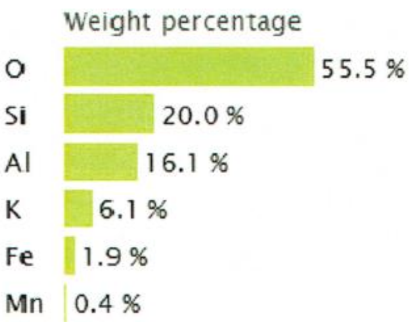


Figure 2: SEM pictogram showing typical mica books

The composition below shows the main elements present in Cinovec zinnwaldite excluding the lithium and fluoride. The photograph shows typical zinnwaldite rocks which have characteristic mica plates. In general, the darker grey the rock the higher is the amount of zinnwaldite present (and lithium). The rocks can also have a green colour due to the zinnwaldite.



THE OPPORTUNITY FOR ZINNWALDITE

The Cinovec project is located 100km North West from Prague, Czech Republic on the border with Germany and is part of the Cinovec-Zinnwald mining district that has been mined since the 14th century. Modern underground mining ceased in 1972 in the central part of the Cinovec district. As the high-grade tin ore was running out, the Czech State Company initiated an extensive underground exploration program that reported significant blind tin-tungsten-lithium mineralization associated with greisenization and silicification. All operations at the mine ceased with the demise of the centralized economy in 1990.

The main minerals of economic interest are cassiterite, wolframite, scheelite, zinnwaldite, topaz and fluorite. The project is estimated to contain a resource of up to 656.5Mt of ore @ 0.43% Li_20 (or 7.0 Mt LCE) and including 262,600 tonnes of Sn.

Proposed Flowsheet

The proposed high level flowsheet, shown in Figure 4, consists of mining, comminution, beneficiation and the lithium chemicals plants.

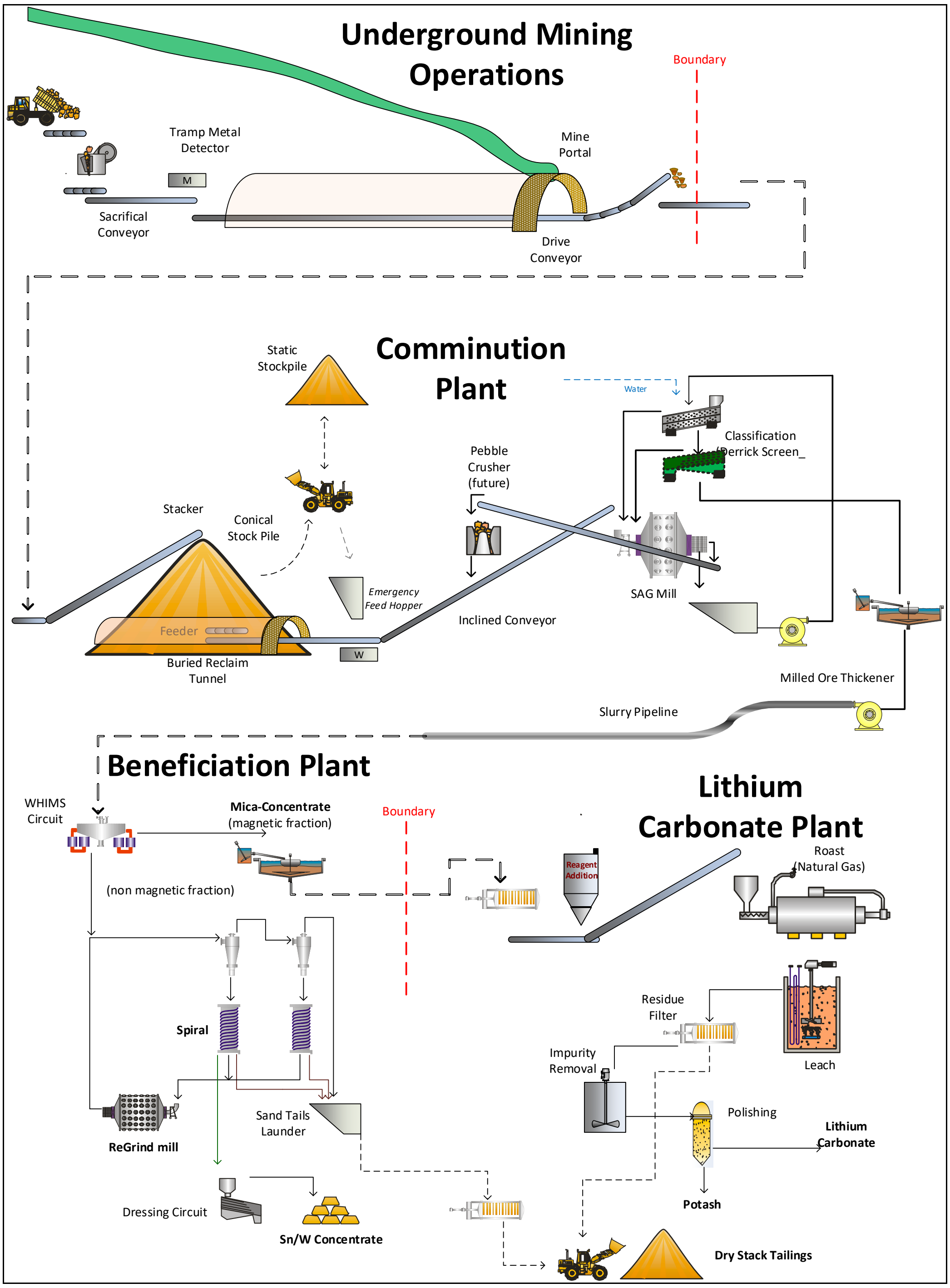


Figure 4: Proposed Flowsheet for the Cinovec Project, Czech Republic.

The ore from underground is crushed prior to being conveyed to a stockpile upstream of the comminution plant.

The Comminution Plant is a simple design with a single SAG mill in closed circuit with screens to produced milled ore suitable for the beneficiation plant.

The Beneficiation Plant has magnetic separators in which the paramagnetic zinnwaldite is separated for the non-magnetic fraction which is transferred to the tin recovery circuit. The lithium bearing mica, is concentrated to an average grade of 1.28 % Li from a ROM grade of 0.31 % Li. The concentrate is roughly 20% of the mass flow of the ROM and contains roughly 90% of the lithium in the feed.

The LCP (Lithium Chemical Plant) receives the concentrate from the Beneficiation plant and in the first step the ore is roasted with recycled sodium sulphate and lime to produce soluble lithium sulphate which is extracted in the leach. The Leach liquor is purified and battery grade lithium carbonate is produced.

SOME THOUGHTS ON LITHIUM BEARING CLAYS

In 1975 Chevron USA undertook an exploration program for uranium in the sediments of the McDermitt Caldera in Nevada, USA. At the same time lithium-bearing clays of the McDermitt caldera were identified by the U.S. Geological Survey and they alerted Chevron to the presence of anomalous concentrations of lithium, which resulted in Chevron adding lithium to its assays and ultimately in Chevron producing a resource estimate with a 0.25% Li cut-off in 1985.

The Unites States Bureau of Mines (USBM) conducted extensive research into technologies to recover lithium from these clays. The extraction techniques investigated which showed the most promise were selective chlorination and limestone-gypsum roasting. The lithium recoveries achieved by the USBM were 70% for selective chlorination and 80- 85% for the limestone-gypsum roast. They concluded that although the process of extracting lithium from hectorite clay was not economical, that the technology exists for lithium recovery from McDermitt clays. (L. Crocker)

Chevron ran beneficiation studies that concluded that dry grinding followed by separation of the fines coupled with upgrading of the coarse material gives the best overall upgrading. They managed to beneficiate the ROM ore with a Li head grade of 0.34% to a final concentrate with a grade of 0.37% by rejecting 35% of the feed. The beneficiated ore was then acid pugged and cured following by water leaching. The best results showed that 85% of the lithium could be extracted with an acid usage of around 1,000 pounds of acid per ton of ore.

Both Chevron and USBM achieved similar results which showed that lithium recovery was proportional to the amount of acid consumed. (Lithium America Corp, June 2016)

The current Lithium Americas Corp flowsheet appears to consist of size reduction, thermally treating the ore by calcining the ore mixed with anhydrite and dolomite followed by leaching.

The initial capital cost estimate for the Western Lithium Project was $247,935 (case 2 with a mining Rate of 4,200tpd) and the estimated corresponding operating cost was $3,472/ t LCE. (WESTERN LITHIUM USA CORPORATION, 2014). The operating cost sits in between the brines and the spodumene producers in figure 1 and on this basis the project should be attractive to investors. It was reported that the project did not manage to get financial backing based on these figures.

There are a number of challenges to exploration companies developing clay projects. These are:

1. The lithium grade of the clays is low and the impact on the increased mass of material to produce the same amount of lithium carbonate is shown pictorially in the two Sankey diagrams below. A typical grade is in the region of 0.3 wt% Lithium (0.6 wt% Li_2O).

2. The lithium, while contained in lithium minerals such hectorite, fordite and polylithionite, is present throughout the clay. This means that there is limited ability to beneficiate the ore other than to remove larger chunks/ rocks of quartz.

3. While the clay is reactive and lithium can be extracted from the clay at low temperature, the acid usage is typically around 1 ton Sulphuric acid: 1 ton of ore. Not only is a significant amount of neutalisation required, there is also typically significant amounts of other elements that are co-extracted. The main element extracted with the lithium is magnesium which increases reagent cost as well as causes problems in the solid and liquid separation of the magnesium hydroxide formed.

4. The projects do not have sufficient metal by-products to materially off-set the operating cost.

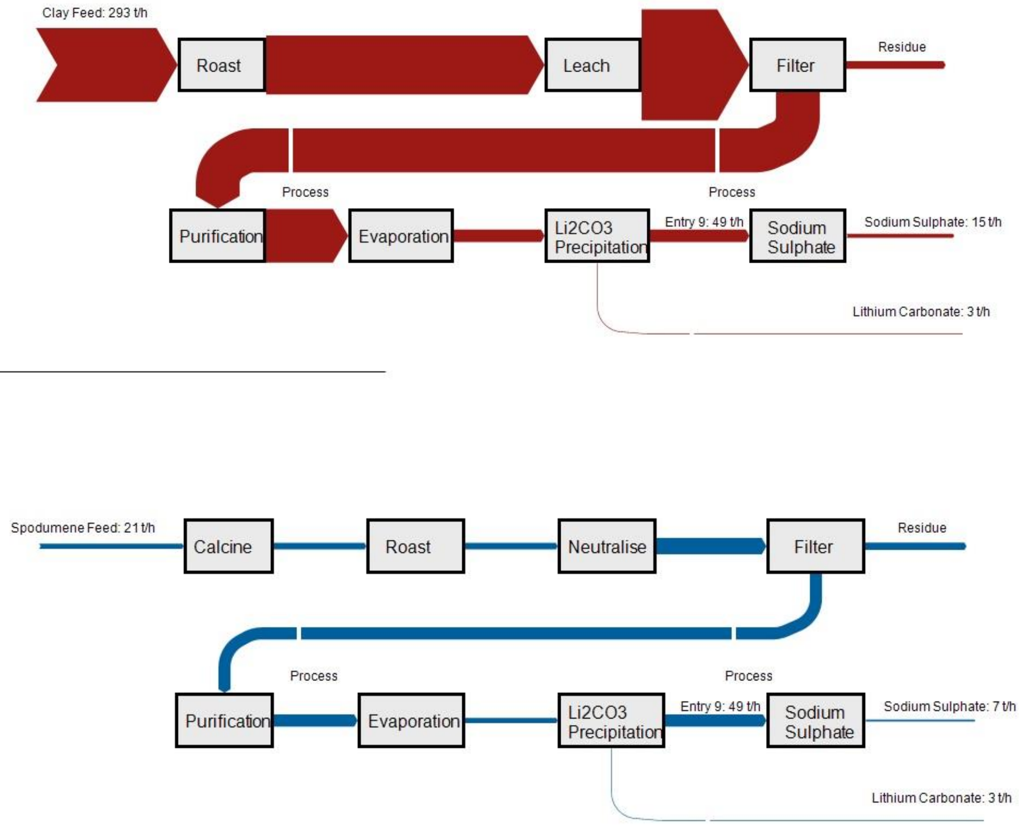


Figure 3: Comparison of Mass Flows through a typical Spodumene and Clay lithium Extraction Plant

THE CASH COST OF PRODUCING LITHIUM CARBONATE FROM SECONDARY LITHIUM SOURCES

Table 5 compares the operating cost of the Cinovec Project with that of the spodumene examples in CASE 2 and CASE 3 in Table 4, using the same model. Based on the assumptions stated below, there is $2,000/ t LCE difference between the cost of lithium carbonate produced by a Chinese converter and the proposed Cinovec plant with the benefit that in the Cinovec case the lithium carbonate would be produced in the heart of Europe.

Table 5: Comparison on the Estimated Cost of Produced Lithium Carbonate from Zinnwaldite versus Spodumene Ores

		Cinovec	Tianqi/ Albemarle using Talison Con	Chinese Converter using Pilbara Con
Cost Concentrate (FOB) net Sn, W & Ta credits and royalties	USD/t Con	\$91	\$200	\$171
Transport to Asia	USD/t Con	\$0	\$50	\$36
Inland transport	USD/t Con	\$0	\$40	\$40
Li Grade	wt% Li_2O	2.7	6	6
VAT 17% CIF	USD/t Con	\$0.00	\$42.50	\$35.19
Total cost	USD/t Con	\$91	\$333	\$282
Lithium content	kg Li_2O/ t Con	27.0	60	60
Lithium recovery in LCP	-	0.85	0.88	0.88
Lithium recovered in LCP	kg Li_2O/ t Con	22.95	52.8	52.8
	kg Li_2CO_3/t Con	56.61	130.24	130.24
Conversion cost	USD/t Li_2CO_3	\$2,274	\$3,000	\$3,000
	USD/ t Con	\$129	\$391	\$391
Potash Credit	USD/t Li_2CO_3	\$324	0	0
Conversion cost net of credits	USD/t Li_2CO_3	\$1,950	\$3,000	\$3,000
	USD/ t Con	\$110	\$391	\$391
TOTAL cost	USD/ t Con	\$201	\$723	\$673
	USD/t Li_2CO_3	\$3,555	\$5,553	\$5,167

Assumptions:

1. The cost of zinnwaldite concentrate production includes the average life of mine tin and tungsten credits and royalties. The mining cost assumed is USD 30/t for underground mining compared with USD 3/t for open pit mining.

2. The overall lithium extraction is estimated to be 85% for Zinnwaldite which is lower than spodumene which commercially was able to achieve 88%.

3. Zinnwaldite conversion cost based on prefeasibility study operating costs.

Reasons Supporting a Competitive Operating Cost for Zinnwaldite

There are a number of factors that drive the cost of Li production from the Cinovec project down:

1. The beneficiation plant flowsheet is simple, requiring only high intensity magnetic separation and single stage milling (SAG mill). This is significantly simpler than a Talison of Pilbara Minerals flowsheet.

2. Superior beneficiation recovery of 90% of the lithium into 21% of the mass.

3. 60% recovery of Sn and recovery of W. Genuine by-product credits as Cinovec was previously a tin mine but current grades are not high enough to support a mine producing only tin.

4. Recycling sodium sulphate to the roast results in a significant reduction in reagent requirements for the whole plant.

5. Reusing the sodium sulphate so that the sodium reports to the residue and there is not the problem that spodumene producers have in having to sell or dispose of a significant mass of soluble sodium sulphate, with a limited market.

6. Zinnwaldite needs a single stage of roasting at 850°C. Spodumene typically needs calcination at around 1,100°C, cooling, milling followed by roasting at 250°C.

7. The plant produces a commercial amount of potassium sulphate which can be considered a genuine by-product.

8. The lithium carbonate product is available in central Europe for European customers and transport cost are low.

CONCLUSION

The paper initially poses the questions as to whether all spodumene concentrates are the same and concludes that they vary considerably. These differences can impact on the ability of existing conversion plants if the feed concentrate is changed. It is also expected that the processing costs of these new concentrates will differ from that for Talison SC6.0. Further, even if the supplier of the spodumene concentrate is not changed, rising levels of impurities, especially iron, will increase the conversion cost and pose serious operational challenges.

The production costs of all producers have risen greatly over the last couple of years and with the strong demand for lithium chemicals expected, there will be opportunity for a number of companies to enter the lithium market.

The Cinovec project was used as an example of a secondary lithium mineral, Zinnwaldite. This project has a number of advantages over spodumene producers, such as the simple beneficiation plant and tin/ tungsten by-products, which offset the higher mining cost. In this paper the cost of producing battery grade lithium carbonate from the traditional spodumene ore was compared with the cost of producing battery grade lithium carbonate from secondary lithium ores, and specifically from zinnwaldite.

Based on the recent feasibility study completed on the European Metal Holdings Cinvovec project, the operating cost estimate suggest that the cost to produce battery grade lithium carbonate from Zinnwaldite is competitive with a Chinese converter using Talison SC6.0 concentrate. The estimated cost is considerably lower than cost for Chinese converters using either Galaxy concentrate or Direct shipped ore from the Pilbara.

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